Welcome and Introduction

On behalf of the scientific committee, we would like to invite you to participate in The 5th International Conference on Additive Manufacturing and Bio-Manufacturing (ICAM-BM 2018) that will be held at Tsinghua University in Beijing from December 2 to 5 2018. Succeeding ICAM-BM 2014 and Biofabrication 2017, it will be another grand international conference in China and devoted to the research and developments on additive manufacturing and Bio-manufacturing. The conference will cover broad topics on fundamental research, technological innovation, interdisciplinary and creative application, education and training, industrial development. The event will provide a unique platform for exchange and communication to the 3D Printing and Biomanufacturing communities. The conference will highlight, but not limited to:

1. New process, technology, and equipment of Additive Manufacturing
2. Metallic Additive Manufacturing
3. Additive Manufacturing for Ceramic, Polymer and Composite Materials
4. Additive Manufacturing for Biomaterials
5. Bio- and Cell- Printing
6. Cell-Chipand in-vitro Living System
7. Micro/Nano-Additive Manufacturing
8. Hybrid Additive Manufacturing
9. Modeling, Simulation and Data Processing
10. On-line Monitoring and Quality Control
11. Intelligentization and Big Data Technique Application
12. Digitalized Architecture and Art
13. Design with Additive Manufacturing
14. Applications and Services
15. Education and Training
16. Industrial Development and Policies, Regulations

We look forward to seeing you at the conference in Beijing.

Prof. Wei Sun
Chair, ICAM-BM2018
Tsinghua University, Beijing, China

Prof. Feng Lin
Co-Chair, ICAM-BM2018
Tsinghua University, Beijing, China

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Congress and Exhibiting Enterprises

Hosted by:

Chinese Mechanical Engineering Society
Chinese Society for Biomaterials
Tsinghua University

Supported by:

Bio-manufacturing and Engineering Living System Overseas Expertise Introduction Center for Discipline Innovation（111 Center）

Organized by:

Biomanufacturing Engineering Institution, Additive Manufacturing Institution and Non-Traditional Machining Institution of Chinese Mechanical Engineering Society
Biomaterials Advanced Manufacturing Institution of Chinese Society For Biomaterials

Exhibiting Enterprises

SunP Biotech, LLC
Tianjin SciTsinghua QuickBeam Tech. Co., Ltd
CELLINK
Beijing Eplus 3D Tech. Co., Ltd
Shaanxi Jugao-AM Technology Co., Ltd.
Jiangsu Yongnian Laser Forming Technology Co., Ltd

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(In alphabetical order of first name)

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Organization Committee

Chair: Wei Sun
Co-Chair: Feng Lin
Secretary: Jia Wang, Yan Sun, Yu Song, Lei Zhang, Yuan Pang

Plenary Speakers

(In alphabetical order of first name)

Carolin Körner, Ph.D. Head of the Institute of Science and Technology for Metals (WTM) in the Materials Science Department; Member of the Collegial Board and head of the "E-Beam Additive Manufacturing" group of the Central Institute of Advanced Materials and Processes (ZMP); Head of the "Additive Manufacturing" group of Neue Materialien Fürth GmbH (Research Company of the Bavarian state)

She studied theoretical physics at the FAU. She earned her PhD with distinction at the Materials Science Department of the FAU Faculty of Engineering in 1997 with a thesis on "Theoretical Investigations on the Interaction of Ultra-short Laser Radiation with Metals" under the supervision of Prof. H.W. Bergmann. Habilitation and venia legendi in Materials Science followed at FAU in the group of Prof. R.F. Singer in 2008 for "Integral Foam Molding of Light Metals: Technology, Foam Physics and Foam Simulation" (Springer Textbook).

In 2011 she took up her current position at FAU. At present, she is advising some 25 PhD students and postdocs in the field of Additive Manufacturing, Casting Technology, Alloy Development and Process Simulation.

Title:
Single crystals by electron beam based additive manufacturing

Abstract:
Currently, additive manufacturing (AM) experiences significant attention in nearly all industrial sectors. AM is already well established in fields such as medicine or spare part production. Nevertheless, processing of high performance nickel-base superalloys and especially single crystalline alloys such as CMSX-4® is challenging due to the difficulty of intense crack formation. Selective electron beam melting (SEBM) takes place at high process temperatures (~ 1000 ℃) and under vacuum conditions. Current work has demonstrated processing of CMSX-4® without crack formation.

In this contribution, we show how single crystals (SX SEBM CMSX-4®) develop directly from the powder bed by using appropriate AM scanning strategies. Numerical 3D simu-lation of the grain structure helps to understand the underlying mechanisms leading to effective grain selection and eventually to the evolution of a single crystal. In addition, we discuss the mechanical properties of SX SEBM CMSX-4® prepared by SEBM in the as-built condition and after heat treatment.

Huaming Wang, Ph.D. Member of the China Academy of Engineering; Professor, Beihang University

Wang Huaming (1962.5—) is a professor and PhD supervisor of the School of Materials Science and Engineering of Beihang University, and a member of the Chinese Academy of Engineering (elected in 2015).

He received his bachelor’s degree from Sichuan Institute of Industry (now known as Xihua University) in 1983, master’s degree from Xi’an Jiaotong University in 1986 and doctor’s degree from China University of Mining and Technology in 1989. After finishing his research at the Institute of Metal Research of the Chinese Academy of Sciences as a postdoctoral fellow, he began to work at Beihang University in 1992, and was sponsored by Alexander von Humboldt Foundation to work at Friedrich-Alexander University Erlangan-Nuremberg, Germany in the same year. Now he is the director of the National Engineering Laboratory of Additive Manufacturing for Large Metallic Components and the Engineering Research Center of Laser Direct Manufacturing for Large Metallic Components, and the chief scientist for aerospace materials and structure of the National Laboratory of Aeronautics and Astronautics.

Prof. Wang has long been engaging in the research on laser additive manufacturing for large metallic components and laser surface engineering. He made breakthroughs in the manufacturing technique, complete sets of equipment, quality control and engineering application of laser additive manufacturing for large metallic key components made from high-performance and difficult-to-machine metal, such as titanium alloys. He also developed the special coating using laser cladding of metalsilicide, which could endure extreme conditions like high temperature and corrosion. His achievements have been applied to planes, missiles, satellites, aircraft engine, etc.

He has published over 180 papers in journals listed in the Science Citation Index. He won a first prize of the State Technological Invention Award in 2012 and other three national or ministry-level prizes. He was also awarded the Ho Leung Ho Lee Prize for Scientific and Technological Progress and the title of Outstanding Talent in Defense Science, Technology and Industry.

Jürgen Groll, Ph.D. Professor, Chair for Functional Materials in Medicine and Dentistry, University Hospital Wuerzburg, Germany

Prof. Groll received his Ph.D. from the RWTH Aachen University with summa com laude in 2005. From 2005 to 2009, he worked in industry in the field of functional coatings and biocomposite materials. In parallel, he built up a research group on polymeric biomaterials at the DWI Interactive Materials Research Institute in Aachen. Since 2010 he holds the chair for Functional Materials in Medicine and Dentistry at the University of Würzburg.

His research interest comprises applied polymer chemistry for life sciences, biomimetic scaffolds, immunomodulation, nanobiotechnology, and biofabrication. Within biofabrication, he coordinates the large European integrated project HydroZONES that focuses on the printing of layered constructs for cartilage regeneration. Since 2014, he also holds the ERC consolidator grant Design2Heal that concerns the evaluation of design criteria for immunomodulatory scaffolds.

He is board member of the international society for biofabrication, editorial board member of the journal Biofabrication and advisory board member of the journal Advanced Biosystems. His work has been recognized by several awards such as the Bayer Early Excellence in Science Award 2009, the Reimund-Stadler award of the Division of Macromolecular Chemistry of the German Chemical Society in 2010 and the Unilever Prize of the Polymer Networks Group in 2014.

Title:

Hydrogel-bioinks: rheological demands and thiol-ene cross-linking for better control over cross-linking density

Abstract:

Biofabrication is a young and dynamically evolving field of research. It aims at the auto-mated generation of hierarchical tissue-like structures from cells and materials through Bi-oprinting or Bioassembly. This approach has the potential to overcome a number of classical challenges relating to organization, personalized shape and mechanical integrity of generated constructs.

Although this has allowed achieving some remarkable successes, it has recently become evident that the lack of variety in printable hydrogel systems is one major drawback for the complete field. In order to be suitable for Biofabrication, hydrogels have to comply with a number of prerequisites with regards to rheological behavior and especially stabilization of the printed structure instantly after printing, while at the same time allowing the cells to proliferate. This contribution will present some of our recent work in this field, starting with a method to assess bioink printability. It will then introduce thiol-ene cross-linking as alternative to the often used free radical polymerization to stabilize printed hydrogel structures with better control over network characteristics. This enables the control over nanoparticle migration in and release from printed hydrogel constructs and can be transferred to gelatin as one of the most widely applied bioink systems.

Roger D. Kamm, Ph.D. Cecil and Ida Green Distinguished Professor, Dept. of Biological Engineering; Dept. of Mechanical Engineering, Massachusetts Institute of Technology (MIT), Cambridge, USA

A primary objective of Kamm's research has been the application of fundamentals in fluid and solid mechanics to better understand essential biological and physiological phenomena. Past studies have addressed issues in the respiratory, ocular and cardiovascular systems. More recently, his attention has focused on the molecular mechanisms of cellular force sensation, cell population dynamics, and the development of new microfluidic platforms for the study of cell-cell and cell-matrix interactions, especially in the context of metastatic cancer. This cumulative work has led to over 290 refereed publications. Recognition for his contributions is reflected in Kamm's election as Fellow to AIMBE, ASME, BMES, AAAS and the IFMBE. He is also the 2010 recipient of the ASME Lissner Medal and the 2015 recipient of the Huiskes Medal, both for lifetime achievements, and is a member of the National Academy of Medicine.

Title:
Microphysiological models of neurological function and disease and their application to drug screening

Abstract:
The capability to produce in vitro models of normal physiological function and disease is rapidly expanding, and it is now becoming clear that these microphysiological sys-tems (MPS) will soon find their place in the multi-step process of identifying and val-idating new drugs, and testing for their potentially toxic side-effects. In order to gain acceptance by the pharma and biotech industries, however, these systems will need to be further developed, validated, and methods developed to fabricate them at high throughput and consistency. In this presentation, we focus on systems being devel-oped to model neurological function, disease, and the process of transport of drugs across the tight blood-brain barrier (BBB) to treat neurological disorders and cancer. These MPS are each derived entirely from human cells, produced in microfluidic plat-forms of different design, and include models of the BBB, Alzheimer's disease, and amyotrophic lateral sclerosis (ALS). In the BBB model, we demonstrate the capabil-ity to generate in vivo levels of permeability, and to discern between paracellular and transcellular transport. Using a monolayer system, we explore interactions between the amyloid-beta protein and vascular permeability, related to cerebral amyloid angi-opathy. Our ALS model, consisting of a motor neuron cell cluster activating a skeletal muscle strip, all in a 3-dimensional environment, is used to demonstrate the potential for drug screening. In the context of cancer, the BBB model is used to test for organ specificity of brain-targeting breast cancer cells, and to address the apparent contra-diction that the brain, while the tightest vascular barrier in the body, is also a preferred target for metastatic cancer.

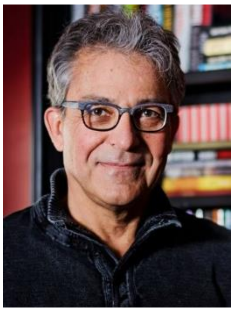
Support from the US National Institutes of Health National Cancer Institute, and the US National Science Foundation is gratefully acknowledged.

Keynote Speakers

(In alphabetical order of first name)

Baohua Chang, Ph.D. Professor, State Key Laboratory of Tribology, Department of Mechanical Engineering, Tsinghua University

Dr. Baohua Chang is currently an associate professor at the Department of Mechanical Engineering, Tsinghua University. He obtained his bachelor's degree and PhD from Xi'an Jiaotong University, carried out post-doctoral research at University of Waterloo, Canada, and he worked at TWI Ltd, UK as a Marie Curie Fellow (IIF) of European Union. Dr. Chang acts as a committee member for high-energy beams and special welding processes in China Welding Society, and an associate editor of the international journal Transactions on Intelligent Welding Manufacturing. His research focuses mainly on the numerical modeling and quality control of advanced materials processing technologies (mainly welding and additive manufacturing). He has published more than 100 papers, been granted 8 invention patents, and coauthored 2 books.



Bill Whitford, Ph.D. Strategic Solutions Leader, BioProcess, GE Healthcare Life Sciences, 925 West 1800 South, Logan, Utah 84321

Bill Whitford is Strategic Solutions Leader, GE Healthcare in Logan, UT with over 20 years experience in biotechnology product and process development. He joined the company as an R&D Leader developing products supporting protein biological and vaccine production in mammalian and invertebrate cell lines. Products he has commercialized include defined hybridoma and perfusion cell culture media, fed-batch supplements and aqueous lipid dispersions. An invited lecturer at international conferences, Bill has published over 250 articles, book chapters and patents in the bioproduction arena. He now enjoys such activities as serving on the editorial advisory board for BioProcess International.

Changchun Zhou, Ph.D. Associate professor, Engineering Research Center in Biomaterials, Sichuan University

Changchun Zhou received a PhD degree from Sichuan University in 2011, From 2008 to 2010, he was a joint PhD student at the university of Washington and the University of Texas at Austin. He joined the National Engineering Research Center for Biomaterials, Sichuan University in 2011. He is now an associate professor of Sichuan University and master's tutor in Biomedical Engineering. He is a member of China society of biological materials, member of the first China medical and biological technology association 3D printing technology branch (2016-), member of the second session of biological manufacturing engineering branch of China mechanical engineering society (2017-). His research interests cover biological materials and artificial organs; Biological 3D printing manufacturing; Bionic design and mechanical simulation of biomaterials. Has involved in the EU "Horizon" 2020 program, ministry of science and technology support "five-year plan", the ministry of science and technology research (National key R&D special projects of the ministry of science and technology 2018 YFB1105602), National natural funds of China, and many other national/ministry projects. He has published more than 30 scientific papers, participated in writing 3 academic books. He has applied 17 national patents, among of which 7 patents have been authorized.

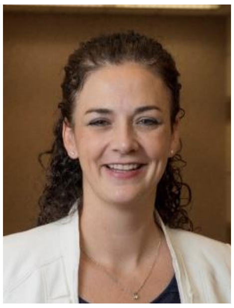
Chee Kai Chua, Ph.D. Professor; Executive Director, Singapore Centre for 3D Printing, School of Mechanical and Aerospace Engineering, Nanyang Technological University

Professor Chua Chee Kai is a distinguished Professor of Nanyang Technologic University, Singapore (NTU, Singapore) and the Executive Director of the Singapore Centre for 3D Printing (SC3DP). He is an active contributor to the additive manufacturing (AM) field for over 28 years. Professor Chua began his journey into AM in 1990. Now, his ongoing research at NTU Singapore are concerned mainly with powder bed fusion processes such as selective laser sintering and selective laser melting, bioprinting, 4D printing and food printing. He has made a number of major contributions in these areas. Specifically, his re-design and re-modeling of additive manufacturing processes for fabrication of innovative products and devices such tissue engineering scaffolds are highly regarded by the scientific community.

Professor Chua won the prestigious International Freeform and Additive Manufacturing Excellence (FAME) Award 2018. In 2014, Professor Chua was elected as the top scientist in his research field of AM by Clarivate Analytics, and has maintained his position as one of the most cited scientists in AM since then. As at 2018, he has contributed more than 300 technical papers in local seminars, technical talks, international conferences and journals, generating more than 9300 citations and a H index of 49 (web of science).

He is also the co-author for four books, “3D Printing and Additive Manufacturing: Principles & Applications in Manufacturing (5th edition)”, “Bioprinting: Principles and Applications”, “Standards, Quality Control and Measurement Sciences in 3D Printing and Additive Manufacturing” and “Lasers in 3D Printing and Manufacturing”. He is also the chief editor of the International Journal of Bioprinting and co chief editor of the “Virtual and Physical Prototyping” international journal.

To date, he has amassed close to S$150 M of research grants, resulting in a number of big centres and labs. These are (1) the Singapore Centre for 3D Printing funded by National Research Foundation (2) NTU Additive Manufacturing Centre funded the Singapore's Economic Development Board (3) NTU-SIMTech Joint Lab in 3D AM (4) NTU-SUTD Joint Lab in Visualization and Prototyping (5) SLM Solutions @ SC3DP Joint Lab. He now heads a centre with 36 professors, 47 PhD students, 52 Master students, 15 research staff and a support team of business development, administrative and technical staff. Another additional 100 PhD students will be recruited in the next 4 years.



Cosgriff-Hernandez Elizabeth, Ph.D. Professor, University of Texas at Austin

Dr. Elizabeth Cosgriff-Hernandez is a Professor of Biomedical Engineering at University of Texas at Austin. She received a B.S. in Biomedical Engineering and Ph.D. in Macromolecular Science and Engineering from Case Western Reserve University under the guidance of Professors Anne Hiltner and Jim Anderson. She then completed a UT-TORCH Postdoctoral Fellowship with Professor Tony Mikos at Rice University with a focus in orthopaedic tissue engineering. Dr. Cosgriff-Hernandez joined the faculty of at Texas A&M University as an Assistant Professor in 2007 and the University of Texas at Austin with the L.B. (Preach) Meaders Professorship in Engineering in 2017. Her laboratory specializes in the synthesis of hybrid biomaterials with targeted integrin interactions and scaffold fabrication strategies (e.g. injectable foams, 3D printing emulsion inks, reactive, in-line blending electrospinning). She also serves on the scientific advisory board of ECM Technologies and as a consultant to numerous companies on biostability evaluation of medical devices. Dr. Cosgriff-Hernandez is an Associate Editor of the Journal of Biomedical Materials Research, Part B, Fellow of AIMBE, and chair of the NIH study section on Musculoskeletal Tissue Engineering

Deyuan Zhang, Ph.D. Professor, the Bionics and Micro/Nano/Bio Manufacturing Technology Research Center,Beihang University

His research fields include the bionic-bio-manufacturing and the ultrasonic processing technology. Professor Zhang is one of the sponsor members of International Society of Bionic Engineering, director of Biological Manufacturing Branch, and committee director of Ultrasonic Machining from Non-traditional Machining Branch in Chinese Mechanical Engineering Society (CMES). He has undertaken more than 10 key projects from the National 863 Program, the National Natural Science Foundation and the General Armaments Department. Professor Zhang has published more than 300 papers and filed more than 40 patents. He has been honored with one International Invention Exhibition Gold Medal and five provincial science & technology progress awards. Professor Zhang is the supervisor of one Top100 national excellent doctoral thesis, and also the corresponding author of a paper published on Nature.

Dongdong Gu, Ph.D. Professor of Nanjing University of Aeronautics and Astronautics (NUAA); Vice-Director of College of Materials Science and Technology of NUAA; Director of Jiangsu Provincial Engineering Laboratory for Laser Additive Manufacturing of High-Performance Metallic Components; Alexander von Humboldt Research Fellow (RWTH Aachen/ Fraunhofer ILT); Senior Editor of J Laser Appl; Editorial Board Member of Int J Mach Tool Manuf, Appl Surf Sci, Additive Manuf, Int J Precis Eng Manuf, Laser Eng, & Heliyon

Prof. Dr. Dongdong Gu is currently a Full Professor of Nanjing University of Aeronautics and Astronautics (NUAA), the Vice-Director of College of Materials Science and Technology of NUAA, and the Director of Jiangsu Provincial Engineering Laboratory for Laser Additive Manufacturing of High-Performance Metallic Components. He was an Alexander von Humboldt Research Fellow in Fraunhofer Institute for Laser Technology ILT, Aachen, Germany from 2009 to 2011. Prof. Gu is presently the Senior Editor of J Laser Appl and the Editorial Board Members of Int J Mach Tool Manuf, Appl Surf Sci, Additive Manuf, Int J Precis Eng Manuf, Laser Eng, & Heliyon. He is the Standing Committee Member of Additive Manufacturing Technology Institution, Chinese Mechanical Engineering Society. His principal research interest is laser-based additive manufacturing of high-performance/multi-function metallic components. His obtained the financial support from more than 20 projects including National Natural Science Foundation of China (NSFC), the National Key Research and Development Program, the NSFC-DFG Sino-German Research Project, etc. Prof. Gu has authored/co-authored 3 books and 132 papers in a number of international peer reviewed journals. He has been involved in 28 international conferences as Co-Chairman, Academic Committee Member and Keynote/Invited Speaker. Prof. Gu has been awarded the Fraunhofer-Bessel Research Award from Alexander von Humboldt Foundation (2018), the Science and Technology Innovative Talents of China (2017), the Youth Science and Technology Award from the China Aeronautical Society (2017), the Cheung Kong Young Scholars Award, Ministry of Education of China (2016), the Top-Notch Young Talents Program of China (2015), the Excellent Young Scientists Fund from NSFC (2013), and the "Green Talents" from the German Federal Ministry of Education and Research (BMBF) (2012).

Dong-Woo Cho, Ph.D. Nam-go Chair Professor, Department of Mechanical Engineering, Pohang University of Science and Technology

Prof. Dong-Woo Cho received his Ph.D. in Mechanical Engineering from the University of Wisconsin-Madison in 1986. Ever since, he has been a professor of Department of Mechanical Engineering at the Pohang University of Science and Technology. He is director of the Center for Rapid Prototyping-based 3D Tissue/Organ printing. His research interests include 3D microfabrication based on 3D Printing technology, its application to tissue engineering, and more generally to bio-related fabrication. He has recently focused on tissue/organ printing technology and development of high-performance bio-inks. He has received several prestigious awards in these academic areas. He serves or has served on the editorial boards of several International Journals. Prof. Cho has published over 240 academic papers in various international journals in the field of manufacturing and tissue engineering, and has contributed chapters to ten books and written a textbook related to tissue engineering and organ printing.

Dong Sung Kim, Ph.D. Department of Mechanical Engineering, Pohang University of Science and Technology (POSTECH), Pohang, Korea

Dr. Dong Sung Kim is an Associate Professor in the Department of Mechanical Engineering at POSTECH, Korea. He received all his B.S., M.S., and Ph.D. (Advisor: the late Prof. Tai Hun Kwon) from POSTECH in 1999, 2001, and 2005, respectively, developing disposable plastic labs-on-a-chip for blood typing. After one year of post-doc in POSTECH, he joined the School of Mechanical Engineering at Chung-Ang University in Korea as a faculty member. After 4 years in Chung-Ang University as a Full-time Lecturer and an Assistant Professor, he came back to POSTECH as a faculty member in 2010. His current research is basically focused on the development of polymer micro/nanofabrication and its utilization in bio-engineering and energy harvesting. He intensively studied on the biomedical fields with micro/nano polymer processing, such as polystyrene micro/nanoengineered cell culture platforms, electrospun nanofiber structures, multifunctional stimuli-responsive structures, and disposable lab on a chip. Prof. Kim has published over 80 peer-reviewed journal papers, registered 27 patents including 3 US patents, and served on the editorial/advisory board of several international journals and symposia.

Gregory F. Payne, Ph.D. Professor; Fischell Department of Bioengineering; Institute for Bioscience and Biotechnology Research

Dr Gregory F. Payne's research focuses on using biology's materials, mechanisms and lessons to fabricate high-performance soft matter that is cheap, safe and sustainable. In particular, my group focuses on building structure/function using stimuli-responsive biological polymers (especially polysaccharides), enzymes (especially tyrosinase and transglutaminase) and redox-active phenolics.

Guifeng Zhang, Ph.D. Professor; State Key Laboratory of Biochemical Engineering; Institute of Process Engineering, Chinese Academy of Sciences; No.1 North 2nd Street, Zhongguancun, Haidian District

Research interests: Preparation of collagen-based biomaterials and its application in bio implant and tissue engineering; Role of collagen in the regulation of cell migration and differentiation; Effect of proline hydroxylation in collagen on protein-protein interaction.

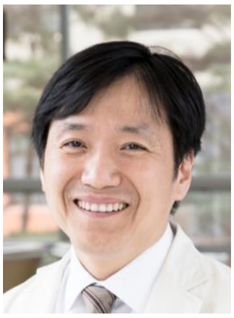
Recent Publications: [1] Gongze Peng, Saina Li, Qing Peng, Yang Li, Jun Weng, Zhidong Jia, Xiongxin Lei, Guifeng Zhang, Yi Gao. Immobilization of native type I collagen on polypropylene fabrics as a substrate for HepG2 cell culture. Journal of Biomaterials Applications, 2017, 32 (1): 93-103. [2] Huimei Wang, Shulan Han, Lianyan Wang, Tingyuan Yang, Guifeng Zhang, LianYu, Yue Zhao. Dual-function baicalin and baicalin-loaded poly(lactic-co-glycolic acid) nanoparticles: Immune activation of dendritic cells and arrest of the melanoma cell cycle at the G2/M phase. Particuology, 2018, 37: 64-71. [3] Qing Li, Tong Wang, Guifeng Zhang, Xin Yu, Jing Zhang, Gang Zhou, Zhi- hui Tang. A comparative evaluation of the mechanical properties of two calcium phosphate/collagen composite materials and their osteogenic effects on adipose-derived stem cells. Stem Cells International, 2016, 395:1-12. [4] Tong Wang, Qing Li, Gui-feng Zhang, Gang Zhou, Xin Yu, Xiu-mei Wang, Zhihui Tang. Comparative evaluation of a biomimic collagen/hydroxyapatite/β-tricaleium phosphate scaffold in alveolarridge preservation with Bio-Oss Collagen. Front. Mater. Sci. 2016, 10(2): 122–133

Heow Pueh LEE, Ph.D. Professor, Department of Mechanical Engineering, National University of Singapore

Dr. Heow Pueh LEE is currently the Deputy Head (Research) for the Department of Mechanical Engineering, National University of Singapore. He graduated with first class honours from Cambridge University. He obtained his PhD in Mechanical Engineering from Stanford University. He was seconded to the Institute of High Performance Computing (IHPC) under the Agency for Science, Technology and Research (A*STAR) in 2002, initially as the Deputy Director for Research and subsequently assumed the role of Deputy Executive Director for research since 2003 till the end of his full-time secondment in 2007. His early works focused on the mechanics of robotic manipulators, mechanism designs, as well as the vibration of structural elements and the mechanics of ultrasonic motors. Notable contributions include the application of “Structural Intensity” for the vibration study to various aspects of engineering disciplines from fracture mechanics to biomechanics. His more recent works focus on mechanics in medicine, numerical methods and noise and vibration.

Jiabin Guo, Ph.D. Associate professor, Evaluation and Research Centre for Toxicology, Center of Disease Control and Prevention, PLA

Dr. Jiabin Guo got his Ph.D in Pharmacology from the School of Basic Medicine, Peking University. He is currently an associate professor of toxicology at the Center for Disease Control and Prevention, PLA (formerly the 10th Institute, Academy of Military Medical Sciences). He was a visiting scholar at the University of California, Irvine during 2007 to 2009. He has published about 50 publications in toxicology over the past decade and got a number of awards such as LUSH Non-Animal Test Asia Outstanding Young Scholar Award, Excellent Young Worker of Chinese Pharmacological Society, Chinese Toxicology Society-Unilever Alternative Method Innovation Award, et al. He is serviced as the Secretary General of the Committee of Toxicity Testing and Alternative Methods, the Society of Chinese Environmental Mutagen Society, and a committee member of the Industrial Toxicology of the Chinese Society of Toxicology. He is a tutor of the Master of Public Health (MPH) of Peking University, a visiting professor of Jiangxi University of Traditional Chinese Medicine, and a reviewer of the National Natural Science Foundation of China, as well as the peer-reviewer of a number of scientific journals such as Food and Chemical Toxicology, Toxicology in Vitro, and International Journal of Cardiology.



Ji Hyeon Ju, M.D., Ph.D. Division of Rheumatology, Department of Internal Medicine; Medical college, The Catholic University of Korea; Seoul St. Mary's Hospital

Appointments:

Mar. 2004 – Apr. 2005 Chief, Dept of Internal Medicine, Army Headquater Hospital, Kaeryongdae Army headquaters.

May. 2005 – Feb. 2007 Clinical Instructor, Division of Rheumatology, Department of Internal Medicine, College of Medicine, The Catholic University of Korea, Seoul, Korea

Mar. 2007 – Feb. 2011 Assistant Professor, Division of Rheumatology, Department of Internal Medicine, College of Medicine, Seoul St. Mary’s Hospital

The Catholic University of Korea, Seoul, Korea

Mar. 2011 – Feb. 2014 Associate Professor, Division of Rheumatology, Department of Internal Medicine, College of Medicine, Seoul St. Mary’s Hospital

The Catholic University of Korea, Seoul, Korea

Mar. 2012 – Jun. 2013 Visiting Scholar, Stanford University

Mar. 2015 – Present Professor, Division of Rheumatology, Department of Internal Medicine, College of Medicine, Seoul St. Marys Hospital ,The Catholic University of Korea, Seoul, Korea

Jiankang He, Ph.D. Professor, the School of Mechanical Engineering, Xi'an Jiaotong University (XJTU), China

Dr. Jiankang He is a full professor at the School of Mechanical Engineering, Xi'an Jiaotong University (XJTU), China. He received his PhD in Mechanical Engineering from XJTU in 2010. During 2008 and 2010, he studied in Harvard-MIT Health Science & Technology (HST) as a joint PhD candidate. He is now the Deputy Director of State Key Laboratory for Manufacturing Systems Engineering. He was selected as the Changjiang Young Scholars Program in 2017 and NSFC Excellent Young Scholars in 2014. His research mainly focuses on multiscale bio-additive manufacturing. He is the authors of 30 chinese invention patents and 70 peer-reviewed articles. Ten of these research articles were featured as "cover image", "highlighted paper", "featured article", "highly commended awards" and "VIP paper". His research on the additive manufacturing of biodegradable scaffolds has been in clinical trials with one product approved by CE certificate. He has been awarded the first prize of Natural Science Awards for Universities from Shaanxi Province in 2017 and the first prize of Technology Invention Awards from Ministry of Education of China in 2011.

Jerry Fuh, Ph.D. Professor, Department of Mechanical Engineering, National University of Singapore

Dr. Jerry Fuh is a Professor at the Department of Mechanical Engineering, National University of Singapore (NUS) and the Co-Director of NUS Centre for Additive Manufacturing (AM.NUS) focused on biomedical technologies. He is a Fellow of SME and ASME and a PE from California, USA. Dr. Fuh has devoted himself to the research of Additive Manufacturing (AM) processes or 3D Printing (3DP) since 1995. He and his colleagues have established the NUS's AM/3DP research programme focusing on biomedical applications and set up an advanced 3DP laboratories through several research & development grants with industrial collaborations.

In 2005, he received the IES Prestigious Engineering Achievement Award for the work on "Development of Rapid Prototyping Technologies for Precision and Biomedical Engineering" from the Institute of Engineers, Singapore (IES) in recognition of outstanding engineering skills which have made notable contributions to progress engineering in Singapore. He has published over 350 technical papers in advanced manufacturing and design, and supervised over 80 graduate students with over 50 are PhD students. He also serves in more than 10 refereed journals as Editor, Associate Editor or Editorial Board Members related to design, manufacturing and AM/3DP.

Kaiming Ye, Ph.D. Professor, Department Chair of Biomedical Engineering; Director of Center of Biomanufacturing for Regenerative Medicine, Binghamton University (BU), State University of New York (SUNY), United States

Dr. Kaiming Ye is Professor and Department Chair of Biomedical Engineering and Director of Center of Biomanufacturing for Regenerative Medicine at the Binghamton University (BU), State University of New York (SUNY). He is one of the top most distinguished and accomplished leaders in the field of Medical and Biological Engineering. He is fellow of AIMBE and senior member of IEEE. His scholarly contributions to the field include the development of the concept of advanced biomanufacturing and his leadership role in promoting and growing the field. He co-organized more than 10 workshops, including two WTEC studies: one for global assessment of stem cell science and engineering and the other for global assessment of advanced biomanufacturing to promote and grow the field of advanced biomanufacturing, He is well known for his work in bioprinting and pancreatic organoid development. He has invented a tissue biofabrication platform tissue organoid development and fluorescent nanosensors for continuous glucose monitoring. His work in advanced biomanufacturing was featured as a cover story of ASEE PRISM journal. His work in glucose sensors was featured in the Pittsburgh Post-Gazette.

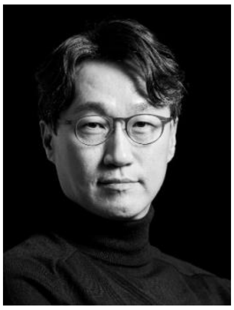
His research has been continuously supported by NIH, NSF, JDRF, ABI and industries. He has chaired and co-chaired a number of international conferences and has delivered keynote/plenary speech in numerous international and national conferences. He is also a highly accomplished administrator and has contributed significantly to national policy-make in science and engineering. During his tenure at NSF, he directed a biomedical engineering program, making funding decisions and implementing post-award management. He was member of a number of interagency working groups, including the Interagency Workgroup for Neuroscience under the Office of Science and Technology Policy (OSTP), Interagency Modeling and Analysis Workgroup, and Multiagency Tissue Engineering and Regenerative Medicine Workgroup. In addition, he was involved in NSF CIF21 IGRET program, cyber-enabled science and engineering program, NIH/NSF joint program on interface between physics and life science, and NIH/NCI-NSF Physicals and Engineering Sciences in Oncology program. Finally, he is a highly accomplished educator in biomedical engineering. As chair of Biomedical Engineering Department at BU, he led the growth of the Department.

Matthew Mail, Master Scientific Application Specialist, CELLINK

Matthew Mail graduated from Osaka University with a master in chemical engineering. He researched bioink formulation and ECM materials in 3D tissue engineering applications. The focus of his research was in developing biomimetic muscle models using murine myoblast cells. Matthew also helped with the development of a new 3D bioprinting method using enzymatically crosslinked hydrogels and studied the attachment mechanobiology of 3D myoblasts based on ECM properties. Matthew has a passion for the biotechnology field and joined CELLINK as a Scientific Application Specialist, where he hopes to help build the future of medicine.

Mian Long, Ph.D. Professor, Institute of Mechanics, Chinese Academy of Sciences (CAS); the Center for Biomechanics and Bioengineering; Beijing Key Laboratory of Engineered Construction and Mechanobiology

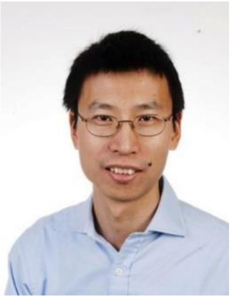
Dr. Long is a professor at Institute of Mechanics, Chinese Academy of Sciences (CAS) and the directors of Center for Biomechanics and Bioengineering and of Beijing Key Laboratory of Engineered Construction and Mechanobiology. His interests are focused on molecular biomechanics, cellular mechanobiology, and tissue construction related to immune responses and liver diseases. He has published 142 peer-reviewed papers together with 11 warranted patents. He is awarded by National Outstanding Young Investigator Award from National Natural Science Foundation of China and by Young Teacher Award from Ministry of Education of China. Dr. Long is a fellow of American Institute of Medical and Biological Engineering and of International Academy of Medical and Biological Engineering.



Min Jun Kim, Ph.D. Robert C. Womack Endowed Chair Professor in Engineering, Department of Mechanical Engineering, Southern Methodist University

Dr. MinJun Kim is presently the Robert C. Womack Endowed Chair Professor of En-gineering at the Department of Mechanical Engineering, Southern Methodist Universi-ty. He received his B.S. and M.S. degrees in Mechanical Engineering from Yonsei University in Korea and Texas A&M University, respectively. Dr. Kim completed his Ph.D. degree in Engineering at Brown University, where he held the prestigious Si-mon Ostrach Fellowship. Following his graduate studies, Dr. Kim was a postdoctoral research fellow at the Rowland Institute in Harvard University. He joined Drexel University in 2006 as Assistant Professor and was later promoted to Professor of Me-chanical Engineering and Mechanics. Dr. Kim has been exploring biological transport phenomena including cellular/molecular mechanics and engineering in novel nano/microscale architectures to produce new types of nanobiotechology, such as na-nopore technology and nano/micro robotics. His notable awards include the National Science Foundation CAREER Award (2008), Drexel Career

Development Award (2008), Human Frontier Science Program Young Investigator Award (2009), Army Research Office Young Investigator Award (2010), Alexander von Humboldt Fel-lowship (2011), KOFST Brain Pool Fellowship (2013 & 2015), Bionic Engineering Outstanding Contribution Award (2013), Louis & Bessie Stein Fellowship (2008 & 2014), ISBE Fellow (2014), ASME Fellow (2014), Top10 Netexplo Award (2016), KSEA & KOFST Engineer of the Year Award (2016), IEEE Senior Member (2017), Sam Taylor Fellowship (2018), and Gerald J. Ford Research Fellowship (2018).



Lang Yuan, Ph.D. Associate Professor, Department of Mechanical Engineering, University of South Carolina

Education:
October 2006– April 2010
Imperial College London, UK, Ph.D. in Materials Science and Engineering
Thesis: "Multiscale Modelling of the Influence of Convection on Dendrite Formation and Freckle Initiation during Vacuum Arc Remelting"
Key author of Open-source code μMatIC (http://www.imperial.ac.uk/engineeringalloys/research/software/)
Supervisors: Prof. P. D. Lee and Prof. K. A. Pericleous (University of Greenwich)
Imperial College London Awards: McLean Medal
September 2003– May 2006
Tsinghua University, China, M. Eng. in Materials Processing and Engineering
Thesis: "Numerical Simulation of Shot Process in Shot Sleeve of Die Casting Process"
Supervisor: Prof. Baicheng Liu and Prof. Shoumei Xiong
September 1999– June 2003
Tsinghua University, China, B. Eng. in Mechanical Engineering
Excellent Graduate of Tsinghua University

Jong-Young Kwak, M.D./Ph.D. Professor/Director, Department of Pharmacology & Immune Network Pioneer Research Center, Ajou University School of Medicine, Korea

Dr. Kwak is professor at Department of Pharmacology, Ajou University School of Medicine, Korea. He is currently the Director of Immune-network Pioneer Research Center, which is sponsored as one of the Pioneer Research Center Program by the Korean ministry of Science ICT & Future Planning. He became a vice-president of Korean Society of Biochemistry and Molecular Biology in 2015 and is a Doctor Honoris Causa in Russian Academy of Science since 2012. He completed his doctorate in Medical Biochemistry with neutrophil activation and signal transduction pathways at the Pusan National University, Korea in 1991. After his study of activation of neutrophils in Emory University as a post doctorate, he directed his research to dendritic cell analysis. Current research topics in his laboratory are dendritic cell regulation, immunogenic response of damaged cells, and 3D culture of immune cells.

Peng Wen, Ph.D. Associate professor, Department of Mechanical Engineering, Tsinghua University

Dr. Wen got his doctor degree in 2009 from Hiroshima University Japan. He joined in Dept. of Mechnical Engineering of Tsinghua University as an assistant professor in 2009 and got promoted to Associate Professor in 2014. His main research interests include laser material processing and welding. He has published more than 40 peer-reviewed papers in the above related fields.

Quanyi Guo, Ph.D. Chief surgeon, orthopedics professor, doctoral tutor of the Department of Orthopedics of the General Hospital of PLA; Deputy director of the PLA Orthopedics Institute

Scientific research characteristics:

Undertake the "863" project of the Ministry of Science and Technology, Support four Subject Plans, four projects of the National Natural Science Foundation, one project of the Beijing Natural Science Foundation as the first person in charge. Participated in the research and development of key military subjects, published more than 100 papers, including more than 70 SCI articles. Received the first prize of the Science and Technology Progress Award of the whole army, the Beijing Medical Award, and the Huang Jiasi Biomedical Engineering Award. Lead the formulation of the State Food and Drug Administration tissue bank management norms and standards, lead the formulation of relevant standards such as the quality management regulations of the China Biomedical Biotechnology Association cell bank. Participate in the development of international standards for non-invasive nuclear magnetic assessment of international cartilage repair. Originally use the fourth generation tissue engineered cartilage to repair of articular cartilage injury internationally, which brings good news to patients with early articular cartilage injury. During the period of leading key technologies and series of products in the "863" biomedical field of the Ministry of Science and Technology, leaded team to research the development of basic and clinical applications in bones, cartilages, nerves, blood vessels, tendons, hearts and livers. Recycled products and technologies are registered by the State Food and Drug Administration and national clinical application license for medical technology. The monographs included in the compilation include: Orthopedic Surgery, Master's Doctoral Textbook, Surgery Textbook, Huang Jiasi Surgery, and Regenerative Medicine: Basic and Clinical, Regenerative Medicine: Principles and Practice.

Rong Wang, Ph.D. Founder & Managing Director, EGGXPERT B.V., The Netherlands; Guest Researcher, Aachen-Maastricht Biobased Materials, Maastricht University, The Netherlands

During 2012-2016, Rong Wang did her PhD thesis project - "Cartilage regeneration by injectable hydrogels" in Twente University, where she was the main research scientist for a start-up company Hy2care B.V.

From 2016, before stepping into business ventures, she was a post-doc researcher working in MERLN Institute for Technology-Inspired Regenerative Medicine, under the leadership of Prof. Lorenzo Moroni and Prof. dr. Clemens van Blitterswijk in Maastricht University. She's working on design and preparation of bio-inductive materials for digital light processing (DLP) fabrication for soft tissue regeneration.

Influenced by entrepreneurial environment both in Twente University and MERLN institute, she is fascinating on efforts in driving clinical-directed biomaterials, as well with strong driven force on translating bio-organic materials/innovations to market. In May 2018, interrupted by attempts in developing more applicable science, she quit her post-doc position within university and initiated an innovative project working on creation added value to industrial biowaste – eggshells (including eggshell membranes and eggshells). The project was successfully founded by province and national subsidies and local Rabobank innovation loan.

Dr. Rong Wang is an entrepreneur with scientific-driven spirit. She's fascinating in 3D printing technology since late of her PhD research. She has a dream to bridge the materials with human

Rui Yao, Ph.D. Associate professor, Biomanufacturing Research Center, Department of Mechanical Engineering, Tsinghua University, Beijing, 100084, China

Rui Yao joined the Department of Mechanical Engineering of Tsinghua University as an assistant professor in 2013. She had been the visiting student in Robert Langer Lab in MIT in 2009 and the visiting scholar in Kam Leong Lab in Columbia University in 2016, respectively. She is now the tenure-track associate professor and special senior researcher in Biomanufacturing Research Center of Tsinghua University.

Her research interest covers biofabrication technologies assisted biomaterial and stem cell research, including development of 3D cell printing technologies, microscale biofabrication and microfluidic technologies, and ultilized these techniques in stem cell and biomaterials research to advance the understanding and applications of cell/tissue engineering and therapy for regenerative medicine, drug testing and pathology investigation, with the ultimate goal to meet the therapeutic and diagnostic needs in clinical medicine and drug discovery. She was founded by five national program, including the young scientist key program of Ministry of Science of Technology (MOST). She has published more than 50 journal and conference papers, 6 of which was selected as highlight article or frontispiece report. She has applied for 16 patents, including 1 PCT patent. She has presented her research work in international conference as an invited speaker for three times and received awards.

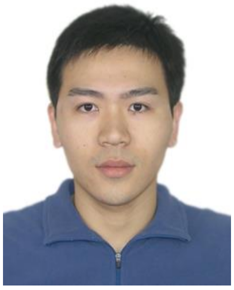
Shengli Mi, Ph.D. Associate professor, Department of Mechanical Engineering and Mechanics, Tsinghua University, Beijing, China

Dr. Shengli Mi currently is a full associate professor of Division of Advanced Manufacturing, the Graduate School at Shenzhen, Tsinghua University; Dr. Mi graduated from Northwest A&F University and awarded Ph.D. degree in the same university. Dr. Mi spent one year (2007-2008) as Joint Ph.D. in School of Optometry and Vision Sciences, Cardiff University, UK. Afterwards, he got his post-doctoral training in University of Reading (UK) for 3 years (2008-2010). From 2011 to now, he worked for Graduate school at Shenzhen, Tsinghua University, first as lecture then as professor.

Research Field:

Dr. Mi was involved in the bio-manufacturing research area: Bio-manufacturing is an emerging interdisciplinary paradigm in which living cells, biologics, proteins and/or biomaterials are used as basic building blocks for fabrication of in vitro biological structures and/or cellular systems in application to biology, tissue engineering, disease pathogeneses study, drug test and discovery, and cell/tissue/organ-on-a-chip devices. Currently, his research are focused on: (1) Precisely controlled cell assembly and three-dimensional in vitro biological functional body construction; (2) In vitro model with biological functions for the study of biology, pathology and pharmacology; (3) Integration of bio-, micro- and nano-fabrication technology.

Xu Song, Ph.D. Singapore Institute of Manufacturing Technology (SIMTech), Singapore



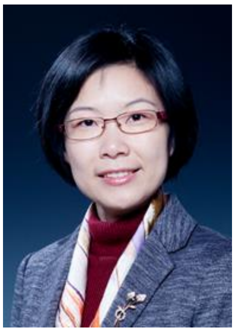
Dr Song Xu has more than 5 years of experience in manufacturing processes, particularly on residual stresses and distortion. His area of interest includes residual stress measurement and simulation, distortion control, finite element simulation techniques in deformation at different scales, advanced joining techniques and rotary forming. He obtained his doctorate degree in Modeling residual stresses and deformation in metal at different scales from University of Oxford, UK. He is currently a scientist in Forming Technology Group (FTG) in Singapore Institute of Manufacturing Technology (SIMTech), a research institute of A*STAR. He was awarded BSSM (British Society for Strain Measurement) - YSA08 (Young Stress Analyst competition 2008)-Best Poster Award for his contribution to the computational and experimental mechanics research.

Su Ryon Shin, Ph.D. Instructor, Division of Engineering in Medicine, Department of Medicine, Brigham and Women's Hospital, Harvard Medical School, Boston, MA 02139, USA.

Dr. Shin is one of the innovative and productive young faculties in regenerative medicine and biomedical engineering, with a growing international reputation for her accomplishments. Dr. Shin fully committed to address this major challenge head-on by using an interdisciplinary approach at the interface between tissue engineering, biomaterials, nanomaterials, biosensor, bioactuator, bioprinting, and organ-on-a-chip. Dr. Shin's research focuses on developing micro- and nanoscale technologies to control and monitor cellular behavior with particular emphasis in developing microscale biomaterials and engineering systems for biomedical applications. She has been developing multifunctional cardiac scaffolds and 3D biohybrid actuator using biocompatible hydrogel for both therapeutic purposes and in vitro studies. Her team currently focuses on developing bioprinting technology to control cellular behavior, as well as regulating cell alignment within engineered systems. Also, Dr. Shin has been developing and testing of integrated organs-on-chip systems with built-in biosensors. Dr. Shin is one of the most productive and prolific young innovators in the country. During my research period at the Brigham, Dr. Shin has been extremely prolific in my work, which has resulted in several funded grants by DOD-Advanced Regenerative Manufacturing Institute, Air Force Office of Sponsored Research, Qatar University, and Toyota Company. In addition, she has published over 87 papers in peer-reviewed journals such as PNAS, Advanced Materials, ACS Nano, Angewandte Chemie, etc. Her H index, which is a measure of scientific productivity, is already at 35. In just a few years she has been cited over 3,690 times. Dr. Shin is a 2015 and 2018 recipient of a BWH Stepping Strong Innovator Award.

Sik Yoon, Ph.D. Department of Anatomy, Pusan National University School of Medicine, Yangsan, Gyeongsangnam-do 626-870, Republic of Korea

Dr. Yoon is a professor at the Department of Anatomy, Pusan National University School of Medicine, Korea. He is currently the Director of Immune Reconstitution Center of the Pusan National University Medical Research Institute. He is also serving as the Secretary-General of Korean Association of Anatomists since 2017. He completed his doctorate in Medical Anatomy with the role of thymic epithelial cells in thymus regneration at the Pusan National University, Korea in 1993. He studied imune cell biology in Washington University School of Medicine, USA as a Visiting Scientist. His current research interests include Nano-engineering of cells for biomedical applications, Development and application of 3D cell culture technology for drug discovery and diagnostic tools, Synthetic biology for T cell regeneration, and Development of therapeutic strategies to combat antitumor drug resistance and to modulate immune function.



Ting Zhang, Ph.D. Associate professor, Biomanufacturing Center, Department of Mechanical Engineering, Tsinghua University

Ting ZHANG received her B.S. in Mechanical Engineering and Ph.D. in Materials Science and Engineering from Tsinghua University. She also obtained an Engineering Diploma (M.S.) from Ecole Centrale de Lyon in France. She once worked in the Department of Biomedical Engineering at Columbia University as a visiting Ph.D. student, and in Brigham and Women's Hospital, Harvard Medical School as a visiting scholar. Dr. Zhang is currently an Associate Professor at Biomanufacturing Center, Department of Mechanical Engineering, Tsinghua University. She is also affiliated to Biomanufacturing and Rapid Forming Technology Key Laboratory of Beijing, and Biomanufacturing and Engineering Living Systems Innovation International Talents Base (111 Base).

Dr. Zhang's research is focused on bio-manufacturing of biomimetic models and complex tissue precursors (especially in the area of cardiac, brain, osteochondral tissue, and tissue vascularization) with different advanced bio-3D printing technologies, construction of multi-functional bioreactors and study the effects of physical cues on tissue development and maturation, as well as different application in tissue engineering, regenerative medicine, tissue/organ-on-a-chip, drug screening studies, biobots, etc.

Wentao Yan, Ph.D. Assistant Professor, Department of Mechanical Engineering, National University of Singapore, Singapore

Dr. Wentao Yan is an assistant professor at the Department of Mechanical Engineering, National University of Singapore (NUS). Prior to this, he was a postdoctoral fellow at Northwestern University and also a guest researcher at the National Institute of Standards and Technology (NIST), in the USA. He finished his phd work jointly between Tsinghua University and Northwestern University, and obtained his bachelor's degree in Tsinghua University. His research interests are advanced manufacturing, computational mechanics and multi-scale modelling. Dr. Yan has been widely recognized and invited to give talks at international conferences (e.g., World Congress in Computational Mechanics), prestigious universities, research institutions and high-tech companies (e.g., University of Waterloo, Peking University, Argonne National Lab, Lawrence Livermore National Lab, NIST, and Livermore Software Technology Corp (LS-DYNA)). He serves as scientific committee members and mini-symposium chairs for international conferences, and reviewers for flagship journals.

Will Wenmiao Shu, Ph.D. Professor, Department of Biomedical Engineering, University of Strathclyde, Glasgow, United Kingdom.

Will Wenmiao Shu is the Hay Professor in Biomedical Engineering at the University of Strathclyde (Glasgow). He obtained his PhD at the Engineering Department from University of Cambridge, UK. His research interests cover a range of biomedical engineering topics including 3D biofabrication, biosensors, microsystems and their applications for regenerative medicine. He led the research to demonstrate the first bioprinting of human embryonic stem cells (h-ESCs) and human induced pluripotent stem cells (h-iPSCs), paving the way for their applications on animal-free drug testing and 3D printed organs. He held a visiting position at Stanford University. He is an editorial board member for IOP Biofabrication Journal and serves as a board director of the International Society for Biofabrication (ISBF).

Woonbong Hwang, Ph.D. Professor and Head, Dept. of Mechanical Engineering, POSTECH, Pohang, Republic of Korea

Dr. Woonbong Hwang received the B.S. degree in precision mechanical engineering from Hanyang University, Seoul, Korea in 1982 and the M.S. and Ph. D. degrees in mechanical engineering from SUNY at Buffalo, Buffalo, NY in 1985 and 1988, respectively. In 1988, he joined the Department of Mechanical Engineering at Pohang University of Science and Technology (POSTECH), Korea where he is currently a full professor and head of the department. He also leads the NSCS Research Group. In 2012 he was invited by Chinese Government as an expert of '1000 Plan' and is director of Micro-Nano Technology Laboratory at China Academy of machinery Science and Technology (CAM), China. From 2000 to 2001, he was a Visiting Scholar at the Digital Appliance Research Lab. in LG Electronics Inc. From 2009 to 2010, he was a Visiting Professor at the Mechanical Engineering Department of Drexel University, USA. Since 2002, he has helped academic programs in creative engineering including axiomatic design and TRIZ. He has published more than 200 papers in internationally renowned journals and conference proceedings. His research interests include composite materials, RF-integrated mechanical structures and nanomechanics.

Xiaolin Tu Ph.D. Laboratory of Skeletal Development and Regeneration, the Institute of Life Sciences, Chongqing Medical University

Research area:

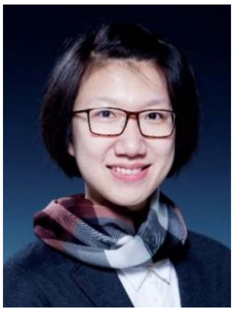
1) In-depth study of bone development and homeostasis maintenance molecular mechanism; 2) Molecular basis of fracture nonunion and nonunion and its prevention and treatment; 3) Molecular and cytological mechanisms of bone loss caused by weightlessness and its prevention and treatment; 4) Three-dimensional printing of stem cells and bone organ construction and its application in the treatment of bone defects; 5) Stem cell differentiation, lineage transformation and the regulation of osteogenesis; 6) The relationship between bone and aging; 7) Biomechanics and bone.

Xin Lin, Ph.D. Associate Dean, the School of Materials Science and Engineering, Key Laboratory of Metal High Performance Additive Manufacturing and Innovative Design, Ministry of Industry and Information Technology (MIIT), the State Key Laboratory of Solidification Processing China, Northwestern Polytechnical University (NPU), China

Prof. Dr. Xin Lin is Associate Dean of School of Materials Science and Engineering, Director of Key Laboratory of Metal High Performance Additive Manufacturing and Innovative Design, Ministry of Industry and Information Technology (MIIT), and Deputy Director of the State Key Laboratory of Solidification Processing China, Northwestern Polytechnical University (NPU), China. His areas of research include metal additive manufacturing (AM) and solidification. He received his PhD from NPU in 2000 and worked as a postdoctoral fellow at The Hong Kong Polytechnic University. He holds 15 Chinese patents and has published two monographs and over 400 articles in journals, such as Acta Mater., J. Crystal Growth, Scripta Materialia, Metallurgical and Materials Transactions A, Journal of Applied Physics, and Materials Science & Engineering A and B. His research on laser AM has found commercial applications in aviation, aerospace, power, energy and medical sectors, and met the urgent needs for high-performance, light-weighting, high integration and high precision fabrication tin these high-tech fields. He was appointed as a New Century Excellent Talent by the Ministry of Education China in 2006, and awarded a Newton Fellowship by Royal Society in the UK in 2015.

Yonghua Chen, Ph.D. Associate professor, Department of Mechanical Engineering, University of Hong Kong, China

Dr. Y.H. Chen is currently an associate professor in the Department of Mechanical Engineering, The University of Hong Kong. He has worked intensively on Additive Manufacturing and Robotics in the past 20 years. Dr. Chen has co-authored more than 200 journal and conference papers, two books, and 5 patents. Recently, he has secured more than $8 million to conduct research on biomimetic and soft robotics. Since 1997, Dr. Chen has organized more than 10 international conferences on manufacturing and automation. He has also served as editorial members for 5 international journals. He is now taking on the challenge of 3D printing smart robotics that could be driven by tissue-engineered muscle.



Yue Zhao, Ph.D. Department of Mechanical Engineering, Tsinghua University, PR China

Dr. Yue Zhao is an assistant researcher in the Department of Mechanical Engineering of Tsinghua University, China. She got her B.S. and Ph.D. from Tsinghua University in 2006 and 2012, respectively. During this period, she also received her M.S. from Tohoku University, Japan, in 2009. After post-doctor in Tsinghua University, she joined the Department of Mechnical Engineering of Tsinghua University as a faculty member. Her research interests include residual stress and deformation of metal additive manufacturing, metallurgy and mechanics of welding. Her research involves a variety of advanced materials such as titanium alloys, Ti-Al based intermetallic compounds, aluminum alloys, superalloys

Yasuyuki Sakai, Ph.D. Professor, Department of Chemical System Engineering, Graduate School of Engineering, University of Tokyo, Tokyo, Japan

Dr. Sakai received Ph.D. in chemical engineering from University of Tokyo in 1993 and stated his work at Institute of Industrial Science, University of Tokyo. In 1997-1998, he stayed in University of Rochester, as a visiting scientist investigating 3D culture of bone marrow cells (Prof. David Wu's Lab). In 2003-2008, he worked as an associate professor of Regenerative Medical Engineering Laboratory at the Center for Disease Biology and Integrative Medicine (CDBIM), Graduate School of Medicine, University of Tokyo. He returned to IIS as a professor and then moved to the current position in 2015. During his research carrier, he got several scientific awards such as young investigator award of Society of Chemical Engineers, Japan, publication awards of Society for Bioscience and Bioengineering, Japan and Japanese Society for Alternatives to Animal Experiments. He recently became a fellow of American Institute for Medical and Biological Engineering (AIMBE).

His current research topics are engineering of multi-scale 3D tissues/organs for clinical applications and cell-based pharmacological or toxicological assays. He has been placing particular importance on simultaneous realization of good mass transfers and 3D organization of stem/progenitor cells together with various micro-technologies.

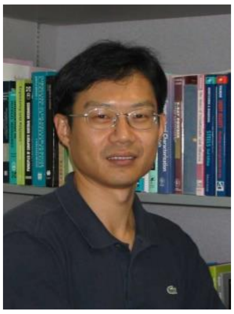
Yusheng Shi, Ph.D. Professor, State Key Laboratory of Materials Processing and Die & Mould Technology, School of Materials Science and Engineering, Huazhong University of Science and Technology, Wuhan 430074, China

Prof. Yusheng Shi, born in 1962, acting as the Huazhong Scholar leading Special Term Professor in Huazhong University of Science and Technology (HUST), is now undertaking several duties including the secretary of the CCP committee of School of Materials Science and Engineering in HUST, director of national-local united engineering laboratory (Hubei) of numerical materials processing technology and equipment, chief scientist of theme expert group in innovation special zone of national defense science and technology, committee member of expert board in industrial alliance of Chinese additive manufacturing, vice-director committee member of additive manufacturing branch of Chinese Mechanical Engineering Society, chairman of Hubei provincial 3D printing alliance. He won 1 Top 10 Science and Technology Progress of China, 1 Second Class Prize of National Technological Invention, 1 Second Class Prize of National Science and Technology Progress, 5 First Class Prizes of Provincial Level, 5 Sceond Class Prizes of Provincial Level, 2 awards of international patent, 1 excellent patent of Hubei Province, 1 Top 10 Science and Technology Achievement Transform Project. He also got outstanding award of China invention and entrepreneurship award and current inventor, top 10 outstanding invention person of China science, award nomination for top 10 national outstanding scientific and technical worker, special national government allowance, personal award for great contribution for Wuhan city and May lst Labour Medal in Hubei province, etc. His group has been selected as the innovation group of Ministry of Education of China and Hubei province, the graduate students tutored by him got 1 award nomination of national outstanding doctor’s thesis, 5 awards of outstanding doctor’s thesis in Hubei province and 3 awards of outstanding master’s thesis in Hubei province.

Yuan Pang, Ph.D. Assistant Professor, Bio-manufacturing center, Tsinghua University; Biomanufacturing Center Dept. of Mechanical Engineering, Tsinghua University

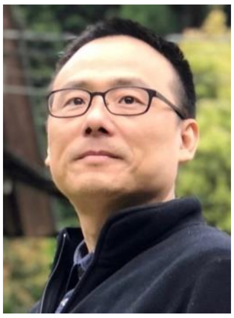
Dr. Pang received Ph.D. in Bio-engineering from the University of Tokyo in 2013 and did her postdoc fellowship at the Institute of Industry and Science (Prof. Yasuyuki Sakai's Lab), University of Tokyo in 2013-2015. She started her work as an Assistant Professor at Bio-manufacturing center in Tsinghua University since 2016. During her research carrier, she got several scientific awards such as young scientific award of International Society of Biomaterials, publication awards of Tissue Engineering and Regenerative Medicine International Society- Asia Pacific. She recently became the committee member of Chinese Society of Toxicity Testing and Alternatives, CEMS.

Her current research interests focus on construction of in vitro functional tissue models through bio-printing, includes: 1) 3D printed tumor model and its application in cancer metastasis study; 2) 3D printed implantable tissue substitutes with drug release functionality; 3) vascularized micro-organ fabrication; 4) 3D printed graphene oxide bio-electrode.



Yunfeng Zhang, Ph.D. Professor, Department of Mechanical Engineering, National University of Singapore

Dr. Yunfeng Zhang received his B.Eng. in Mechanical Engineering from Shanghai Jiao Tong University, China in 1985 and Ph.D. from the University of Bath, UK in 1991. He is currently an Associate Professor at the Department of Mechanical Engineering, National University of Singapore. His research interests include (1) operations research, in particular, computational intelligence in design and manufacturing (process planning, scheduling, and their integration, VRP, and multi-objective optimization for UAV mission planning); (2) hybrid manufacturing (3D printing and 5-axis machining) technology for parts repair. He has authored more than 200 publications and received various international awards including the Kayamori Best Paper Award in ICRA 1999 and the IMechE Thatcher Bros Prize in 2011.



Zhongze Gu, Ph.D. Professor, State Key Laboratory of Bioelectronics, School of Biological Science and Medical Engineering, Southeast University, Sipailou 2, Nanjing, Jiangsu 210096, China

Dr. Zhongze Gu graduated from Southeast University (China) in 1989 and got his M.S. in 1992 there. He went to The University of Tokyo (Japan) in 1994 and obtained his Ph.D. in 1998. Since then, he had been working as a researcher at the Kanagawa Academy of Science and Technology. He then began a project to study the opal photonic crystals and made a lot of excellent work in this field. Since 2003, he began to work at Southeast University as a professor Cheung Kong Scholars of Biomedical Science and Medical Engineering. Now he is the dean of School of Biological Science and Medical Engineering, the director of State Key Laboratory of Bioelectronics. His researches related to bio-inspired intelligent materials, photonic crystal, biosensor and bioelectronics. He has published more than two hundred research papers in international journals and applied more than 70 related patents.

Zhengwei You, Ph.D. Professor, the State Key Laboratory of Chemical Fibers & Polymer Materials, the Department of Composite Materials, College of Material Science & Engineering, Donghua University

Dr Zhengwei You is a full professor at the State Key Laboratory of Chemical Fibers & Polymer Materials and the Chair of the Department of Composite Materials, College of Material Science & Engineering at Donghua University. He received his degrees of B.S. (2000) from Shanghai Jiao Tong University and Ph.D. (2007) from Shanghai Institute of Organic Chemistry, Chinese Academy of Sciences. From 2007 to 2012, he conducted his postdoctoral research on biomaterials at Georgia Institute of Technology and University of

Pittsburgh. Prior to joining Donghua University in 2013, he was an innovation manager in Bayer MaterialScience. His current research involves smart polymers, biomaterials, 3D printing, and flexible electronics.

Zhongde Shan, Ph.D. Director, State Key Laboratory of Advanced Forming Technology and Equipment, China Academy of Machinery Science and Technology

Professor Zhongde Shan, Ph.D., Candidate Supervisor; Vice President of China Academy of Machinery Science and Technology Group Co., Ltd.; Director of state key lab of advanced forming technology & equipment of China. He is a recipient of National Outstanding Youth Fund, vice general president of China Association of Machinery Manufacturing Technology, Fellow of Chinese Mechanical Engineering Society, Fellow of the Institution of Engineering and Technology of UK. Guest Professor, POSTECH of South Korea, et al. Graduated from Department of Mechanical Engineering, Tsinghua University in 2002, then he studied in CARDIFF University of UK as a visiting scholar.

He has long been engaged in the research of Advanced Manufacturing Technology and Equipment for the Mechanical Industry. More than 40 state-level key projects have been finished. He has issued 4 books and more than 100 papers on core journals or at the international conferences. More than 80 invention patents including in 32 international patents were authorized. Many awards and honorary titles of the scientific research national and provincial-level incentives were won, such as The First Prize of National prize for progress in science and technology, The Second Prize of National Technology Invention Award, The First Prize of Science and Technology Award in Green Manufacturing, and so on. More than 10 pieces developed technology and equipment have been applied in mechanical industry.

Conference Agenda

Brief:

Registration		
Date	**Time**	**Location**
December 2, 2018 (Sunday)	14:00-19:00	Lobby, Beijing Xijiao Hotel
December 3, 2018 (Monday)	07:00-18:00	2nd floor, Beijing Xijiao Hotel building 1#
December 4, 2018 (Tuesday)	08:00-12:00	2nd floor, Beijing Xijiao Hotel building 1#

<table>
<tr><th colspan="5">Monday, December 3, 2018</th></tr>
<tr><th>Time</th><th colspan="3">Program</th><th>Location</th></tr>
<tr><td colspan="5">Plenary Session (08:30-11:55), 3F, Building 1#</td></tr>
<tr><td>08:30-08:50</td><td colspan="3">Conference opening, welcome remark</td><td>Gingko hall, 3F, Building 1#</td></tr>
<tr><td>08:50-11:55</td><td colspan="3">Plenary Presentation/ Group photo</td><td>Gingko hall, 3F, Building 1# / Yard</td></tr>
<tr><td>11:55-14:00</td><td colspan="3">Lunch</td><td>Shang Yuan restaurant, 2F, Building 5#</td></tr>
<tr><td colspan="5">Parallel Session (14:00-17:40), 2F, Building 1#</td></tr>
<tr><td>14:00-17:40</td><td>Session 1 (Room 1)
NUS-THU Joint Session</td><td>Session 2 (Room 5)
New process, technology, and equipment of Additive Manufacturing</td><td>Session 3 (Room 6)
Cell-Chip and in-vitro Living System</td><td>Meeting Rooms of 2F, Building 1#</td></tr>
</table>

<table>
<tr><th colspan="5">Tuesday, December 4, 2018</th></tr>
<tr><th>Time</th><th colspan="3">Program</th><th>Location</th></tr>
<tr><td colspan="5">Parallel Session (08:30-12:15), 2F, Building 1#</td></tr>
<tr><td>08:30-12:15</td><td>Session 4 (Room 1)
NUS-THU Joint Session</td><td>Session 5 (Room 5)
Metallic Additive Manufacturing</td><td>Session 6 (Room 6)
Cell-Chip and in-vitro Living System</td><td>Meeting Rooms of 2F, Building 1#</td></tr>
<tr><td>12:15-14:00</td><td colspan="3">Lunch</td><td>Shang Yuan restaurant, 2F, Building 5#</td></tr>
<tr><td colspan="5">Parallel Session (14:00-17:30), 2F, Building 1#</td></tr>
<tr><td>14:00-17:30</td><td>Session 7 (Room 1)
Additive Manufacturing for Ceramic, Polymer and Composite Materials</td><td>Session 8 (Room 5)
On-line Monitoring and Quality Control</td><td>Session 9 (Room 6)
Additive Manufacturing for Biomaterials</td><td>Meeting Rooms of 2F, Building 1#</td></tr>
<tr><td>17:30-20:30</td><td colspan="3">Banquet</td><td>Xiyuan Seafood restaurant, Ground floor, Building 1#</td></tr>
</table>

Wednesday, December 5, 2018				
Time	**Program**			**Location**
Parallel Session (08:30-12:15), 2F, Building 1#				
08:30-12:15	**Session 10 (Room 1)** Additive Manufacturing for Ceramic, Polymer and Composite Materials	**Session 11 (Room 5)** Additive Manufacturing for Biomaterials & Rapid Fire	**Session 12 (Room 6)** Additive Manufacturing for Biomaterials	Meeting Rooms of 2F, Building 1#
12:15-14:00	Lunch			Shang Yuan restaurant, 2F, Building 5#
14:00-15:15	**Session 13** **Industry Presentations**			Jin Yuan hall, 2F, Building 5#
15:15-16:00	**Close Ceremony**			Jin Yuan hall, 2F, Building 5#
16:00-18:00	**Lab Tour**			Tsinghua University

Lab Tour on December 5th:
Tsinghua Shuttle bus(s) will departure at 16:00 on December 5th from Bejiing Xijiao Hotel and get back at 18:00. (Get on/off at the same stop)

Detailed:

December 2, 2018		
Time	**Program**	**Location**
14:00-19:00	Registration	Lobby, Beijing Xijiao Hotel

December 3, 2018 (Morning)				
08:30- 08:50 Conference Opening and Welcome Remark **Location: Gingko hall, 3F, Building 1# ,Beijing Xijiao Hotel** **Chair: Dr. Wei Sun**				
08:50-11:55 Plenary Presentation / Group Photo **Location: Gingko hall, 3F, Building 1# / Yard** **Co-Chair: Dr. Carolin Körner**				
No.	**Time**	**Authors**	**Title**	**Institute**
1	08:50-09:30	Roger D. Kamm	Microphysiological models of neurological function and disease and their application to drug screening	Massachusetts Institute of Technology (MIT)
2	09:30-10:10	Carolin Körner	Single crystals by electron beam based additive manufacturing	University of Erlangen Nuremberg
	10:10-10:20	**Group Photo (move to the yard)**		
	10:20-10:35	Tea Break: 3F, Building 1#		
3	10:35-11:15	Jürgen Groll	Hydrogel-bioinks: rheological demands and thiol-ene cross-linking for better control over cross-linking density	University of Würz-burg
4	11:15-11:55	Huaming Wang	Additive Manufacturing for High-Petformance Large Critical Metallic Components and its Impacts on Aerospace Manufacturing Industries	Beihang University

December 3, 2018 (Afternoon)

14:00-17:35 Session 1 NUS-THU Joint Session

Location: Meeting Room 1, 2F, Building 1#, Xijiao Hotel

No.	Time	Authors	Title	Institute
14:00-15:55 Co-Chair: Dr. Heow Pueh Lee				
Invited Keynote				
1	14:00-14:20	Xu Song	Advances in AM Process Simulation: Residual Stress Predictions for Laser Direct Energy Deposited Thin Wall Components and Overhanging Structures Manufactured via Selective Laser Melting	Singapore Institute of Manufacturing Technology (SIM Tech)
2	14:20-14:40	Yue Zhao	Research on high-efficient prediction and measurement of deformation during metal additive manufacturing	Tsinghua University
Oral Presentation				
3	14:40-14:55	Xue Wang	Mechanical characterization of parts fabricated by selective laser melting processes	National University of Singapore
4	14:55-15:10	Mohammad Saleh Kenevisi	Investigating the processability and microstructural evolution of high strength Al2024 aluminum alloy by selective electron beam melting	Tsinghua University
5	15:10-15:25	Lina Yan	Design and Evaluation of Functional Structures with Planar and Lattice Features via Selective Laser Melting using Stainless Steel 316L	National University of Singapore
6	15:25-15:40	Jun Zhou	Research on aluminum component change and microstructure evolution of Ti47Al2Cr2Nb alloy in electron beam selective melting (EBSM) process under argon atmosphere	Tsinghua University
	15:40-15:55	Tea Break: 2F, Building 1#		
15:55-17:35 Co-Chair: Dr. Haiyan Zhao				
Invited Keynote				
7	15:55-16:15	Yunfeng Zhang	Thermal Analyses for Laser Scanning Pattern Evaluation in Laser Aided Additive Manufacturing using Deep Neural Network	National University of Singapore
8	16:15-16:35	Peng Wen	Laser powder bed fusion of pure Zn metal parts for biodegradable implant applications	Tsinghua University
Oral Presentation				
9	16:35-16:50	Yingjie Zhang	In-situ Monitoring of Additive Manufacturing by Vision Method and Convolutional Neural Network	National University of Singapore
10	16:50-17:05	Chaochao Wu	Investigation on Surface Roughness of Ti-6Al-4V by Electron Beam Selective Melting	Tsinghua University
11	17:05-17:20	Hongxin Li	The Structure Design and Simulation of Laser-heated Electron Gun for Additive Manufacturing	Tsinghua University
12	17:20-17:35	Xuyang Chen	Study on solidification behavior in electron beam additive manufacturing	Tsinghua University

December 3, 2018 (Afternoon)				
14:00-17:35 Session 2 New process, technology, and equipment of Additive Manufacturing				
Location: Meeting Room 5, 2F, Building 1#, Xijiao Hotel				
No.	**Time**	**Authors**	**Title**	**Institute**
14:00-15:55 Co-Chair: Dr. Ji Hyeon Ju				
Invited Keynote				
1	14:00-14:20	Woon Bong Hwang	From Superhydrophilicity to Superhydrophobicity: Fabrication and Applications	Pohang University of Science and Technology
2	14:20-14:40	Lang Yuan	From Art-to-Part: Multidisciplinary Toolset for Laser Powder-bed Fusion Additive Manufacturing	University of South Carolina
Oral Presentation				
3	14:40-14:55	Kai Tang	Variable-depth Curved Layer Fused Deposition Modeling of Thin-shell Structures	Hong Kong University of Science and Technology
4	14:55-15:10	Yu Long	High Efficient Powder Bed Laser 3D Printing	Hans Laser Smart Equipment Group
5	15:10-15:25	Yilin Amelia Lee	Preliminary Results of The Feasibility of Alcohol As A Stimulus For 4D Printing	Nanyang Technological University
6	15:25-15:40	Changyong Liu	3D-printed Lithium-ion Batteries by Low Temperature Direct Writing	Shenzhen University
	15:40-15:55	Tea Break: 2F, Building 1#		
15:55-17:35 Co-Chair: Dr. Lang Yuan				
Invited Keynote				
7	15:55-16:15	Ji Hyeon Ju	New strategy to repair osteoarthritic cartilage using injectable chondrosheroid	The Catholic University of Korea
8	16:15-16:35	Zhengwei You	A new general strategy to 3D print thermosets for diverse applications	Donghua University
Oral Presentation				
9	16:35-16:50	Guo Liang Goh	Aerosol Jet Printing of Preferentially Aligned Carbon Nanotube Lines via Coffee Ring Effect Utilizing Evaporation-driven Self-assembly	Nanyang Technological University
10	16:50-17:05	Jaeseung Yoon	Development of nanofiber membrane inducing orthogonal cell arrangement in vitro artery model	Pohang University of Science and Technology
11	17:05-17:20	Qi Lei	Electrohydrodynamic Printing of Microscale Features with Tunable Conductive/Thermal Properties at Mild Temperature	Xi'an Jiaotong University
12	17:20-17:35	Hongwei Tang	3D Printed Resistor: Design, Measurement and Standards	Nanyang Technology University

December 3, 2018 (Afternoon)				
14:00-17:40 Session 3 Cell-Chip and in-vitro Living System **Location: Meeting Room 6, 2F, Building 1#, Xijiao Hotel**				
No.	**Time**	**Authors**	**Title**	**Institute**
14:00-16:00 Co-Chair: Dr. Zhongze Gu				
Invited Keynote				
1	14:00-14:20	Jiankang He	Multiscale additive manufacturing for biomedical applications	Xi'an Jiaotong University
2	14:20-14:40	Will Shu	3D Bioprinting of Mature Bacteria Biofilm	University of Strathclyde
3	14:40-15:00	Dong-Woo Cho	3D Printing Technology with Tissue Specific Bioinks	Pohang University of Science and Technology
Oral Presentation				
4	15:00-15:15	Jie Na	Biomanufacture of human pluripotent stem cells derived blood vessels and application in drug testing	Tsinghua University
5	15:15-15:30	Ge Gao	Coaxial Cell-printing of Freestanding, Perfusable and Function-al in vitro Vascular Models for Recapitulation of Native Vascular Endothelium Pathophysiology	Pohang University of Science and Technology
6	15:30-15:45	Yongcong Fang	Biomimetic design and fabrication of oriented micro-pores scaffold with channel network for myocardial tissue engineering	Tsinghua University
	15:45-16:00	Tea Break: 2F, Building 1#		
16:00-17:40 Co-Chair: Dr. Jie Na				
Invited Keynote				
7	16:00-16:20	Zhongze Gu	Advanced 3D Printing System and Automated Detection System for Organs-on-a-Chip	Southeast University
8	16:20-16:40	Dong Sung Kim	Electrolyte-assisted Electrospun Nanofiber Membrane for Organ-on-a-chip and Tissue Regeneration	Pohang University of Science and Technology
Oral Presentation				
9	16:40-16:55	Jun Yin	Manufacturing of hiHep Cells-Based Artificial Liver Support System Using Digital Light Processing	Zhejiang University
10	16:55-17:10	Lei Zhang	3D Printing in vascular stent fabrication	Tsinghua University
11	17:10-17:25	Fengzhi Zhang	Biofabrication of functional human cardiac miro-units using human induced pluripotent stem cells	Chinese PLA Academy of Military Sciences
12	17:25-17:40	Byoung Soo Kim	Development of Perfusable Vascularized Human Skin Equivalent Using 3D Cell-printing Technique for Better Recapitulation of Complexity of Skin Anatomy	Pohang University of Science and Technology

December 4, 2018 (Morning)

8:30-11:50 Session 4 NUS-THU Joint Session

Location: Meeting Room 1, 2F, Building 1#, Xijiao Hotel

No.	Time	Authors	Title	Institute
8:30-10:25 Co-Chair: Dr. Wentao Yan				
Invited Keynote				
1	8:30-8:50	Heow Pueh Lee	A benchmark study between selective laser sintering and selective laser melting techniques: quantitative comparisons of repeatability and reproducibility	National University of Singapore
2	8:50-9:10	Feng Lin	The exploration for electron beam based powder bed fusion technique in Tsinghua University	Tsinghua University
Oral Presentation				
3	9:10-9:25	Khoo Boo Cheong	Recent advances in the modelling of fiber suspension in non-Newtonian fluids	National University of Singapore
4	9:25-9:40	Phan-Thien Nhan	Smoothed Particle Hydrodynamics (SPH) modelling of fibre orientation in a 3DP process	National University of Singapore
5	9:40-9:55	Dechen Zhao	Research on secondary electron monitoring in EBSM process	Tsinghua University
6	9:55-10:10	Zhenhao Zhao	In Situ Investigation of the Growth of Directional Needle-Sharp Crystals(MAPbI¬3) Perovskite from Microdroplets	Tsinghua University
	10:10-10:25	Tea Break: 2F, Building 1#		
10:25-11:50 Co-Chair: Dr. Feng Lin				
Invited Keynote				
7	10:25-10:45	Wentao Yan	Multi-scale multi-physics modeling of powder-based additive manufacturing with experimental validation	National University of Singapore
8	10:45-11:05	Baohua Chang	Influences of cooling conditions in laser metal deposition of a directionally-solidified superalloy	Tsinghua University
Oral Presentation				
9	11:05-11:20	Yanping Lian	A Cellular Automaton/Finite Element Model to Microstructure Predictions for Additively Manufactured Metals	Beijing Institute of Technology
10	11:20-11:35	Ya Qian	Data Generalizing and Mining for Mesoscopic Simulation of Electron Beam Melting	Tsinghua University
11	11:35-11:50	Jiong Zhang	Post-processing of additively manufactured metallic components	National University of Singapore

December 4, 2018 (Morning)				
8:30-11:55 Session 5 Metallic Additive Manufacturing **Location: Meeting Room 5, 2F, Building 1#, Xijiao Hotel**				
No.	**Time**	**Authors**	**Title**	**Institute**
8:30-10:20 Co-Chair: Dr. Dongdong Gu				
Invited Keynote				
1	8:30-8:50	Xin Lin	Microstructure and Compressive/Tensile Characteristic of Large Size Zr-based Bulk Metallic Glass Prepared by Laser Additive Manufacturing	Northwestern Polytechnical University
Oral Presentation				
2	8:50-9:05	Zongwen Fu	Additive Manufacturing of Dense Copper by Selective Electron Beam Melting	Friedrich-Alexander University Erlangen-Nürnberg
3	9:05-9:20	Zhijun Tan(Zhao Zhang)	Friction Stir Additive Manufacturing and Its Data Driven Design	Dalian University of Technology
4	9:20-9:35	Jizhan Li	A Novel Self Dispersion Reinforcement High Entropy Alloy Prepared by Selective Laser Melting	Huazhong University of Science & Technology
5	9:35-9:50	Xulong Ma	Machine development and process study of Electron Beam Selective Melting	Tsinghua University
6	9:50-10:05	Yu Long	The Tool Path Planning for Selective Laser Melting	Hans Laser Smart Equipment Group
	10:05-10:20	Tea Break: 2F, Building 1#		
10:20-11:55 Co-Chair: Dr. Xin Lin				
Invited Keynote				
7	10:20-10:40	Dongdong Gu	Function-Driven Laser Additive Manufacturing of Metallic Components	Nanjing University of Aeronautics & Astronautics
Oral Presentation				
8	10:40-10:55	Yunlong Li	Zirconium modified Nb-22Ti-16Si alloys fabricated by laser solid forming: microstructure and mechanical property	Northwestern Polytechnical University
9	10:55-11:10	Guoqing Zhang	Simulation study of spatter formation mechanisms during selective laser melting	Wuhan University
10	11:10-11:25	Yu Long	High Efficient Process Monitoring and Intelligent Defect Detection for Powder Bed Laser Melting Process	Hans Laser Smart Equipment Group
11	11:25-11:40	Xiaowen Zhao	The Study and Clinical Application of Additive Manufacturing Based on Tissue Digital Analysis and Reconstruction	Shenzhen Excellent Technology Company Limited
12	11:40-11:55	Hui Chen	Numerical simulation on powder-spreading process of selective laser melting via discrete element method: packing density of powder layer	National University of Singapore

December 4, 2018 (Morning)

8:30-12:00 Session 6 Cell-Chip and in-vitro Living System

Location: Meeting Room 6, 2F, Building 1#, Xijiao Hotel

No.	Time	Authors	Title	Institute
8:30-10:30 Co-Chair: Dr. Rui Yao				
Invited Keynote				
1	8:30-8:50	William Whitford	Development of Perfusion Culture Media for Continuous Biomanufacturing	GE Healthcare in Logan
2	8:50-9:10	Jong Young Kwak	Three Dimensional Monolayer Culture of Epithelial Cells on Electrospun Poly(vinyl alcohol) Nanofibrous Membrane	Ajou University
3	9:10-9:30	Shengli Mi	Microfluidic system for modelling 3D tumour invasion into surrounding stroma and drug screening	Tsinghua University
Oral Presentation				
4	9:30-9:45	Sanskrita Das	Decellularized Extracellular Matrix Bioinks and the External Stimuli to Enhance Cardiac Tissue Development in vitro	Pohang University of Science and Technology
5	9:45-10:00	Yu Song	An in vitro brain-like drug screen model based on advanced 3D bioprinting technology	Tsinghua University
6	10:00-10:15	Guangliang Zhang	Control of the formation of vascular network in 3D bioprinted tissue by tensile force	Ruihua Affiliated Hospital of Soochow University
	10:15-10:30	Tea Break: 2F, Building 1#		
10:30-12:00 Co-Chair: Dr. Shengli Mi				
Invited Keynote				
7	10:30-10:50	Yonghua Chen	3D Printing Smart Soft Robotics	University of Hong Kong
8	10:50-11:10	Sik Yoon	Biomimetic 3D hydrogel-based cell culture model of human ovarian cancer: implications for novel therapeutic targets in ovarian cancer	Pusan National University
9	11:10-11:30	Rui Yao	3D cell printing of pluripotent stem cells	Tsinghua University
Oral Presentation				
10	11:30-11:45	Tianzou Hu	Fabrication Of Three-Dimensional Organic/Inorganic Scaffold by Direct Ink Writing Technology	East China University of Science and Technology
11	11:45-12:00	Chengjin Wang	Fabrication and in vitro evaluation of 3D-printed biodegradable stents	Tsinghua University

December 4, 2018 (Afternoon)				
14:00-17:10 Session 7 Additive Manufacturing for Ceramic, Polymer and Composite Materials				
Location: Meeting Room 1, 2F, Building 1#, Xijiao Hotel				
No.	**Time**	**Authors**	**Title**	**Institute**
14:00-15:35 Co-Chair: Dr. Zhongde Shan				
Invited Keynote				
1	14:00-14:20	Yusheng Shi	Additive manufacturing of ceramics and its potential applications	Huazhong University of Science and Technology
Oral Presentation				
2	14:20-14:35	Rongzhen Liu	Microstructure evolution of porous SiC with low residual silicon content fabricated by direct laser sintering method	Huazhong University of Science and Technology
3	14:35-14:50	Shenggui Chen	A study of 3D-printable reinforced composite resin: PMMA modified with TiO2/PEEK micro- and nano-composite	Dongguan University of Technology
4	14:50-15:05	Xiaowen Shi	Hierarchical structure of soft materials: A cathodic writing approach to control the function and properties of polysaccharide hydrogel	Wuhan University
5	15:05-15:20	Yueke Ming	A novel method of 3D printing for continuous fiber reinforced thermosetting polymer composites	Xi'an Jiaotong University
	15:20-15:35	Tea Break: 2F, Building 1#		
15:35-17:10 Co-Chair: Dr. Yusheng Shi				
Invited Keynote				
6	15:35-15:55	Zhongde Shan	Digital Hybrid Forming Technology & Equipment Based on Patternless Casting	Tsinghua University
Oral Presentation				
7	15:55-16:10	Wenliang Xu	Ceramic Mold for Casting Single-crystal Superalloys Based on Stereolithography	Xi'an Jiaotong University
8	16:10-16:25	Zhongrui Wang	Rapid Precision Casting of Complex Pipeline Based on Stereolithography Prototype	Xi'an Jiaotong University
9	16:25-16:40	Guodong Goh	Additive Manufacturing of Topology Optimized Landing Gear Fabricated With Continuous Carbon Fiber Reinforced Thermoplastic Composite	Singapore Centre for 3D printing
10	16:40-16:55	Hui Ren	High-density bio-glass ceramics fabricated by stereo-lithography	Xi'an Jiaotong University
11	16:55-17:10	Lin Sang	Development of PLA/BF composites and their feasible evaluation for 3D printing applications	Dalian University of Technology

December 4, 2018 (Afternoon)				
14:00-17:30 Session 8 On-line Monitoring and Quality Control **Location: Meeting Room 5, 2F, Building 1#, Xijiao Hotel**				
No.	**Time**	**Authors**	**Title**	**Institute**
14:00-15:55 Co-Chair: Dr. Xiayun Zhao				
Invited Keynote				
1	14:00-14:20	Chee Kai Chua	Building a World Class 3D Printing Research Centre: Strategies and Lessons	Nanyang Technological University
2	14:20-14:40	Yongqiang Yang	Innovative Design of Porous Structure and Implementation of Additive Manufacturing for Medical Applications	South China University of Technology
Oral Presentation				
3	14:40-14:55	Dong Qiu	Development of high performance titanium-copper alloys through laser metal deposition	RMIT University
4	14:55-15:10	Fangyong Niu	Suppressing Effect and Mechanism of Titanium Oxide Doping on Cracking Behavior of Directed Laser Deposition of Alumina Structure	Dalian University of Technology
5	15:10-15:25	Nan Kang	Microstructure, mechanical and magnetic properties of soft magnetic Fe-Ni-Si by using selective laser melting from nickel coated high silicon steel powder	Northwestern Ploytechnical University
6	15:25-15:40	Wuzhu Yan	Effects of deposition strategy on residual stress and deformation in additive manufacturing	Northwestern Polytechnical University
	15:40-15:55	Tea Break: 2F, Building 1#		
15:55-17:30 Co-Chair: Dr. Yongqiang Yang				
Invited Keynote				
7	15:55-16:15	Jiabin Guo	In Vitro Alternatives in Drug Discovery and Safety Evaluation	Center of Disease Control and Prevention, PLA
Oral Presentation				
8	16:15-16:30	Jie Sun	Electrohydrodynamic Printing Process Monitoring by Microscope Image Identification	Xi'an Jiaotong-Liverpool University
9	16:30-16:45	Xiayun Zhao	Towards Intelligent Precision Additive Manufacturing – a case study on interferometry sensor data mining for in-process 3D measurement of photopolymerized part dimensions	University of Pittsburgh
10	16:45-17:00	Yu Long	Generative Design of Robot Component	Hans Laser Smart Equipment Group
11	17:00-17:15	Wenjing Yang	3D-Printed Polymeric Structures for Tunable Wideband Acoustic Absorption	Nanyang Technological University
12	17:15-17:30	Dekun Yang	In-situ capture of spatter signature of SLM processing using maximum entropy double threshold segmentation method	Wuhan University

December 4, 2018 (Afternoon)				
14:00-17:30 Session 9 Additive Manufacturing for Biomaterials **Location: Meeting Room 6, 2F, Building 1#, Xijiao Hotel**				
No.	**Time**	**Authors**	**Title**	**Institute**
14:00-16:00 Co-Chair: Dr. Su Ryon Shin				
Invited Keynote				
1	14:00-14:20	Jerry Fuh	E-Jet Bioprinting of Hierarchical Scaffold for Esophagus Tissue Repair	National University of Singapore
2	14:20-14:40	Changchun Zhou	3DP of bioceramics with accurate hierarchical porosity for bone tissue repair	Sichuan University
3	14:40-15:00	Matthew Lincoln Mail	Bioinks for 3D Bioprinting of Biomimetic Tissue Models	CELLINK
Oral Presentation				
4	15:00-15:15	Maling Gou	3D printing for peripheral nerve regeneration	West China Hospital, Sichuan University
5	15:15-15:30	Xue Qu	Electro-fabrication of polysaccharide films with biomedical applications	East China University of Science and Technology
6	15:30-15:45	Jinyang Li	Electrofabrication of Biomaterials： A Bio-mimetic Electrochemical Approach to Fabricate Hydrogel and Confer Functions	University of Maryland
	15:45-16:00	Tea Break: 2F, Building 1#		
16:00-17:30 Co-Chair: Dr. Jerry Fuh				
Invited Keynote				
7	16:00-16:20	Yasuyuki Sakai	Oxygen transfer-based design of 3D scaffolds for large metabolic tissues: an integrative methodology based on a branching/joining flow channel network and micro-tissue assembly	University of Tokyo
8	16:20-16:40	Cosgriff-Hernandez Elizabeth	Emulsion Inks for 3D Printing of High Porosity Materials	University of Texas at Austin
9	16:40-17:00	Su Ryon Shin	Microengineered hydrogels for tissue fabrication and organ-on-a-chip application	Brigham and Women's Hospital, Harvard Medical School
Oral Presentation				
10	17:00-17:15	Wenfeng Lu	Design of Conforming Surface for Human Skin at Highly-Stretched Joint Areas with Additive Manufacturing	National University of Singapore
11	17:15-17:30	Hang Liu	Investigation of Ink Properties on the Printability and Stability in Electrohydrodynamic Printing System	National University of Singapore (Suzhou) Research Institute

December 5, 2018 (Morning)				
8:30-12:05 Session 10 Additive Manufacturing for Ceramic, Polymer and Composite Materials				
Location: Meeting Room 1, 2F, Building 1#, Xijiao Hotel				
No.	**Time**	**Authors**	**Title**	**Institute**
8:30-10:25 Co-Chair: Dr. Guifeng Zhang				
Invited Keynote				
1	8:30-8:50	Kaiming Ye	Bioinks for 3D Printing Tissue Engineered Vascular Grafts	Binghamton University, State University of New York (SUNY)
2	8:50-9:10	Min Jun Kim	Micro-Assembly Exploiting SofT Robotics (MAESTRO)	Southern Methodist University
Oral Presentation				
3	9:10-9:25	Hongzhi Wu	Effects of Cross-linkers Concentration on the Thermal and Shape Memory Properties of a New Acrylate-based Polymer Printed by Digital Light Processing	Huazhong University of Science and Technology
4	9:25-9:40	Yongcai Liu	Material Extrusion Additive Manufacturing of Polycaprolac-tone–Magnesium Composite for Bone Tissue Engineering	Xi’An Jiaotong University
5	9:40-9:55	Yongdi Zhang	The Design and Verification of A FDM 3D Printer with Double Nozzles Working Synchronously	Hebei University of Science and Technology
6	9:55-10:10	Yu Sun	Fabrication of Graphite/mullite Composite via Indirect Selective Laser Sintering and Gelcasting Process	China Three Gorges University
	10:10-10:25	Tea Break: 2F, Building 1#		
10:25-12:05 Co-Chair: Dr. Kaiming Ye				
Invited Keynote				
7	10:25-10:45	Gregory F. Payne	Electro-biofabrication to create complex materials systems for emerging life science applications	University of Maryland
8	10:45-11:05	Guifeng Zhang	Collagen based biomaterials and its application in biopriting	Institute of Process Engineering, Chinese Academy of Sciences
Oral Presentation				
9	11:05-11:20	Bin Hu	Design considerations of high temperature FDM technology for PEEK materials	Huazhong University of Science and Technology
10	11:20-11:35	Jiamin Wu	High-porosity Mullite Ceramics with Enhanced Properties Prepared by Selective Laser Sintering using Fly Ash Hollow Spheres as Raw Materials	Huazhong University of Science and Technology
11	11:35-11:50	Lifeng Kang	Recent Development in Additive Manufacturing for Drug Delivery and Testing	University of Sydney
12	11:50-12:05	Yang Lei	New Process for Customized Patient-Specific Aortic Stent Graft using the Additive Manufacturing Technique	Tsinghua University

December 5, 2018 (Morning)				
8:30-12:33 Session 11 Additive Manufacturing for Biomaterials & Rapid Fire **Location: Meeting Room 5, 2F, Building 1#, Xijiao Hotel**				
No.	**Time**	**Authors**	**Title**	**Institute**
8:30-10:45 Co-Chair: Dr. Maling Gou				
Invited Keynote				
1	8:30-8:50	Deyuan Zhang	Biomimetic anti-slipping surface design of surgical instrument	Beihang University
2	8:50-9:10	Quanyi Guo	Medicine and bioengineering integration to solve clinical problems—the story of the combination of bio-manufacturing and orthopedic biomaterials	Department of Orthopedics of the General Hospital of PLA
3	9:10-9:30	Xiaolin Tu	Study of osteocytic Wnt-Jag1 niche on the biofabrication of stem cell-derived organoid bone with dual biological function	Chongqing Medical University
Oral Presentation				
4	9:30-9:45	Jiapeng Luo	Additive Manufacturing of ultralow modulus, biocompatible Ti-Nb-Ta-Zr alloy with controllable porosity & Young's modulus	Southern University of Science and Technology
5	9:45-10:00	Kevin F. Firouzian	An image-guided technique for intra-scaffold cell printing	Tsinghua University
6	10:00-10:15	Chenjia Zhao	Implantable cervix uterus with protein sustained release functionality by 3D printing	Tsinghua University
7	10:15-10:30	Zhongyu Zhang	Preparation and Properties of Bio-piezoelectric Coatings Prepared by RF Magnetron Technology	Xinjiang University
	10:30-10:45	Tea Break: 2F, Building 1#		
10:45-12:33 Co-Chair: Dr. Yu Song				
Rapid Fire				
8	10:45-12:33	Posters		

December 5, 2018 (Morning)

8:30-11:50 Session 12 Additive Manufacturing for Biomaterials

Location: Meeting Room 6, 2F, Building 1#, Xijiao Hotel

No.	Time	Authors	Title	Institute
8:30-10:10 Co-Chair: Dr. Ting Zhang				
Invited Keynote				
1	8:30-8:50	Mian Long	Multiscale Mechanobiology and Engineered Construction in Liver Sinusoids	Institute of Mechanics, Chinese Academy of Sciences
2	8:50-9:10	Yuan Pang	Organization of liver organoid using Raschig ring-like micro-scaffolds and triple co-culture toward modular assembly-based scalable liver tissue engineering	Tsinghua University
Oral Presentation				
3	9:10-9:25	Ruixue Yin	Fabrication of PLA Scaffolds with Photo-active Controlled Properties by 3D Fiber Deposition	East China University of Science and Technology
4	9:25-9:40	Liliang Ouyang	Bio-fabrication of Complex Multilayered Tubular Hydrogels Using Diffusion-induced Gelation and 3D Printing	Tsinghua University
5	9:40-9:55	Siddharth Kumar	3D bio-printer with special add-on extruder compatible with FFF (Fused Filament Fabrication) based 3D Printers with extensive software platform for soft tissue engineering applications	BITS Pilani, K K Birla Goa Campus
	9:55-10:10	Tea Break: 2F, Building 1#		
10:10-11:50 Co-Chair: Dr. Mian Long				
Invited Keynote				
6	10:10-10:30	Rong wang	Choice of bioinks: synthetic or natural materials or combination	Southern Methodist University
7	10:30-10:50	Ting Zhang	Biomimetic design and fabrication of pre-vascularized myocardial tissue	Tsinghua University
Oral Presentation				
8	10:50-11:05	Lei Yang	Gyroid cellular structures used in biomedical implant: Mathematical design additive manufacturing and mechanical properties	Huazhong University of Science and Technology
9	11:05-11:20	Zhi Yao	A rapid Micro-MRI nerve scanning method for three-dimensional reconstruction of peripheral nerve fascicles	The First Affiliated Hospital, Sun Yat-sen University
10	11:20-11:35	Shuai Qiu	The specificity of motor and sensory nerve architecture in nerve tissue engineering scaffold designing-Histological assessment and three-dimensional reconstruction visualization of the motor and sensory pathways in femoral nerve	The First Affiliated Hospital, Sun Yat-sen University
11	11:35-11:50	Xujing Zhang	Effect of Freeze-drying on the Properties of Silk Fibroin/Polyvinyl Alcohol/Hydroxyapatite Composites	Mechanics Institute

December 5, 2018 (Afternoon)

14:00-16:00 Session 13 Industry Presentation & Close Ceremony

Location: Meeting Room Jin Yuan hall, 2F, Building 5#, Xijiao Hotel

Co-Chair: Dr. Lei Zhang

No.	Time	Enterprise	Title	Presenter
1	14:00-14:15	PERA Global	Integrated solution of AM design and process simulation	Gangqiang Bao
2	14:15-14:30	SunP Biotech	3D Bioprinting Services for Boosting Research Efficiency	Ruhan Guo
3	14:30-14:45	Tianjin SciTsinghua QuickBeam Tech (QBEAM)	Building high performance metal parts using Electron Beam Selective Melting	Chao Guo
4	14:45-15:00	Beijing e-Plus 3D Tech.	E-Plus 3D Printing Solution For Medical Rehabilitation	Tivon Guo
5	15:00-15:15	Shaanxi Jugao-AM Technology	Performance-controlled 3D printing technology for personalized PEEK orthopedic implant	Changquan Shi
15:15-16:00 Close Ceremony (Co-Chair: Dr. Tao Xu)				
16:00-18:00 Lab Tour at Tsinghua University				

Abstract

December 3 Session 1

Advances in AM Process Simulation: Residual Stress Predictions for Laser Direct Energy Deposited Thin Wall Components and Overhanging Structures Manufactured via Selective Laser Melting

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Due to solidification of melted powders in additive manufacturing processes, large residual stresses are created in the build. This can lead to unwanted distortions during the building phase, as well as crack initiation, propagation and immature failure. The main aim of this work is to optimize the additive manufacturing process parameters by finite element modeling and to simulate the resulting residual stresses and distortions. We focus on two manufacturing processes: (a) Laser Direct Energy Deposition (LDED), which is a powder-blown AM technology and (b) Selective Laser Melting (SLM), which is a powder-bed AM technology. The modelling results are validated through microstructure studies, residual stress measurements and distortion measurements. We employ the latest ABAQUS AM module to simulate both processes, as it provides new interface allowing the user to define floating point data as a function of position *and time* to achieve a fully-automated two-step 3D printing process simulation. Heat transfer and stress analysis are performed sequentially. For LDED processes, thin wall components are simulated and the residual stresses are predicted and compared with both FIB-DIC and XRD residual stress measurement results at different scales. It is shown that by using the optimal processing parameters for laser cladding, tensile residual stresses are still generated, with a high value, at the starting and ending positions of the wall, and especially at the corners. Cracks at the corners are also observed during sample preparation. For the SLM process, overhanging structures with different support thicknesses are simulated. The influence of laser path time series description, time increment and surrounding powder-bed material on the resulting stresses and distortions was evaluated. We show that the support thickness plays a key role in controlling residual stresses and resulting distortions, which is also supported by experimental measurements.

Research on high-efficient prediction and measurement of deformation during metal additive manufacturing

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Due to the complex non-equilibrium thermal process, the problem of component deformation is one of the major bottleneck restricting the application of metal additive manufacturing. The present study focus on the numerical prediction and in situ measurement of deformation during directed energy deposition processing. The temperature filed and deformation were accurately predicted by transient thermal-force sequential coupled finite element analysis, the error of temperature is within 10%. In order to improve the efficiency of calculation, the high efficient segmented temperature function method and segmented heat source method were applied to deformation prediction, respectively. On the basis of maintaining relatively high accuracy, the prediction efficiency can be increased by more than 90%. On the other hand, the continuous full-field strain during deposition was in situ measured based on digital image correlation method. The transient strain evolution and deformation mode of titanium alloy single-arm wall during manufacturing were revealed.

Mechanical characterization of parts fabricated by selective laser melting processes

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Additive Manufacturing (AM) is defined as a family of technologies to deposit and consolidate materials for creating a 3D part as opposed to subtractive manufacturing methodologies. When it comes to fabricating metals, selective laser melting (SLM) is a promising powder bed AM process where a computer controlled laser beam is applied over the required cross-sectional area in powder beds to melt and bond particles into a designed thin slice. Subsequently, additional layers of powders are spread on top of the processed slice and the laser scanning is repeated to consolidate each new layer and bond it to the existing layers, such that the entire part is built as a successive stack of 2D layers [2][1].

In such a SLM technique, process parameters such as hatch spacing and layer thickness have significant effects on mechanical properties and microstructure as extensively reported in research works (see, for example, [1] and [4]). However, few reported works [3] have investigated in detail how contour related process parameters affect mechanical performance of the manufactured parts. The present study aims to characterize the mechanical behavior of the parts fabricated by using various process parameters of the part contour. More specifically, the effects of parameters such as contour thickness and contour energy density on geometric features, mechanical properties and microstructure are investigated in details. Such experimental characterization is beneficial to seeking a balance between part quality and build cost. Also, this study provides references for understanding the limitations of SLM and seeking potential manufacturing applications.

Keywords: Additive Manufacturing, Selective Laser Sintering, Mechanical Characterization.

References

[1]. Carter LN, Martin C, Withers PJ and Attallah MM, The influence of the laser scan strategy on grain structure and cracking behaviour in SLM powder-bed fabricated nickel superalloy, *Journal of Alloys and Compounds* **615** (2014) 338-347.

[2]. Frazier and William E, Metal additive manufacturing: a review, *Journal of Materials Engineering and Performance* **23** (2014) 1917-1928.

[3]. Tammas-Williams S et al., XCT analysis of the influence of melt strategies on defect population in Ti–6Al–4V components manufactured by Selective Electron Beam Melting, *Materials Characterization* **102** (2015) 47-61.

[4]. Wei K, Gao M, Wang Z and Zeng X, Effect of energy input on formability, microstructure and mechanical properties of selective laser melted AZ91D magnesium alloy, *Materials Science and Engineering: A* **611** (2014) 212-222.

Investigating the processability and microstructural evolution of high strength Al2024 aluminum alloy by selective electron beam melting

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Additive Manufacturing (AM) of aluminum alloys has become a highly interested topic in various industries such as aerospace and automotive in recent years because of its great potential advantages compared to conventional manufacturing processes. Though, AM has not become widespread for manufacturing practical aluminum net shape parts due to the limitations in fabricating sound parts. High thermal conductivity, reflectivity, and susceptibility to oxidation, wide solidification range, poor flowability, and the evaporation of alloying elements during processing are some main factors lead to internal defects such as porosities and cracks formation which limit the mechanical performance of the fabricated parts built by most AM processes. Selective Electron Beam Melting

(SEBM) can be considered as an alternative technique to process aluminum alloys. In the literature, most of the works are concerned in manufacturing Al- Si eutectics alloys which are known to be the most suitable aluminum alloys for AM, mainly by SLM process, yet there is still a need to tackle the manufacturing problems such as solidification cracking and porosities with regard to high strength Al grades. In this study, the processability of manufacturing high strength Al2024 samples by electron beam melting was investigated and the effect of processing parameters on the internal defects formation was studied. The base plate was preheated to 350℃ and samples fabricated using an alternating raster scan pattern with different processing parameters such as scan speed, beam current, and hatch spacing. Results showed that samples with high relative density values of more than 95% can be fabricated. Light Optical Microscopy (LOM) and Scanning Electron Microscopy (SEM) were used to investigate the microstructural evolution and equiaxed grains were observed. Micrographs also revealed that micro porosities and cracks are present within the samples which are mainly formed at grain boundaries. However, they can be diminished by optimizing the processing parameters which led to almost full dense parts fabrication.

Keywords: Additive Manufacturing, Selective Electrom Beam Melting, Al2024, High Strength Al alloy

Research on aluminum component change and microstructure evolution of Ti47Al2Cr2Nb alloy in electron beam selective melting (EBSM) process under argon atmosphere

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With the development and application of additive manufacturing technology, the additive manufacturing of TiAl alloy has been widely researched. EBSM has the advantages of high energy, high vacuum, and high preheating temperature baseplate (＞1000℃), which can effectively avoid the cracks and oxidation of TiAl alloy. However, EBSM could cause the evaporation of elements, which may change the element composition of the alloy, and eventually changes the microstructure and properties of the alloy. The composition change of Ti47Al2Cr2Nb alloy by EBSM was studied and discussed systematically based on the following experiments. The phase composition and microstructure of the as-built samples were examined by scanning electron microscope in back-scattered electron mode with energy dispersive spectroscopy, transmission electron microscope and X-ray diffraction.

The results showed that the aluminum component decreases with increasing of line energy density, and the alpha/beta phases were formed by evaporation of aluminum of multiple scanning per layer in the EBSM process. The alpha/beta phases exhibited higher room temperature strength and ductility. It is feasible to obtain gradient structural materials with different phases by EBSM using the same metal powders of Ti47Al2Cr2Nb alloy with an average particle size of 15–53 μm.

Keywords: Electron beam selective melting; Evaporation of aluminum; Alpha/beta phases.

Thermal Analyses for Laser Scanning Pattern Evaluation in Laser Aided Additive Manufacturing using Deep Neural Network

K Ren, Y F Zhang, J Y H Fuh

Laser aided additive manufacturing (LAAM) is one of the key metal 3D printing technologies for surface cladding and fabrication of near-net shape parts. Its laser scanning strategies can have significant effects on the temperature distribution for multi-bead, multi-layered additive manufacturing, resulting in distinct residual stress distribution and substrate deformation. However, existing thermal analyses models are time consuming and laser scanning pattern selection still relies on empirical experience. This paper proposed an efficient thermal analyses model for LAAM with Deep Neural Network (DNN), containing following parts:

Firstly, a novel finite element (FE) thermal analyses simulation architecture was designed to continuously predict

the temperature field among the whole simulation domain during the entire LAAM process. It laid foundations for the large-scale thermal history data set generation by providing predicting temperature field in each unit simulation step.

Secondly, LAAM thermal analyses data structure was designed to describe the deposition state and corresponding temperature field. For a given simulation time *t*, a three-dimensional matrix $s^t \in S$ was designed to describe the deposition status, and a three-dimensional matrix $t^t \in T_1$ was designed to describe the predicting temperature field, as shown in Fig 1. Thereafter, a one-layer LAAM deposition thermal history data set was built, containing over 20,000 deposition status.

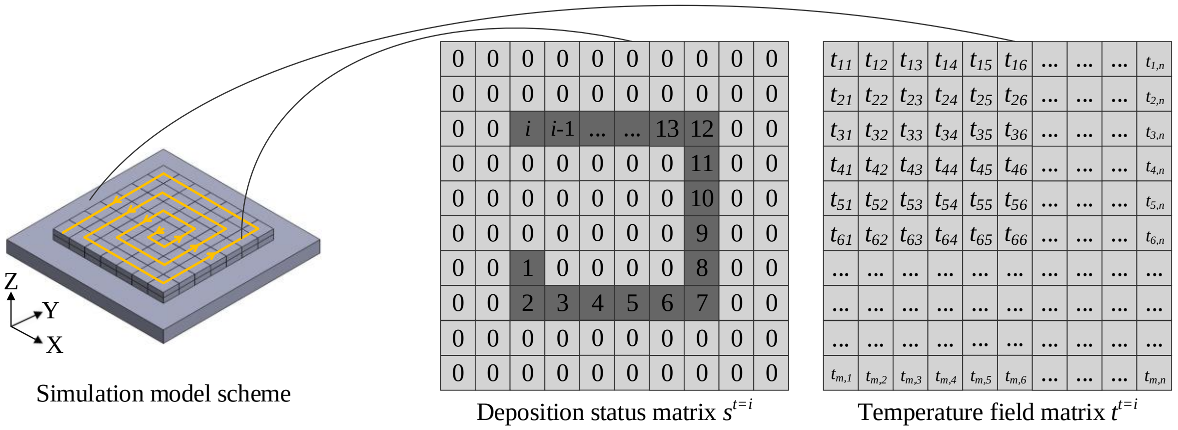

Figure 1. Deposition status matrix and temperature field matrix generation

Thirdly, a DNN model was designed to describe the connection between laser deposition status and corresponding temperature distribution with a function *f*: $R^S \rightarrow R^{T1}$. The RNN model contained 5 fully connected layers, including 3 hidden layers with 200 neurons, as shown in the Fig 2. The rectified linear unit (ReLU) was selected as the activation function in order to speed up the training. The normalized mean square error (nMSE) was selected as the evaluation matrix and the parameters of the DNN was updated using stochastic gradient decent by backpropagating the error information at the output layer.

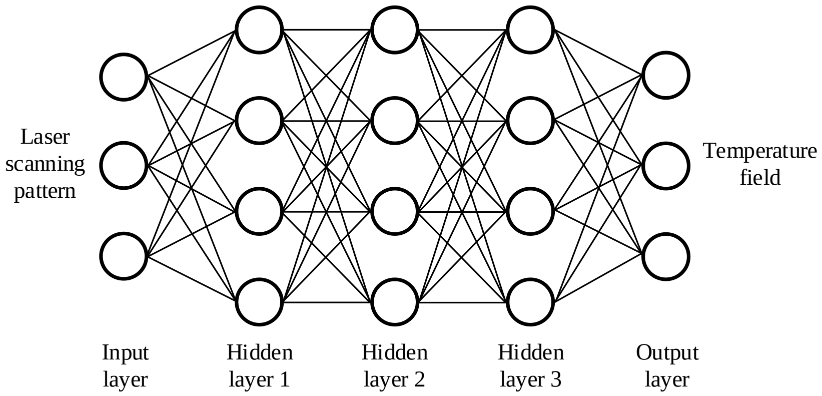

Figure 2. DNN model structure

All training and validation are implemented with Tensorflow. The loss curve during the training phase is shown in Fig 3. It can be observed that the nMSE decrease from over 200,000 to around 7,000 after 1500 epochs, which implies that the DNN model fits the function *f* well. The comparison of simulation results and DNN model prediction results for a given 2D deposition geometry is shown in Fig 4. It can be found that both simulation results and DNN model prediction results show the comparable temperature concentration at the center part of the plate. The DNN model was validated to be able to predict the temperature field based on the deposition status.

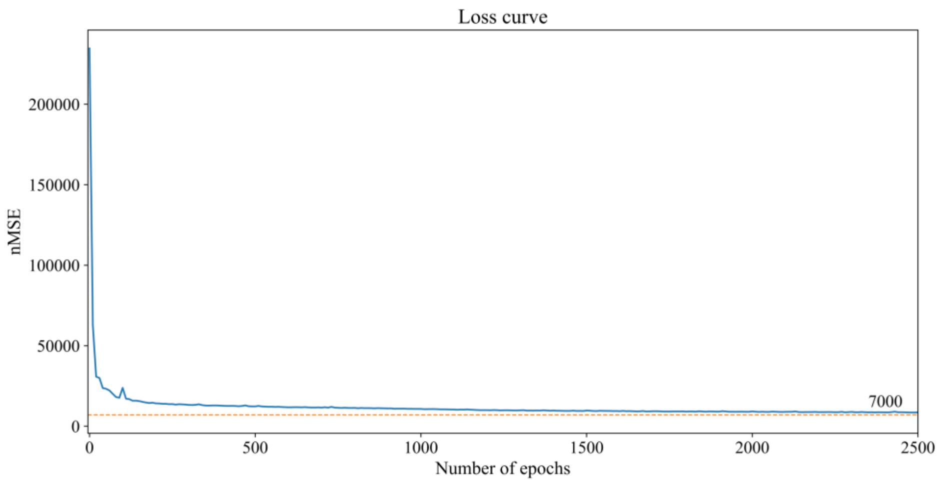

Figure 3. Training loss curve

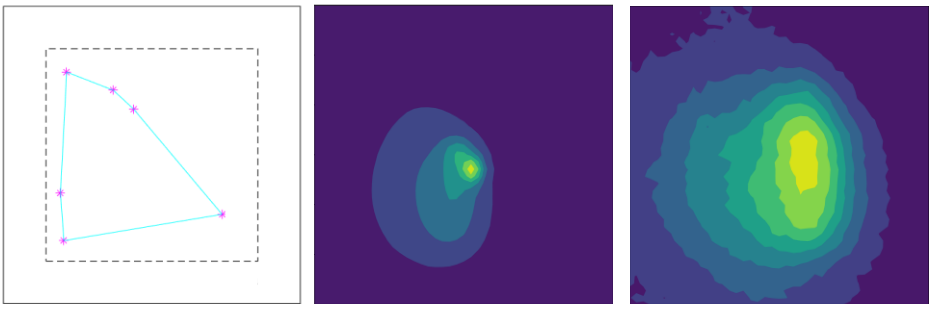

Figure 4. Comparison between simulation results and DNN model prediction results

In our future work, an optimized dataset will be built with more different laser scanning patterns. 3D deposition cases will also be included to extend the capability of the DNN model. Other machine learning algorithms will be introduced to improve the performance of LAAM process simulation like Recurrent Neural Network (RNN).

Laser Powder Bed Fusion of Pure Zn Metal Parts for Biodegradable Implant Applications

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Biodegradable metal is a hot topic for medical implants. It is not only excellent in mechanical properties, but also can degrade in human body, without concerning long term damage and secondary surgery. Zn is an essential element in human body. Degradation of Zn is slower than that of Mg and faster than Fe, which is attracting attention as an ideal biodegradable metal. Laser powder bed fusion (LPBF) has unique advantages for manufacturing customized implants. However, the current research on additive manufacturing of Zn metal is very limited. In this paper, porous and stent structures were demonstrated for typical application of biodegradable implants. The effect of processing parameters on density, surface quality and mechanical properties were discussed. The overlap remelting and good wetting behavior of Zn powder resulted to high density and good surface quality of LPBF products. The density was over 99.9% and the lowest surface roughness was about 10μm for optimal processing conditions. The average values of hardness, elastic modulus, yield strength, ultimate strength and elongation was 42HV, 23GPa, 114MPa, 134MPa, and 10.1% respectively for LPBF produced pure Zn parts,

superior to those of samples obtained by most manufacturing methods like casting and rolling. The good mechanical properties were contributed to high densification and fine grains. A typical cleavage fracture mode was observed with intragranular cracks, cleavage steps and cleavage planes surrounded by tearing ridges at the fracture surfaces. It was the first time to obtain Zn metal implant structures by additive manufacturing, and manifest the mechanical properties. The results provided theoretical and experimental support for the application of additive manufacturing of Zn based biodegradable metal implants.

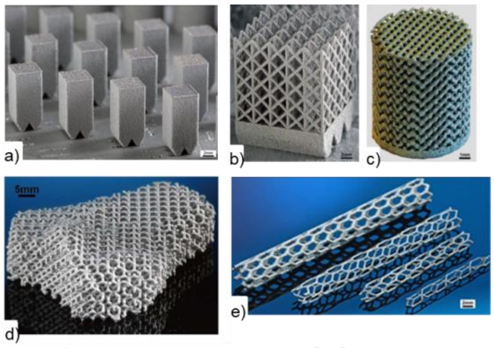

Figure 1 Structures made by L-PBF

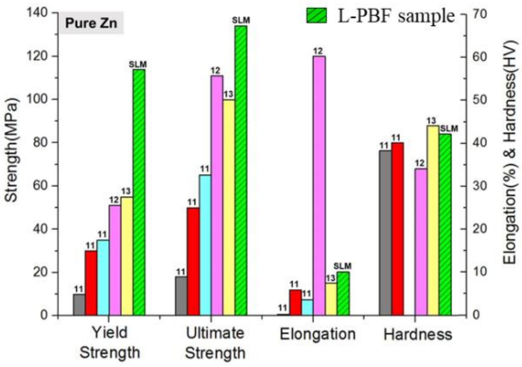

Figure 2 Mechanical properties of L-PBF products

In-situ Monitoring of Additive Manufacturing by Vision Method and Convolutional Neural Network

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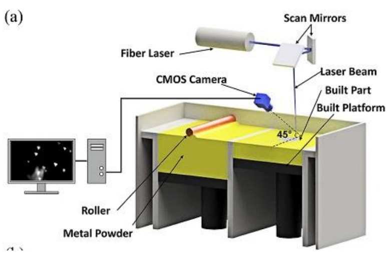
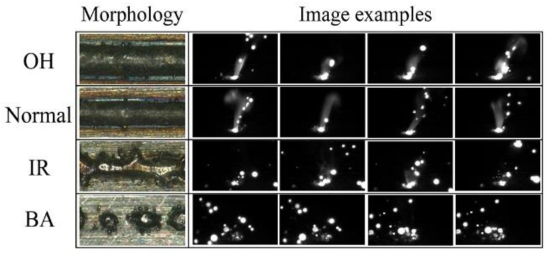
With the development of Additive manufacturing (AM) technique, currently part quality becomes a major barrier for its wider adoption. To improve the reliability and repeatability of AM built quality, process melt pool monitoring and control was proposed as a promising solution. Among the proposed monitoring methods, the two dimensional image monitoring of the heat affected zone of melt pool contains the most information on the process, including the information of melt pool, plume and spatters. However, making fully use of heat affected zone information for monitoring is quite challenging, as the optical emission of the melt pool, plume and spatters are convoluted as a result of a complex heat, mass and momentum transfer during the AM process. Therefore, the development of advanced monitoring algorithm for melt pool vision monitoring is necessary.

In the study, an off-axial melt pool heat affected zone vision monitoring method with the selected cut-off filter for the improvement of image contrast was proposed, as shown in Fig.1 (a). Based on the proposed method, the images under different melt pool regimes was collected, as shown in Fig.1 (b). Furthermore, the convolutional neural network (CNN) was introduced and discussed for the process condition detection. CNN as one type of deep learning has shown its excellent performance on image processing and pattern recognition recently. The main advantage is that it can learn the representative features from the raw data through training. Therefore, it can save the steps on image processing for feature extraction compared with the conventional machine learning method, which makes it have greater potential for real-time application. In addition, the classification accuracy for different melt pool regimes by CNN and the conventional machine learning methods, e.g. k nearest neighbor, support vector machine, and random forest, were compared. For the conventional methods, the features on melt pool, plume and spatters were extracted through our developed image processing algorithm. The extracted features include melt pool area, melt pool intensity distribution, plume area, plume intensity, plume orientation, plume major and minor axial length, spatter number, spatter area, spatter orientation, and spatter orientation variance. The comparison results demonstrated that the classification accuracy of CNN can be up to 86%, which is higher than that of the other three conventional methods which are 72.6%, 81.8% and 79.9%, respectively. Therefore, the proposed method is very promising for AM process monitoring.





(a) (b)

Fig.1 (a) The schematic of experiment setup for the proposed method; (b) Example of images collected under different melt pool regimes (OH: overheating, Normal: normal, IR: irregularity, BA: balling)

Investigation on Surface Roughness of Ti-6Al-4V by Electron Beam Selective Melting

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Surface roughness is one of the most important features of additive manufacturing(AM) processed intricate parts. This paper studies the parameter effects and mechanisms of different surface roughness by using simulation and experiment. Powder-scale models were developed to include the powder packing, melting, flow and solidification. First, the subroutine to obtain the particle distribution that treats the powder bed as randomly distributed particles was programing; then, the finite volume method is used to simulate the particle melting and flowing process. A ray tracing method implemented for energy input of the electron beam is applied and the volume of fluid method is coupled to capture the free surface. Cases under different scanning speeds and power parameters were run to collect surface morphologies of Ti–6Al–4V. Finally, the surface roughness values was derivated from the calculated results and compared with the experimental results.

Keywords: Electron beam selective melting; Surface roughness; Numerical simulation.

The Structure Design and Simulation of Laser-heated Electron Gun for Additive Manufacturing

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Electron beam additive manufacturing technology has higher requirements of the long continuous working time and fine focus spot with high current output of the cathode. In order to prevent the overheating and uncouple the cathode heating system with the high voltage supply, a laser-heating technique was proposed to replace the electrical heating or electron beam heating. The laser-heated electron gun used a lan-thanum hexaboride (LaB6) cathode with an emitting surface diameter of 1.5 mm. The cathode was fixed on a graphite upholder to prevent cathode contamination. A fiber laser with a center wavelength of 1064 nm was used to heat the cathode. A two-color infrared thermometer with detection bands of 1280nm and 1650nm respectively was introduced to measure the cathode temperature. A dichroic mirror with the cutoff wavelength of 1180 nm was placed in the optical path to separate the thermometer detection band from the laser-heated band so that the laser and the thermometer could use the same optical path, which simplified the structure of the electron gun. The CST Particle Studio was used to simulate the beam generation process and optimize the electron gun structure. In this research, a beam current up to 50mA was achieved with a laser power of 26W. The cathode temperature was limited to an optimal range by using the temperature monitoring system, which could extend the cathode life span significantly. The spot size was improved compared with the electric heated gun due to the absence of the heated current magnetic field.

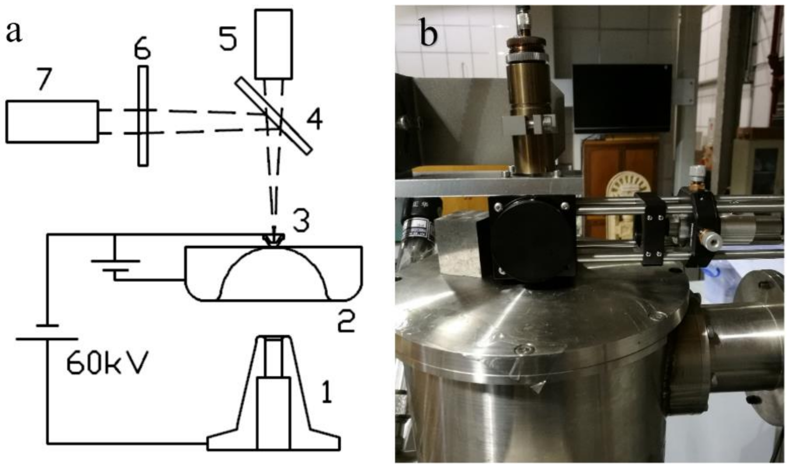

Figure 1 （a）schematic overview of the laser-heated electron gun and （b）the picture of the device.
1: anode; 2: grid, 3: LaB6 cathode, 4: dichroic mirror, 5: infrared thermometer, 6: focus lens, 7: laser source.

Keywords: additive manufacturing; laser-heating cathode; electron gun; temperature control.

Study on solidification behavior in electron beam additive manufacturing

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Electron beam additive manufacturing was a dynamic and complex process, and the process was characterised by multi-scale, multi-interface and multi-parameter. During the process, the solidification behavior was directly affected the quality of the parts. To profoundly understand the complex physical process, the solidification behavior of the molten pool in electron beam additive manufacturing was analyzed and the organization was predicted. The temperature gradient G and the solidification growth rate R were key parameters which affected the solidification structure of the superalloy. G × R affected the size of the microstructure, with the increase of G × R, the microstructure size become smaller. In addition, G / R affected the morphology of microstructures. With the decrease of G / R, the microstructures change from equiaxed crystals to cell crystals, columnar crystals and equiaxed crystals. The solidification parameters of the molten pool under different technological conditions were calculated and the results were compared and analyzed to predict the microstructure evolution characteristics. The validity and correctness of the model were verified by the relevant experimental results.

Keywords: Electron beam, additive manufacturing, solidification behavior, microstructure

From Superhydrophilicity to Superhydrophobicity: Fabrication and Applications

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Nano-engineered surfaces on various metal such as aluminum, copper & stainless steel were fabricated and investigated for superhydrophilicity or superhydrophobicity. The fabrication methods and applications of superhydrophilic/superhydrophobic surface with nano-engineered surfaces are presented.

*** Fabrication methods**

To make superhydrophilic/superhydrophobic surface, morphology of surface and its surface energy are important. In case of aluminum, nano-engineered surfaces, such as nanohoneycomb, nanofiber, and nanoflake are fabricated by dipping method which is applicable to any size, shape and suitable for mass production. This surface has superhydrophilicity, however, by coating the surface with polymer, which has low surface energy, superhydrophobic surface can be obtained. Superhydrophilic/superhydrophobic surface on other materials, such as copper, stainless steel and others can be fabricated by similar method.

*** Applications of nanostructures**

Through the superhydrophilic/superhydrophobic surfaces with nano-engineered structure, we developed transparent self-cleaning superhydrophobic surface and nanofilter for immune rejection. In addition, we have investigated drag reduction, antifungal effect, and anti-frosting/ defrosting behavior on the superhydrophobic surface. Based on nano-engineered surface, superhydrophobic heat exchanger used in air-conditioner and refrigerator, is developed and fabricated successfully. Furthermore, we designed a patterning method for superhydrophilic and superhydrophobic surface, as a result, a liquid handler is developed for precise liquid injection. Moreover, the superhydrophilic/superhydrophobic aluminum mesh which enables selective separation of oil and water is also developed.

From Art-to-Part: Multidisciplinary Toolset for Laser Powder-bed Fusion Additive Manufacturing

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Structured methods to mature and certify Powder-bed Fusion Additive Manufacturing processes (PBFAM) are in their infancy meaning that numerous process iterations are required to achieve the requisite tolerances and properties. This talk takes a holistic look at optimizing the manufacturing process chain for process certification. A designed part will be demonstrated and evaluated through the optimization of part geometry and material state through PBFAM, heat treatments and bulk machining. Analytical and process optimization tools will be presented including: 1) model-based producibility tool for PBFAM and machining; 2) PBFAM scan path optimization for high material integrity; 3) prediction of thermal distortion; 4) part compensation for distortion and machining; 5) machining consideration and evaluation. The integrated work flow can accelerate the process certification by shifting more than 60% of the process iterations to the digital world, thus, reducing the certification time by a factor of three.

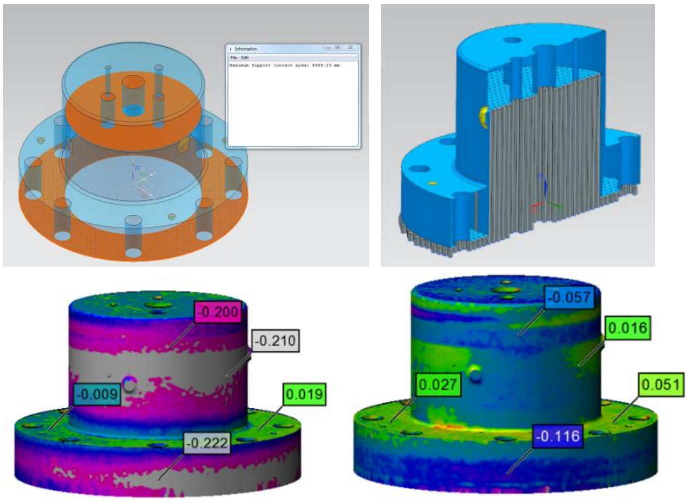

Figure 1. Preprocesing and distortion compensation

Variable-depth Curved Layer Fused Deposition Modeling of Thin-shell Structures

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This paper presents a framework containing thin shell modeling, curved layer slicing, and process planning algorithms for a variable-depth curved layer multi-axis additive manufacturing process for printing thin-shells. Currently, to print a thin-shell part such as a blade, under the popular paradigm of fused deposition modeling (FDM), the traditional type of flat layer three-axis printing suffers from the severe stair-step effect on the printed surface.

Even with a more advanced multi-axis 3D printer that enables curved layer FDM (CLFDM), at present, only uniform-thickness layers are supported, which again is unable to resolve the pronounced stair-step problem. However, by allowing the sliced layers to have variable thicknesses and adjusting the build direction adaptively with respect to the surface normal, the stair-step effect can be either completely eradicated or reduced to the minimum.

The presented framework is targeted specifically at the algorithmic aspect of this ideal five-axis CLFDM printer. Specifically, for the variable-thickness modeling method, a normalized distance-field is first introduced to represent the non-uniform thickness solid implicitly with user-specified thickness set. The solid is reconstructed by the contouring method. We believe the new variable-thickness modeling may bring a new angle to the field of topology optimization. After the input solid is parameterized, a series of morphing-based interface surfaces are generated in the curved layer slicing stage subject to the maximally allowed print thickness. On each interface surface, a boundary-conformed printing path planning algorithm is adopted to obtain a certain amount of lateral bonding between neighboring print curves.

A thin-shell model with small curvature change is tested on a conventional three-axis FDM printer. The preliminary physical result and two simulation results validate the feasibility of the proposed framework and the accompanying algorithms. It is expected that, upon the availability of a true five-axis CLFDM printer, the presented framework will enable printing of thin shells with high printed surface quality and productivity which is direly needed in many applications.

High Efficient Powder Bed Laser 3D Printing

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Mostly the powder bed laser 3D printing process uses fiber laser with Gaussian distribution as its energy input. The efficiency is low due to the line scanning with small spot size. The roughness and quality is hard to improve due to the often partially melt particles and spatter.

In this study, the effect of adjustable laser beam shape is investigated in a self-developed powder bed laser melting equipment. With the flat-top beam distribution with larger beam size and higher laser power, the efficiency is significantly improved. And defects such as spatter, void, and denudation are closely examined. A qualitative physics-based model is also built to provide a theoretical explanation for the findings in this study. This study potentially provides a novel approach to overcome the common defects to improve the quality and efficiency of laser 3D printing.

Preliminary Results of The Feasibility of Alcohol As A Stimulus For 4D Printing

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There are various stimuli for 4D printing and one of them is chemo-responsive. While for conventional shape memory polymers (SMPs), there are various different substances used as actuation, in 4D printing, only water has been used. The lack of variety in actuation mechanisms limits the uses of 4D printing in comparison to conventional SMPs. This study investigates the possibility of alcohol as stimulus for 4D printing of polymer. Elastomers are generally capable of absorbing large quantity of organic liquids. This suggest possible elastomer swelling in the presence of ethanol. The material used was a PolyJet material, TangoblackPlus. The swelling ratio was rather significant at 1.7 at room temperature. Several factors that will affect the amount of swelling were studied. The factors are temperature, time and thickness. As there is significant amount of swelling, it suggests that alcohol can be used as a mechanism for chemo-responsive 4D printing.

3D-printed Lithium-ion Batteries by Low Temperature Direct Writing

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Lithium-ion batteries play a very important role in modern society. 3D printing can be used to address some of the challenges faced by current Lithium-ion battery industry. In this presentation, we fabricated $LiFePO_4$ (LFP) cathodes and $Li_4Ti_5O_{12}$ (LTO) anodes by a low temperature direct writing process. LFP and LTO inks with appropriate rheological properties that are capable of freezing at low temperature were developed and fabricated into three-dimensional (3D) electrodes. The microstructures and porous structures were characterized. Electrochemical performance including charge/discharge, rate performance, cycling performance, cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS) of LFP cathodes and LTO anodes were measured. The performance of the fabricated electrodes were compared to conventional roller-coated electrodes and it was found that improved rate performance can be achieved by tuning the porous structures via low temperature direct writing.

New strategy to repair osteoarthritic cartilage using injectable chondrosheroid

Ji Hyeon Ju

Regeneration of articular cartilage is of great interest in cartilage tissue engineering since the articular cartilage has low regenerative capacity. Due to the difficulty to obtain a healthy cartilage for transplantation, it is focused to develop an alternative and effective regeneration therapy to treat degenerative or damaged joint diseases. Stem cells including various adult stem cells and pluripotent stem cells are now actively used in tissue engineering. Several stem cell products come out in the market. These commercial products are made from mesenchymal stem cell or cultured chondrocyte. However, commercially available cell therapeutics revealed no direct regenerative effect on cartilage till now. Here, we developed a novel strategy using "spheroid-based", "induced pluripotent stem cell-derived" and intra-articular injectable form. The novel therapy is effective for cartilage regeneration in rat, rabbit and beagle osteoarthritic models. Origin of regenerated cartilage tissue is proven to be human, which means this therapeutics play a direct role in cartilage regeneration.

A new general strategy to 3D print thermosets for diverse applications

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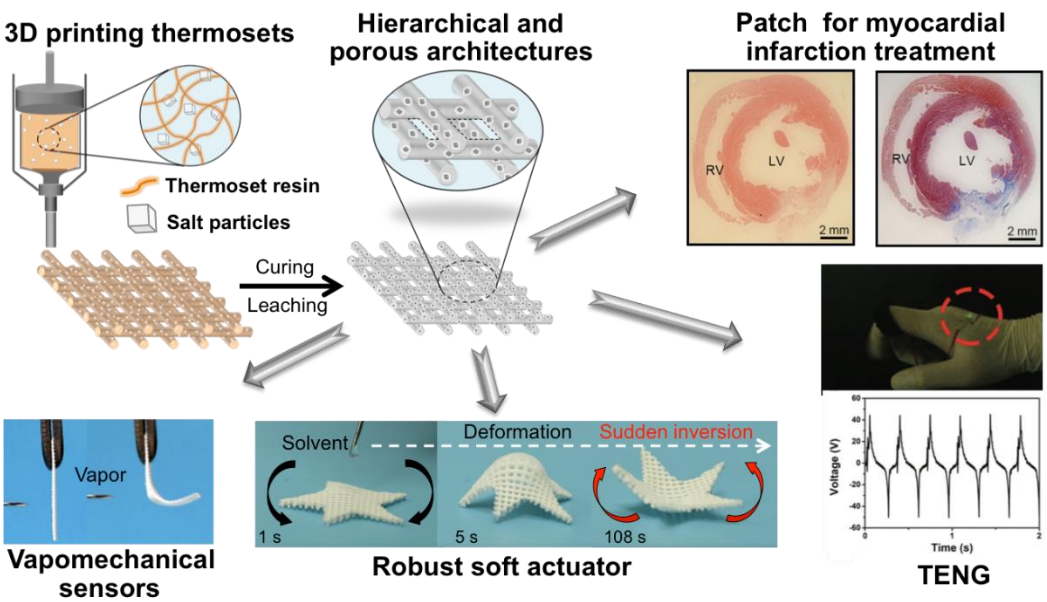
Three-dimensional (3D) printing offers great power to customize sophisticated constructs for a myriad of applications. However, many thermosets require a long term curing at harsh conditions, which are not compatible with rapid 3D printing processing. 3D printing these thermosets remains a challenge. Here we report a new strategy to directly 3D print various thermosets via readily available fused deposition modeling using sacrificial sodium chloride particles as the removable thicker for printing and reinforcer for curing exemplified by crosslinked polyester, polyurethane and epoxy resin. Specifically, the 3D constructs exhibited hierarchical and porous architectures, highly desired for many applications including regenerative medicine, sensors, actuators, catalyst supports, and energy absorbers. To demonstrate proof-of-concept, we 3D printed vapomechanical sensors and actuators featuring fast, large, robust, and gradient responsiveness, and elastic and sustainable triboelectric nanogenerators for wearable electronics, in addition to biodegradable scaffolds used to promote vascularization and tissue ingrowth *in vivo*, and elastic myocardial patches to efficiently treat myocardial infarction. We expect this study will pave a new way to tailor the sophisticated 3D structures of thermosets and will be very useful for diverse applications.



Reference

1. Lei, D. *et al.* A general strategy of 3D printing thermosets for diverse applications *Mater. Horiz.*, 2018, DOI: 10.1039/C8MH00937F
2. Chen, S. *et al.* A single integrated 3D-printing process customizes elastic and sustainable triboelectric nanogenerators for wearable electronics *Adv. Funct. Mater.* DOI: 10.1002/adfm.201805108.

Aerosol Jet Printing of Preferentially Aligned Carbon Nanotube Lines via Coffee Ring Effect Utilizing Evaporation-driven Self-assembly

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Alignment of carbon nanotubes is of paramount importance in the fabrication of high performance electronic devices. Here, we report about the aerosol jet printing of single-walled carbon nanotubes for conductive tracks. A homogeneous aerosol jet printable CNT ink formulation was used and high-resolution patterns were obtained by aerosol jet printing onto flexible polyimide substrates utilizing evaporation-driven self-assembly process. Upon the deposition of the ink, the solvent of the ink starts to evaporate which induces fluid flow and results in the movement of CNTs towards the ink-substrate-air interface, more commonly known as the coffee ring effect. The field emission scanning electron microscopy (FESEM) images reveal that highly self-ordered CNT in the resulting high-resolution deposit patterns. Various aerosol jet parameters such as print speed, substrate temperature, ink flow, and sheath flow have been investigated to obtain printed tracks in the range of 30-80 μm and conductive tracks (coffee ring width) in the range of 600-1500 nm. The microstructure of the printed carbon nanotubes lines was investigated by ImageJ image analysis software to check for the degree of alignment. Lastly, the electrical property of the printed carbon nanotube films was measured.

Keywords: Aerosol jet printing, Carbon nanotube, coffee-ring effect, evaporation-driven self-assembly, alignment of CNT

Development of nanofiber membrane inducing orthogonal cell arrangement in vitro artery model

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Engineering human artery model in vitro provides profound understandings of the pathological process such as cardiovascular disease. Basically, Artery in our body is composed of endothelium, smooth muscle layer surrounding the endothelium and very thin, fibrous basement membrane between two layers. Endothelial cells are aligned along the blood flow direction with the flow shear stress, whereas the smooth muscle cells are aligned perpendicular to the blood flow direction with radial cyclic strain, and as a results, these two types of cells constitute the orthogonal structure to each other. Thus, constructing 3D anisotropic structure of vascular layers is essential to recapitulate the artery model.

Various attempts including patterned substrates or microfluidic systems enabling reconstruction of some part of artery structure, however, the orthogonal arrangement of two cell layers cannot be reproduced because of the limited functionalities of conventional membranes. In addition, though smooth muscle cell is having spindle phenotype in normal state in vivo, it transforms to the proliferative state right after they seeded on the conventional flat cell culture dish. There are some researches of in vitro model keeping the smooth muscle cell in spindle shape, but there is no model that allow to keep the smooth muscle cell in spindle phenotype and to co-culture with the endothelium monolayer.

Here, we successfully developed orthogonally aligned nanofiber membrane for artery in vitro model that inducing the orthogonal alignment between endothelial cells and smooth muscle cells by utilizing electrospinning and series transfer method membrane. Co-culturing HUVECs and smooth muscle cells on our membrane verified the cellular alignment which possess perpendicular cell alignment to each other. Immunofluorescence image verified cellular alignment in desired way and the more in vivo like phenotype of smooth muscle cell, resembling spindle-like phenotype. Further, the increased gene expression of α-SMA also demonstrates the maintenance of smooth muscle cell characteristics in vivo like state. Considering the enhanced 3D in vivo mimetic structure and enhanced cell function and phenotype, we believe that the orthogonally aligned nanofiber membrane possess great potential to development of artery in vitro model.

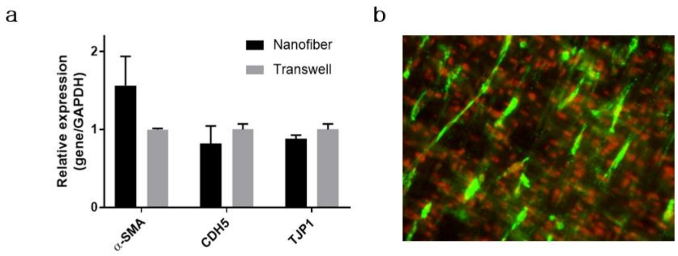

Figure 5 a) Increased α-SMA of smooth muscle cells cultured on orthogonally aligned nanofiber membrane demonstrating the smooth muscle cells keep contractile phenotype as normal in vivo state. b) immunofluorescence image showing smooth muscle cells(green) and endothelium(red) are aligned orthogonal to each other.

Electrohydrodynamic Printing of Microscale Features with Tunable Conductive/Thermal Properties at Mild Temperature

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Electrohydrodynamic (EHD) printing is a promising approach to fabricate high-resolution features with low cost and high efficiency. However, the existing EHD printing explorations based on nanoparticle inks commonly require high post-treatment temperature (>150 ℃) to achieve desired conductivity, which limits their application in flexible substrates like polymers. When the conductive inks were electrohydrodynamically printed in a continuous cone-jet mode, the electric discharging between the nozzle and the conductive collectors will immediately stop the printing process.

Here we developed a novel EHD printing strategy to fabricate microscale conductive features onto different flexible substrate in a low temperature cone-jet mode. Different conductive materials such as metal solution and conductive polymers could be EHD printed with a smallest size of < 30 μm. Particle free, *in situ* reactive silver ink was EHD printed with the smallest size of 27.6 ± 3.4 μm and exhibits an electrical conductivity of 3.3×10^6 S/m at 90 ℃. PEDOT:PSS solution was printed with the smallest size of 27.25 ± 3.76 μm at room temperature. In addition, different conductive features were printed and the width of the EHD printed features can be flexibly tuned by process parameters as shown in Figure 1a. The resistance can be tuned by the number of printing layers from 10^4 to 10^0 Ω (Figure 1b). It was interesting to find that electrohydrodynamically printed PEDOT:PSS features exhibited unique thermal properties at relatively low voltages (Figure 1c). The printed 100-layer PEDOT:PSS lines could reach a high temperature of 190 ℃ under a low DC voltage of 14 V. The printed features also showed good adhesion to different flexible substrates such as polydimethylsiloxane, papers, polyethylene terephthalate and electrospun films.

We envision that the presented EHD printing strategy will mature into a high-resolution and flexible strategy to fabricate microscale conductive features on various flexible substrates and advance innovations of macro/nano-scale flexible electronics and wearable microdevices.

Figure 1. The EHD printed conductive features and the conductive/thermal property

3D Printed Resistors: Design, Measurements and Standards

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Additive manufacturing technologies have revolutionised the fabrication process of functional electronic components and circuitries and are capable of reducing wastes and time-bottlenecks in prototyping stages over traditional fabrication techniques. Despite the potentials of 3D printed electronics, there is lack of quality control procedures during fabrication, consensus industrial standards, quantitative measurement and characterisation approach for 3d printed electronics to ensure their reproducibility, quality and consistency. Therefore, there is a widening gap between rapidly growing additive manufacturing technologies and their acceptance by the electronics industry, and efforts to address these problems are somewhat limited. In this paper, we discuss the quality control procedures during the fabrication process of printed resistors through the aerosol jet printing technology. Printed resistors are one of the most fundamental passive electrical components in printed electronics and used for controlling current flow in circuits. The design parameters, quantitative measurement and characterisation approaches for printed resistors are also discussed.

Keywords: Additive Manufacturing; Printed Electronics; Printed Resistors; Aerosol Jet; 3D Printing.

Multiscale additive manufacturing for biomedical applications

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The application of additive manufacturing (AM) in biomedical and tissue engineering fields enables to fabricate artificial implants with patient-specific geometry and biomimetic internal microstructures, which could potentially enhance their biological functions *in vitro* and *in vivo*. Here we will introduce our bio-additive manufacturing researches in three parts. The first part is related to the use of AM techniques to customize non-living implants with patient-specific geometry for personalized surgery. In the second part, AM-based fabrication of biodegradable tissue-engineering scaffolds with biomimetic microstructures and gradient interface will be presented. In the third part, we will introduce our latest micro/nanoscale biprinting strategies to fabricate high-resolution fibrous structures as well as living tissue models. We mainly investigate the relationship between scaffold structures and tissue functions, and the ultimate goal is to fabricate living tissue-engineered constructs with biological functions.

3D Bioprinting of Mature Bacteria Biofilm

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Antimicrobial resistance (AMR) is rising to dangerously high levels worldwide. According to the World Health Organization (WHO), urgent actions are required to avoid a “post-antibiotic era”, in which common infections and minor injuries can once again kill. Unlike most acute infection caused by planktonic bacterial, that can often be treated effectively with antibiotics, biofilm infections are much harder to successfully treat with available antimicrobials due to its complicate structures. Whilst there are recent attempts in 3D printed biofilms, none of the approaches so far have successfully recapitulated the 3D bacterial biofilm’s complex microenvironment, life cycle and their responses to antibiotics. In this talk, we will present our recent on the 3D bioprinting of bacterial biofilm using a specially formulated hydrogel bioink. The effects of thickness, porosity and printing conditions on the biofilm formation and the responses of the 3D printed biofilms to antibiotics will be discussed. It is envisaged that the *in vitro* 3D bioprinted biofilm model will provide a versatile platform in biofilm studies, with specific value for the discovery of novel therapeutic targets in antimicrobial resistance study and medicine.

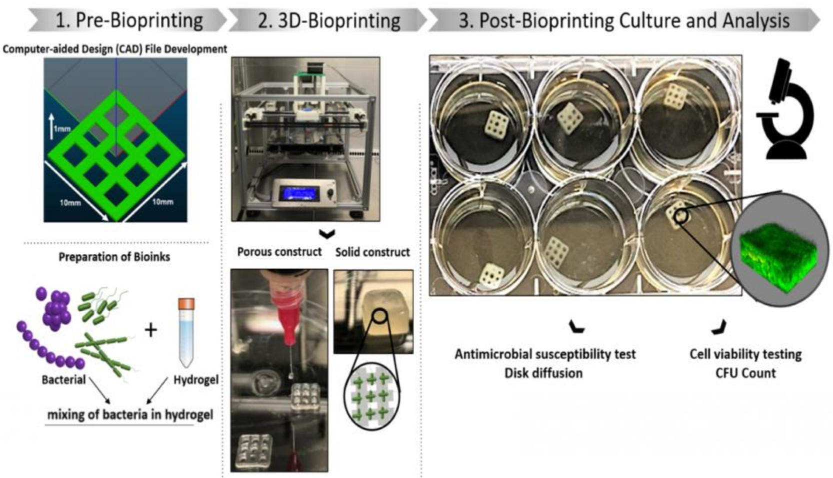

Figure 1. Schematic of bacterial biofilm bioprinting process.

3D Printing Technology with Tissue Specific Bioinks

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The research at the Intelligent Manufacturing Systems Laboratory is in the application of 3D printing technology to the field of biomedical engineering by fabricating complex 3D structures. Specifically, the 3D printing technology lies at the basis of the research for the development of tissue regeneration and in vitro testing platforms that relate to the big picture of tissue engineering and regenerative medicine. Beyond the fabrication of 3D scaffolds, the laboratory has now developed a 3D cell/tissue printing technology for the fabrication of live scaffolds of which the integrated pre-tissues can be fabricated in a single step with the use of multiple types of cells and biological materials. In addition, the laboratory has also developed tissue- and organ- derived extracellular matrix bioink that would optimize the mimicry of the native tissue's biochemical microenvironments and enhance pre-tissues functionalities. Taken together, the research done at the IMS laboratory includes the development of composite cell-based scaffolds for the treatment of areas of defects and hard-to-cure diseases through the help of cell/tissue printing technology and bioink. The lab also works on the development of in vitro testing models including organ-on-a-chip, and is steered towards the actual clinical application and new drug discovery. The following presentation will demonstrate the role and significance of 3D cell printing rather than ordinary 3D printing in the biomedical field and provide us with a time for deep discussions on the aforementioned research topics.

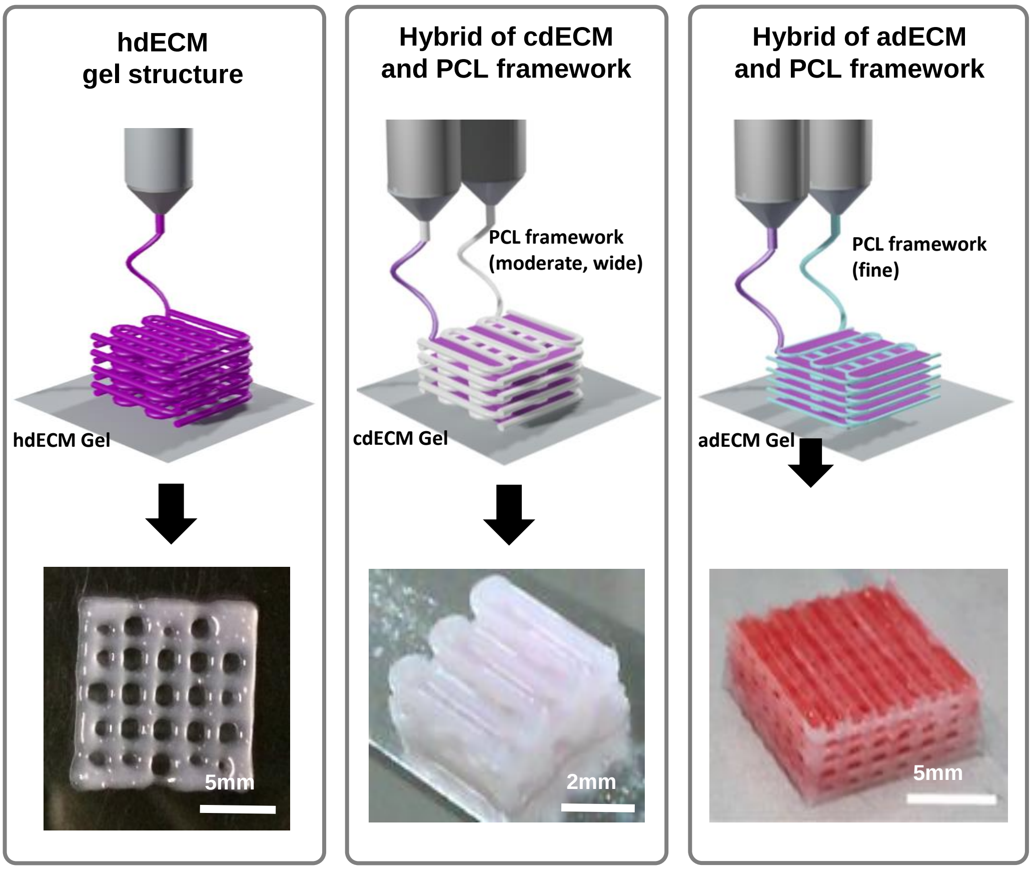

Figure 1 Printed structures with various Tissue specific dECM bioinks

Biomanufacture of human pluripotent stem cells derived blood vessels and application in drug testing

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Endothelial cells play important roles in inflammation reaction, regulation of blood pressure, coagulation or anticoagulation and other physiological processes. Endothelial cell transplantation is also used to treat ischemic disease including atherosclerosis, critical limb ischemic, and myocardial infarction. Generation of large quantities of endothelial cells is highly desirable for cell transplantation, for the study of disease mechanism, for the drug evaluation, and for tissue regeneration. To achieve this goal, we developed a novel biomanufacture system to efficiently and rapidly differentiate endothelial cells from stem cells and incorporate them into 3D printed blood vessels.

We have established a highly efficient protocol to differentiate endothelial cells (ECs) from human pluripotent stem cells in a chemically defined simple medium. We also constructed a cell compatible, three-layered vessel scaffold using 3D bioprinting machine, which have a similar structure with mid-size blood vessels in the human body. We show that ECs can attach and spread well on 3D bioprinted vessels. Following adhesion, ECs continue to proliferate for long-term and maintained normal endothelial functionality. We compared the transcriptome of ECs grow in 2D and 3D vessel like structure, and characterized the effect of solid state biophysical factors, on cell function and behavior. We also performed drug toxicity test using ECs grow in 2D and in 3D vessel scaffold, and identified interesting different responses.

Our study demonstrates that human pluripotent stem cells derived ECs can be incorporated with tissue-engineered 3D scaffold at an early stage to make blood vessel mimicks in the laboratory. This system can be used for biomanufacture human blood vessel in large quantity for drug screen. The laboratory manufactured nascent blood vessels can also be incorporated into larger 3D printed cellular structures to construct vascularized human tissues and organoids.

Coaxial Cell-printing of Freestanding, Perfusable and Functional in vitro Vascular Models for Recapitulation of Native Vascular Endothelium Pathophysiology

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3D printing technology is used to produce channels within hydrogels followed by en-dothelial cells (ECs)-seeding to establish in vitro vascular models. However, as built-in bulk hydrogels, it is difficult to incorporate additional cells and molecules into the crosslinked matrix to study the pathophysiological responses of healthy endothelium. In this study, freestanding in vitro vascular models (VMs) are developed using the coaxial cell printing technique and a vascular tissue-specific bioink. It has various ad-vantages in plotting tubular cell-laden vessels with designed patterns, providing pump-driven circulating perfusion, generating endothelium without ECs-seeding, and im-plementing further expansions to study vascular pathophysiology. Following the matu-ration of endothelium, the VMs exhibit representative vascular functions (i.e., selec-tive permeability, anti-platelets/leukocytes adhesion, and vessel remodeling under shear stress). Moreover, with the expansions of the VMs, the directional angiogenesis and inflammatory responses are demonstrated by giving asymmetric distributions of proangiogenic factors and an airway inflammatory ambience, respectively. Therefore, the freestanding, perfusable, and functional VMs can be useful devices to engineer diverse in vitro platforms for a wide range of biomedical applications, from modeling blood vessel relevant diseases to building vascularized tissues/organs.

Keywords: coaxial cell printing, vascular models, freestanding, perfusion, vascular pathophysiology

Biomimetic Design and Fabrication of Scaffolds Integrating Oriented Micro-pores with Branched Channel Networks for Myocardial Tissue Engineering

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The ability to fabricate three-dimensional (3D) thick vascularized myocardial tissue could enable scientific and technological advances in tissue engineering and drug screening, and may accelerate its application in myocardium repair. In this study, we developed a novel biomimetic scaffold integrating oriented micro-pores with branched channel networks to mimic the anisotropy and vasculature of native myocardium. The oriented micro-pores were fabricated using an "Oriented Thermally Induced Phase Separation (OTIPS)" technique, and the channel network was produced by embedding and subsequently dissolving a 3D-printed sacrificial template after crosslinking. In vitro culture experiments demonstrated unidirectional alignment of cardiomyocytes along the microporous structure and confluent elongation of endothelial cells within the branch channels. This novel biomimetic scaffold facilitates the fabrication of thick vascularized myocardial tissue allowing advances in its clinical applications.

Advanced 3D Printing System and Automated Detection System for Organs-on-a-Chip

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Organs-on-a-chip system, or microphysiological system (MPS), is a new type of biomedical research method that aims to recapitulate organ-level tissue structures and functions for drug evaluation and disease modeling. The MPS can be used to simulate the microstructure, microenvironment, and functional features of human organs, and apply in drug screening and clinical diagnosis and treatment. In previous study, we have developed multiple organ-on-a-chip systems including biomimetic blood vessels, kidney, liver, heart, etc. [1-2] Our previous work demonstrated that the miniature organs made with advanced microfabrication, 3D printing, microfluidics and tissue engineering techniques could form tissue-specific structures and could maintain some desirable organ functions for more than four weeks [3-5].

In this work, we report development of a tumor-on-a-chip system for automated oncology drug screening. In current preclinical oncology drug development, 2D-cultured cell models cannot accurately predict drug efficacy in vivo, while animal models are expensive and low-throughput. Further, neither model is able to assess cancer cell migration and metastasis data in real-time effectively. Our technology offers the packaged solutions to solve the problems above by providing the 3D in vitro tumor-on-a-chip system including creating tumor spheroids (TSs), constructing 3D-microenviroments and fine 3D-structures with two-photon printing at a resolution ~150nm, imaging TSs with an automated system, and analyzing TSs using multiple AI-algorisms. This system has a standardized multi-well setup (96 or 384) thus is convenient for customer's usage and application in high-throughput drug screenings. This system will enable drug developers to monitor cancer cell viability, migration and metastasis quantitatively and automatically.

Electrolyte-assisted Electrospun Nanofiber Membrane for Organ-on-a-chip and Tissue Regeneration

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Interactions between cells and their surrounding microenvironment play the fundamental roles to regulate the cell fate and functions. Among the various fabrication strategies to mimic the *in vivo* microenvironment, electrospinning provides the simplest way to ECM-mimetic structure, which possesses nanofibrillar structures. Here, we suggest a novel electrolyte-assisted electrospinning (ELES) process, which enabled to build *in vivo*-mimetic organ-on-a-chips and further apply to the regeneration of *in vivo* muscle tissue. Conventional electrospinning process generally produced a nanofiber membrane that was strongly adhered to the grounded metal surface, and thus, inevitably required post-processing, such as detachment and handling, to integrate the nanofiber membrane with *in vitro* cell culture platform. However, the ELES process facilitated the direct fabrication of a nanofiber membrane on the desired platform owing to the role of the electrolyte solution as a sacrificial grounded collector. Using the ELES process, the free-standing nanofiber membrane was readily integrated with *in vitro* cell culture platform such as a microfluidics chip and a transwell insert. On the nanofiber membrane-integrated cell culture platforms, we developed two different types of *in vitro* models, a blood vessel-on-a-chip and a choroidal neovascularization model, mimicking physiological properties of *in vivo* microenvironment. Further improvement of the ELES process enabled to generate a 3D artificial muscle construct covered by a permeable electrospun nanofiber membrane. The 3D artificial muscle construct was successfully transplanted inside the gastrocnemius muscle of rat without any inflammatory response.

Manufacturing of hiHep Cells-Based Artificial Liver Support System Using Digital Light Processing

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Currently, the liver cancer leads to the highest morbidity among all kinds of cancers in the world. Due to the shortage of liver donors for transplantation, the surgical resection is still considered as one of the most effective treatments for benign and malignant liver tumors. However, the postoperative liver failure has been found to be the most serious complication of a large number of patients with liver resection.

In this study, a scaffold with liver cells was designed with a serrated construct and fabricated as the artificial liver support system, which is used to replace the cutting off liver part to perform some of the functions of synthesis and metabolism. A multi-material digital light processing (DLP) technology was developed to manufacture the artificial liver support system. Gelatin methacryloyl (GelMA) was used as the cell-laden bioink, where dECM (decellularized extracellular matrix) was also added; and the hiHep cells were printed with GelMA/dECM hydrogels to fabricate designed constructs. By measuring the printing resolution and the cell viability after printing, the optimized printing parameters and formula of GelMA/dECM bioink were obtained. It should be noticed that dECM was found to be helpful for both cell viability and printability of the bioink. The printed artificial liver support system was found to have the similar function with original liver to synthesize albumin and metabolize urea which provided a promising approach to solve liver failure for liver function recovery and regeneration.

3D Printing in vascular stent fabrication

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Vascular trauma and defect, as well as cardiovascular and cerebrovascular diseases, have become the main threats to human life and health. Due to the good performance on reconstruction of vascular structure, stents implantation has become the main treatment for vascular diseases[1]. Based on different fabricate structures, vascular stents can be divided into dense mesh stents and stent grafts. Dense mesh stents[2] include bare metal stents (BMS), drug eluting stents (DES) and bioresorbable stents (BRS)[3, 4]. After expanded, such stents can support blood vessels, while be fixed by the pressure produced by the vessel wall, in which case, the lumen unobstructed will be guaranteed. Dense mesh stents are used to treat coronary heart disease, ischemic stroke, peripheral vascular stenosis, etc.[5] Stent graft is a type of vascular stent with a fabric coat, it is expandable like bare metal stents, and the film creates a contained tube to replace the vascular wall. It is mainly used to repair aortic dissection, true aortic aneurysm, pseudoaneurysm, aortic penetrating ulcer and other diseases. It is also used in the treatment of intracranial aneurysms[6].

The current manufacturing methods of vascular stents are standardized, that is, the diameter and length of stents are serialized or standardized. However, there are individual differences in the diameter and shape of real blood vessels in the human body, which makes standardized stents difficult to match the personalized needs. If the stent size is not consistent with the patient's real vascular size after implantation, the therapeutic effect will be affected. Too small diameter of the stent will lead to poor adherence to the wall of the stent, resulting in internal leakage or displacement. Too large diameter can rupture blood vessels, leading to treatment failure. At the same time, the shape of real blood vessels in the human body is curved, therefore, some standardized stents may "shrivelled" after implantation, because they cannot adapt to the physiological structure of blood vessels. Therefore, the individualized customization of vascular stent is required in clinic [7-10].

Additive manufacturing (3D printing) can not only achieve the personalized vascular stent in a short time, but also avoid the treatment failure caused by the poor compliance of the traditional stent. In addition, compared with other personalized fabricate technology, the 3D printing efficiency of vascular stents is higher. Now, with the maturity of the additive manufacture technology, it has gained widely concern in the field of vascular stent fabrication and shown a good application prospect in the clinical treatment.

In this paper, the structural characteristics of vascular scaffolds are reviewed, as well as the status and prospect of the additive manufacture technology in vascular stent fabrication.

Keywords: additive manufacturing, vascular stent, stent graft, personalized medicine, biomechanical engineering

Reference:

1. Fuster, V., Top 10 cardiovascular therapies and interventions for the next decade. Nature Reviews Cardiology, 2014. 11(11): p. 671-683.
2. Li, M., A novel technique of endovascular treatment for the cerebral aneurysm: the development of covered stent specially designed for intracranial vasculature. Journal of Interventional Radiology, 2010. 19(4): p. 253-256.
3. Guo, Y. and Z. Tan, Features of endovascular stent materials and their therapeutic effects on ischemic stroke. Journal of Clinical Rehabilitative Tissue Engineering Research, 2013. 17(12): p. 2257-2264.
4. Mei, M., Characteristics and clinical application of different types of cerebral vascular scaffolds. Journal of Clinical Rehabilitative Tissue Engineering Research, 2014.
5. Liu, D., Q. Luo, and Z. Chang, Current Status and Progress of Minimally Invasive Medical Devices. Chinese Journal of Medical Instrumentation, 2008. 14(3): p. 2-11.
6. Liu, D. and T. Xi, Current Situation and Development Tendency of Interventional Medical Device&Material Industry. Chinese Journal of Medical Instrumentation, 2006. 12(12): p. 1-14.

Biofabrication of functional human cardiac miro-units using human induced pluripotent stem cells

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Human induced pluripotent stem cells (hiPSCs) hold great promise for personalized and regenerative medicine. Although most of the methods using these cells have successfully derived homogenous populations of specialized cells, it is necessary to explore functional units for tissue construction and repair. Here, we present the biofabrication of functional human cardiac micro-units using hiPSCs. First, we optimized the current protocols to robustly generate hiPSC-CMs (hiPSC-derived cardiomyocytes), hiPSC-ECs (hiPSC-derived endothelial cells) and hiPSC-SMCs (hiPSC-derived smooth muscle cells) in a simple, cost-effective and chemically defined culture system. Through remodeling of native extracellular matrix (ECM) components, hiPSC-CMs could self-assembled into 3D micro-units and displayed key molecular and physiological characteristics of the native ventricle, and showed expected mechanical and electrophysiological responses to a range of pharmacological interventions (including positive and negative inotropes). We reasoned that adding hiPSC-ECs and hiPSC-SMCs to hiPSC-CMs could assist in acquiring the ability to efficiently vascularize and integrate in vivo. Interestingly, we observed that the three cardiac lineages began to self-assemble into 3D micro-units within 24h, which have more compact tissue-like structure compared with those hiPSC-CMs alone. Histology and immunostaining showed that hiPSC-ECs and hiPSC-SMCs provided structural support and vascular microenvironment. Furthermore, 7-d-old human cardiac miro-units with intact structures could be harvested from the culture matrix, then could be also transplanted in the infarcted rat hearts. In contrast to monolayer cultures, hiPSC-CMs cultured in a 3D-ECM environment have prolonged viability and can retain their contractile properties. Collectively, our approach demonstrates biofabrication of functional human micro-units have the potential to rapidly expand our knowledge of tissue repair and potentially unlock therapeutic strategies.

Keywords: hiPSCs, cardiomyocytes, ECM, cardiac micro-units, tissue repair

Development of Perfusable Vascularized Human Skin Equivalent Using 3D Cell-printing Technique for Better Recapitulation of Complexity of Skin Anatomy

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Although skin cell-printing has exhibited promises for fabrication of functional skin equivalents, existing skin models through 3D cell printing are composed of mere dermal and epidermal layers. However, a key hope for printing skin is to improve structural complexity of human skin over conventional construction, enabling the precise localization of multiple cell types and biomaterials. Here, the complexity of skin anatomy is increased using 3D cell printing. A novel printing platform is suggested for engineering a matured perfusable vascularized 3D human skin equivalent including epidermis, dermis, and hypodermis (full-thickness). The skin model is evaluated using functional markers representing each region of epidermis, dermis, and hypodermis to confirm tissue maturation. We hypothesized that the vascularized dermal and hypodermal compartments that provide more realistic microenvironment could promote cross-talks with epidermal compartment, producing better recapitulation of epidermal morphogenesis. To verify the hypothesis, skin stemness in epithelial tissue were investigated. Our findings revealed that the full-thickness skin had more similarities to the native human skin compared with the dermal and epidermal skin model, indicating that it better reflects the actual complexity of native human skin. We envision that it offers better predictive and reliable *in vitro* platform for investigation of mechanisms of pathological research and skin disease modeling.

Keywords: skin cell-printing, novel printing platform, 3D skin equivalent, functional markers, skin stemness

A benchmark study between selective laser sintering and selective laser melting techniques: quantitative comparisons of repeatability and reproducibility

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Selective laser sintering/melting (SLS/SLM) is a promising Additive Manufacturing (AM) process which deposits and consolidates material to create 3D parts in a layer-by-layer manner. In such process, a computer controlled laser beam is applied over the required cross-sectional area in powder beds to sinter, melt and bond particles into a designed thin slice. Subsequently, additional layers of powders are spread on top of the processed slice and the laser scanning is repeated to consolidate each new layer and bond it to the existing layers, such that the entire part is built as a successive stack of 2D layers [6].

Although commercial SLS/SLM processes and machines have been extensively available in aerospace, medical and other industries, considerable challenges remain for them to reach the status of a complete production-ready technology due to the immature development of standardizations and regulations [4]. Two important challenges include the process repeatability and part-to-part reproducibility which are defined in reported AM studies [5] as the facilities to repeat the same process and to reproduce the part with minimum variation. The objective of the present work is to characterize and benchmark quantitatively the repeatability and reproducibility of SLS and SLM processes. Specifically, variations of mechanical properties and geometric features of parts fabricated by the two processes will be investigated and compared via experimental studies. This work is not attempting to compare results from the tested SLS and SLM processes due to their differences in powder material, speed and accuracy. Instead, our interest is to understand the potentials and limitations of the two processes and provide experimental references for future AM standard development.

Keywords: Additive Manufacturing, Selective Laser Sintering, Selective laser melting, Repeatability, Reproducibility.

References

[5]. Kim DB, Witherell P, Lu Y and Feng S, Toward a digital thread and data package for metals-additive manufacturing, *Smart and Sustainable Manufacturing Systems* **1** (2017) 75-99.

[6]. Kruth JP, Vandenbroucke B, Van Vaerenbergh J. and Mercelis, P, Benchmarking of different SLS/SLM processes as rapid manufacturing techniques, *International Conference Polymers & Moulds Innovations (PMI)* (2005) 525.

[7]. NIST, *Measurement Science Roadmap for Metal-Based Additive Manufacturing*, Energetics Incorporated, U.S. Department of Commerce, National Institute of Standards and Technology, Gaithersburg, MD, 2013.

The exploration for electron beam based powder bed fusion technique in Tsinghua University

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Since 2004, Electron beam selective melting (EBSM), an electron beam based powder bed fusion additive manufacturing technique, has been explored in the Department of Mechanical Engineering of Tsinghua University. Beginning with transferring an EB welding system into a powder bed fusion system, a series of attempts have been exe-cuted to exploit the potential and improve EBSM technique, including the develop-ments of dual metal gradient structure forming, EB-laser hybrid selective melting, EB additive/subtractive manufacturing, secondary

electron optical image based online monitoring, and laser-heated cathode EB gun, etc. Besides to review the above at-tempts, the presentation will try to reveal the capability and potential of EBSM as well.

Smoothed Particle Hydrodynamics (SPH) modelling of fibre orientation in a 3DP process

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In this presentation, our recent work on the numerical simulation of Fused Deposited Modelling (FDM), 3D printing process or fiber-filled polymer materials by Smoothed Particle Hydrodynamics (SPH) is reported[1]. A brief description of the classical fiber suspension model used is given[2-5], followed by some details on the SPH method and the model implementation. Several parameters are then tested on a representative FDM case. These include the effect of barrel angle, initial fiber orientation and fluid viscosity. A major finding lies in the prediction of a skin/core effect in which a higher fiber orientation is found in the skin region compared to the core region. This effect is found to be very sensitive to the ratio between extrusion and printing head translation velocity. It is observed to be reduced by an increase of head velocity and to be closely related to the compression/extension flow occurring near the nozzle outlet which can also lead to excessive die swell effect. While accurate experimental measurements of fiber orientation in FDM parts is still lacking, there is possible evidence of a slight reduction of fiber alignment in core regions.

(1) Bertevas, Férec, Khoo, Ausias and Phan-Thien, Smoothed Particle Hydrodynamics (SPH) modeling of fiber orientation in a 3D printing process. Accepted for publication in Physics of Fluids (2018).
(2) Hinch and Leal, Constitutive equations in suspension mechanics. Part 1. General formulation J. Fluid Mech. 71 (1975) 481-495
(3) N. Phan-Thien and A.L. Graham, A new constitutive model for fibre suspensions: flow past a sphere, Rheol Acta 30 (1991) 44-57
(4) Lipscomb, Denn, Hur and Boger, The flow of fiber suspensions in complex geometries, J. Non-Newton. Fluid Mech. 26 (1988) 297-325
(5) Phan-Thien, Fan, Tanner and Zheng, Folgar-Tucker constant for a fibre suspension in a Newtonian fluid, J. non-Newtonian Fluid Mech., 103 (2002) 251-260

Research on secondary electron monitoring in EBSM process

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Electron beam selective melting (EBSM) is a promising technique which has obtained extensive attentions since its birth. However the instability and lack of repeatability are obstacles which greatly limit its applications. Online monitoring is a valid solution which can help to guarantee process stability and specimen quality, to document the process and establish production manager system, and also to contribute to the feedback control. However, current online monitoring methods are primarily based on optical detectors which need stable detecting accesses. The accuracy and stability are greatly restricted by the poor working conditions, such as serious evaporation, high temperature and intense irradiation. Considering that secondary electron monitoring is based on electron signal and not sensitive to these bad conditions, it has been introduced to EBSM process to provide an online detection with high dynamic response and high spatial and temporal resolution. In this work, a dual-detector off-axial monitoring system based on secondary electron was developed and implemented in the EBSM machine. The secondary electron images of deposited layers were acquired after each layer-wise melting. As show in Figure 6, boundary between powder area and deposited areas is obvious and different types of features are reflected with the distribution of gray values. Moreover, a method of identifying different kinds of defects was proposed and online

monitoring was performed to validate the feasibility and capability of this monitoring system.

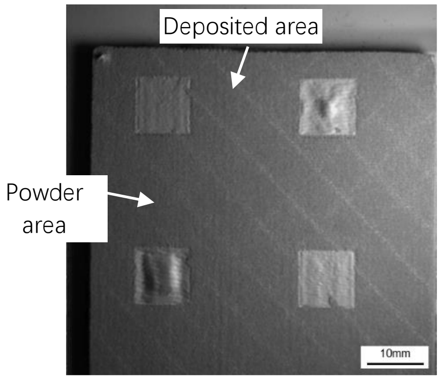

Figure 6 A secondary electron image of finished part with micro-sintered powder bed using off-axis monitoring system

In Situ Investigation of Growth of Methylammonium Lead Halide(MAPbX_3) Perovskite from Microdroplets

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It is important to observe the nucleation and growth of organic-inorganic hybrid perovskites crystals from solution to obtain high quality active layers for efficient perovskite solar cells. We develop a facile method to in situ investigate crystallization of Methylammonium lead halide(MAPbX_3) perovskite from micro-droplets ejected by an alternating viscous-inertial force with electrostatic force jetting method. Using this alternating viscous-inertial force with electrostatic force jetting system, we create a 3D printer which has Micron accuracy. With this 3D printer, we can easily print complex pattern of perovskite crystals such as dot matrix and linear array. We can easily conduct high-throughput experiment by changing lots of experiment condition such as temperature, the proportion of organic and inorganic composition in the solution, the composition of solvent , electric field etc. The morphology of the perovskite relative films are controlled by this experiment condition, we can explore how the perovskike crystal nucleate and grow by the high-throughput experiment. If we know how the perovskike crystal nucleate and grow, we can easily create high quality active layers for efficient perovskite solar cells. The perovskite crystals tends to from needle intermediate crystals of MAPbX_3-DMF from the precursor solution at room temperature but the needle. Granular perovskite crystals can also nucleate from the solution if we change the experiment condition.A typical use of our 3D printer is obtain directional needle perovskite crystals as we show in the Figure 1. In this example, we use 3d printing system to print line pattern, electric field to control the direction of needle crystals, in situ investigating system to in situ observe the nucleation and growth of perovskites crystals.

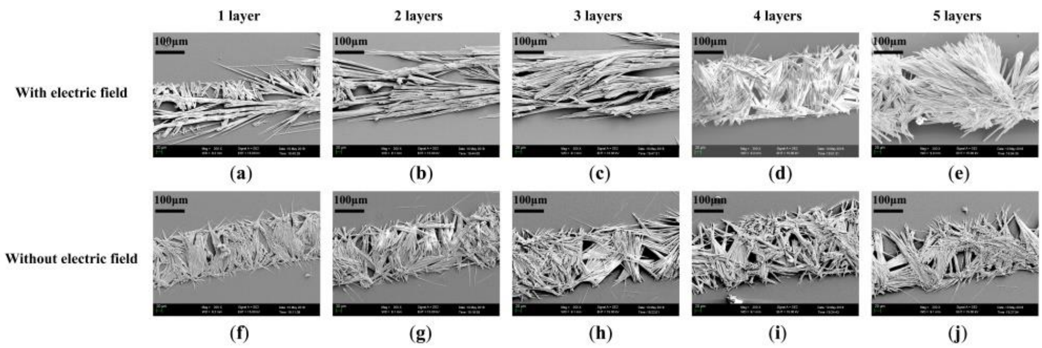

Figure 1. SEM images of the perovskite precursors prepared from PbI2/MAI/DMF solution with and without electric field.

Keywords: perovskite; crystallization; in situ invstigation; Microdroplets

Multi-scale multi-physics modeling of powder-based additive manufacturing with experimental validation

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Metallic powder-based additive manufacturing (AM) technologies show promising potentials to reshape manufacturing industries. However, the wide adoption is hindered by the lack of understanding of physical mechanisms and assessment of numerous influential factors. To this end, I have developed a multi-scale multi-physics modeling framework consisting of: physically-informed heat source models, specifically, for an electron beam from micro-scale simulations of electron-atom interactions, and for a laser incorporating multi-reflection and Fresnel absorption; high-fidelity powder-scale Discrete Element Method-Computational Fluid Dynamics (DEM-CFD) models to simulate powder being spread and then melted; and an efficient Finite Element (FE) heat transfer model at part-scale. I will also introduce our efforts on seamlessly linking Process-Structure-Property models. With the experimental configuration and material-dependence incorporated, the models have proved to be valuable to understand and optimize the AM process of complex materials.

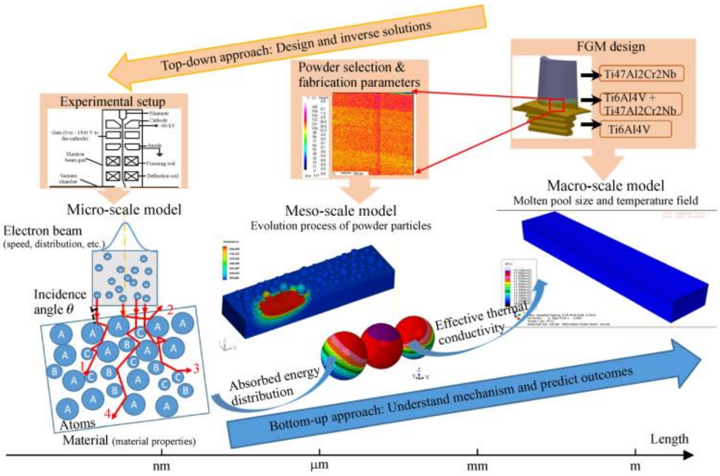

Figure 1. Multi-scale Multiphysics modeling of powder-based additive manufacturing

Influences of cooling conditions in laser metal deposition of a directionally-solidified superalloy

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Directionally solidified nickel-based superalloys are widely used in manufacturing turbine blades, which may fail due to cracking and material loss during service. Laser metal deposition has been considered as a promising technology in repairing the damaged components thanks to its high temperature gradient that is conducive to the growth of directional microstructure. In this paper, the influences of cooling conditions (natural and forced cooling) on the microstructure development and liquation cracks were studied for the laser deposition of a directionally solidified superalloy IC10. Experimental results showed that compared to the natural cooling, the height of columnar crystals in the deposits was significantly increased, and the liquation cracks in base metal were reduced under the forced cooling condition. The effects of cooling conditions on temperature and stress fields were

analyzed through a thermo-elastoplastic finite element analysis. It was revealed that the ratio of temperature gradient to solidification rate (G/v) in the growth direction of the columnar crystals was notably increased by employing the forced cooling condition. Meanwhile, the maximum tensile stress and high tensile stress region in the substrates were reduced. The numerical findings explained the experimental observation quite well.

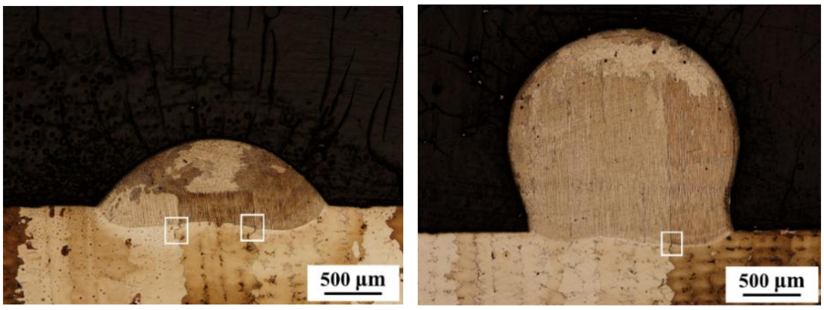

Figure 1. Cross sections of laser deposits formed under two cooling conditions

A Cellular Automaton/Finite Element Model to Microstructure Predictions for Additively Manufactured Metals

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Additive Manufacturing (AM) has found potential to revolutionize the global part manufacturing landscape in recent years given its ability to realize rapid fabrication, precise geometric control, and flexibility to create or repair without the use of any die or mold. However, the extreme thermal conditions (e.g. high cooling rate, large thermal gradient) associated with various process parameters in AM may easily result in spatially heterogeneous microstructure. Such a microstructure leads to anisotropic mechanical properties of the builds that may be even worse than that of traditional wrought produces.

To predict the detailed microstructure in additively manufactured parts, a 3D parallelized Cellular Automaton/Finite Element (CAFE) model has been developed linking the thermal field with the formation of grain structure to shed light in the understanding of the relationship between the AM process parameters and microstructure. Simulations exploring the effects of process parameters are compared with experimental measurements, showing to be in good agreement. Additionally, statistical descriptors of the microstructure are presented that allow quantitative comparison with experiments and help the experimental measurements.

Data Generalizing and Mining for Mesoscopic Simulation of Electron Beam Melting

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Electron beam melting enables the manufacturing of complicated structures or specific materials, while its product quality suffers from defects originating from unsuitable process conditions. Since the mesoscopic modeling approach is developed, it has helped reveal mechanisms of pore defects and surface morphologies. However, the full potential of the mesoscopic simulation is unreached as the data describing melt pool or track is not effectively extracted or assessed. In this work, based on the mesoscopic modeling previously built, we first define geometric characteristics of the deposited melt track and realize measuring these characteristic values from simulation results. In this way, different morphologies of melt tracks can be quantitatively represented. Then the relationship between

processing parameters like energy power and scan speed and pre-defined geometric characteristics is investigated by running sets of sample conditions. All data is systematically collected and the mapping from inputs to outputs is drawn by data mining techniques. Finally a self-assistant framework for processing parameter optimizations composed of mesoscopic modeling, data quantification and assessment is proposed, aiming at replacing the extensive experimental work with the computational tool.

Post-processing of additively manufactured metallic components

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Additive manufacturing (AM) technology enables the fabrication of complex structures and cost-effective for mass customization. Though some of the additively manufactured (AM-ed) components have already been successfully adopted in the industry, tangible challenges still impede the wider application of AM-ed parts among which is concerning the poor surface finish. Due to the principle of layer-by-layer fabrication, surface finish of the AM-ed components is much worse that that produced by conventional manufacturing processes. Thus, post-processing is essential for enhancing the surface finish of AM-ed parts. This talk will tap on the performances of typical post-processing techniques, such as sandblasting, electropolishing, magnetic abrasive finishing and laser polishing, regarding surface finish, tool accessibility, and process efficiency

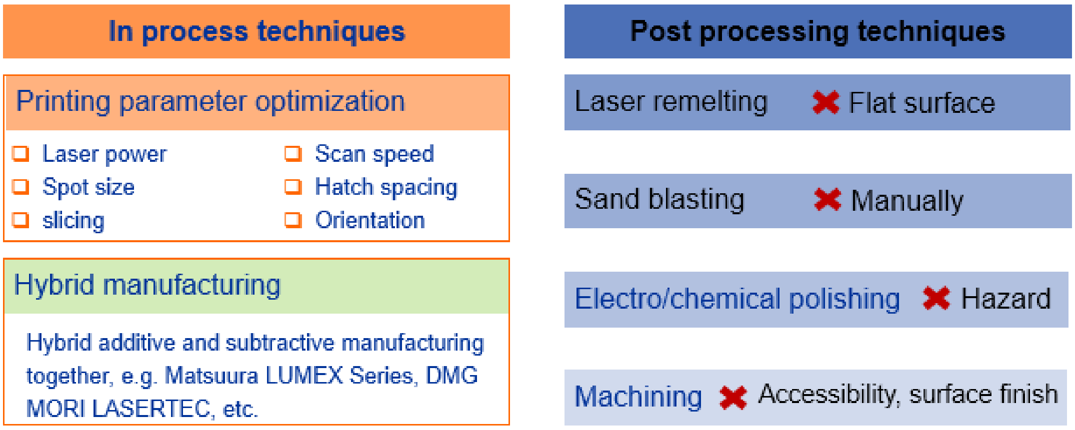

Figure: Techniques for improving surface finish of the AM-ed parts

Microstructure and Compressive/Tensile Characteristic of Large Size Zr-based Bulk Metallic Glass Prepared by Laser Additive Manufacturing

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The large size, crack-free $Zr_{55}Cu_{30}Al_{10}Ni_5$ bulk metallic glass (BMGs) with the diameter of 54 mm and the height of 15 mm was built by laser solid forming additive manufacturing technology, whose size is larger than the critical diameter by casting. The microstructure, tensile and compressive deformation behaviors and fracture morphology of laser solid formed $Zr_{55}Cu_{30}Al_{10}Ni_5$ BMGs were investigated. It is found that the crystallization mainly occurs in the heat-affected zones of deposition layers, which consist of $Al_5Ni_3Zr_2$, $NiZr_2$, ZrCu, $CuZr_2$ phases. The content of amorphous phase in the deposit is about 63%. Under the compressive loading, the deposit presents no plasticity before fracture occurs. The fracture process is mainly controlled by the shear stress and the compressive shear fracture angles of about 39°. The compressive strength reaches 1452 MPa, which is equivalent to that of as-Cast $Zr_{55}Cu_{30}Al_{10}Ni_5$ BMGs, and there exist vein-like patterns, river-like patterns and smooth regions at the compressive fractography. Under the tensile loading, the deposit presents the brittle fracture pattern without plastic deformation. The fracture process exhibits normal fracture model, and the tensile shear fracture angle of about 90°. The tensile strength is only about 609 MPa, and the tensile fractography mainly consists of micro-scaled cores and vein-like patterns, dimple-like patterns, chocolate-like patterns and smooth regions. The results further verified the feasibility and large potential of laser additive manufacturing on fabrication and industrial application of large-scale BMGs parts.

Additive Manufacturing of Dense Copper by Selective Electron Beam Melting

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Copper with superior electrical and thermal conductivity is being used in a wide range of applications. Bringing together copper and Additive Manufacturing (AM), which allows high design freedom and near-net-shape fabrication, opens new perspectives and fields, especially for electronic and heat exchange applications. Powder bed based AM technologies, such as binder jetting, selective laser melting (SLM) and selective electron beam melting (SEBM), were especially developed for the fabrication of metallic parts with complex geometries. In literature, porous copper has been successfully derived by binder jetting and SLM. SEBM, which uses electron beam instead of laser beam as heat source, shows significant advantages over SLM. Especially for the case of AM pure copper powder, owing to the poor energy absorption during SLM, SEBM is considered to be the optimal AM method for the fabrication of dense copper parts. In addition, SEBM takes place under high vacuum conditions. Thus, surface oxidation during processing can be minimized.

In this work, gas atomized copper powder with high purity (> 99.95%) was used. Dense copper parts were successfully fabricated by SEBM. Process window for SEBM of dense copper was developed. Electrical and thermal conductivity, hardness, as well as mechanical and microstructural properties of the SEBM processed copper components were investigated.

Friction Stir Additive Manufacturing and Its Data Driven Design

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Friction stir additive manufacturing (FSAM) is a new developed solid state additive manufacturing technology. Different to laser additive manufacturing, the material is added in solid state to avoid problems caused by solidification and excessive thermal input. In FSAM, material flows in solid state and the induced recrystallization play key role for the manufacturing. When new layer is added, the re-stirring and re-heating caused by the rotating tool affect the formed layers. The mechanism on controlling of the re-stirring and re-heating effects is very important for this solid state additive manufacturing. Different specimens, as shown in Fig.1, are used to study this special mechanism both experimental and numerically.

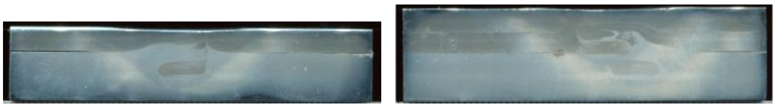
Figure 1. The used specimens for comparison

Monte Carlo model [1] is used for predication of grain morphologies and precipitate evolution model [2] is used for calculation of precipitates. Then the mechanical properties can be predicted. Results indicate that the re-stirring and re-reheating effects can affect the grain morphologies and mechanical properties on the formed layers. Re-stirring and re-heating can lead to finer grains. After 2-3 layers, this influence can become very small and can be neglected. Artificial Neural Network (ANN), as shown in Fig.2, is used for data analysis with consideration of chemical compositions and process parameters for design of FSAM.

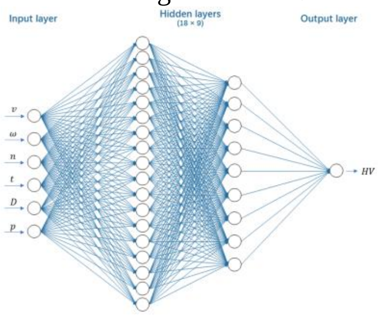

Figure 2. ANN for FSAM

Acknowledgements:
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References:
1. Z. Zhang, Q. Wu, M. Grujicic, et al. Journal of Materials Science, 2016, 51:1882–1895.
2. Z. Zhang, Z.Y. Wan, L.E. Lindgren, et al. Journal of Materials Engineering and Performance, 2017, 26(12): 5731-5740.

A Novel Self Dispersion Reinforcement High Entropy Alloy Prepared by Selective Laser Melting

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A high entropy alloy with the chemical composition of 35 at.% Fe, 30 at.% Cr,15 at.% Mn, 10 at.% Ni, 5 at.% Al

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and 5 at.% Cu was prepared by selective laser melting. The results show the nano size self dispersion phase uniformly precipitated on the matrix. In this study, the effect of the various processes of selective laser melting on the self dispersion phase was investigated in detail. The various processes of selective laser melting were designed via the change of the laser scanning velocity, the layer thickness and the energy density according to the orthogonal experiment.

Keywords: High entropy alloy; Selective laser melting; Self dispersion reinforcement

Machine development and Process study of Electron Beam Selective Melting.

XULONG MA, CHAO GUO, FENG LIN

Electron beam selective melting(EBSM) additive manufacturing is a technology for metal materials processing layer by layer to manufacture three dimensional solid parts. At present, electron beam automatic calibration is an urgent need for a EBSM machine, because manual calibration is a laborious and time-consuming work. We develop an automatic calibration system using secondary electron(SE) signals collected when electron beam is scanning a specially designed cross slot. We can also use the SE detection system to capture a surface quality image to analyze surface deformation and porosity in every layer of the EBSM process as online monitor system. Using automatic calibration and online-monitoring in metal EBSM process, the level of intelligentized EBSM additive manufacturing technology has been enhanced.

The Tool Path Planning for Selective Laser Melting

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The tool path planning strategy for the model preparation of selective laser melting (SLM) usually includes horizontal and vertical scanning, combined orthogonal scanning, as well as spiral scanning and profile offset scanning to minimize the residual stress effect. Unfortunately, it often comes from complex algorithms, demands expensive computing resources and memory, sometimes generating poor quality due to unstable numerical performance, and leaving partial area unmelted.

This paper reviews the recent progress, and investigates a novel efficient tool path planning algorithm and its software implementation. With reference to CLI (common layer interface) file format, firstly two types of data structures for internal and external contour profiles, path generation and storage are constructed. Then based on these two types of data structures, this paper proposes an extendable software architecture, which has an interface friendly for CAD data processing and 3D Printing process parameter setup to generate different kinds of tool paths, recognize contour profiles, and perform graphic Boolean calculation. Last, based on factors such as printing efficiency and surface quality, a branch structure path optimization method is proposed to optimize the printing sequence order of SLM. Experimental observations prove the efficiency and quality of this study compared with existing commercial software.

Function-Driven Laser Additive Manufacturing of Metallic Components

Dongdong Gu

This presentation summarizes the latest research progress in our group on laser additive manufacturing of metal components with high-performance and multi-function, including the structural optimization, material innovation, process control, performance evaluation and engineering applications. This presentation also provides some considerations in the future research and development of laser additive manufacturing technologies in the production of high-performance/multi-function metallic components in the aerospace industries with high efficiency, high quality and sustainable development capability.

Zirconium modified Nb-22Ti-16Si alloys fabricated by laser solid forming: microstructure and mechanical property

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Microstructural analysis and mechanical behavior of Nb-22Ti-16Si-*x*Zr alloys, where *x*=0, 1, 5, 10, 15 at.%, hereafter referred to as 0Zr, 1Zr, 5Zr, 10Zr and 15Zr alloys, respectively, fabricated by blended pure elemental Nb, Ti, Si and Zr powder using laser solid forming were investigated. The addition of Zr was found to promote the formation of Nbss/γ-$(Nb)_5Si_3$ lamellar eutectic microstructure and affect the solidification path of the as-deposited Nb-Ti-Si alloys. The as-deposited 0Zr alloy consisted of primary Nbss (Nb solid solution) dendritic and Nbss/Nb_3Si eutectic dendrites. And 1Zr and 5Zr alloys consisted of primary Nbss dendritic, Nbss/Nb_3Si eutectic dendrites and Nbss/γ-$(Nb)_5Si_3$ lamellar eutectic microstructure. 10Zr alloy consisted of primary Nbss dendritic and Nbss/γ-$(Nb)_5Si_3$ lamellar eutectic microstructure. 15Zr alloy consisted of primary γ-$(Nb)_5Si_3$ blocks and Nbss/γ-$(Nb)_5Si_3$ eutectic microstructure. The fracture toughness of Nb-22Ti-16Si-*x*Zr alloy increased first and reached a peak value (15.28MPa $m^{1/2}$) in 5 at. % Zr, and then slightly dropped with the increases of Zr contents. As a result, using blended elemental powder in laser solid forming is a suitable method for preparing Nb-Si based alloys.

Simulation study of spatter formation mechanisms during selective laser melting

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Selective laser melting (SLM) process is a complex process involving heat and mass transfer, melting and solidification as well as evaporation of metal powders. Spatter is inevitably generated during the layer-by layer fabrication and can lead to some defects, such as rough surface and under. A clear understanding of spatter formation mechanisms is essential to manufacture parts with high quality.

In this work, a laser scanning powder-bed model was built to investigate the complex physical phenomena during SLM process using the commercial software Flow-3d. The size of metal powders was in a normal distribution with mean diameter of 30 μm. Subroutines were developed to describe the moving Gauss laser and recoil force.

Simulation results show that the spatter occur both in Ti6Al4V and SS316L laser melting process when the momentum of molten metal is sufficient to overcome the surface tension force and viscous force. Spatter is visible throughout the SS316L laser melting process while intermittently appears in Ti6Al4V laser melting process with laser power of 200 W and scanning speed of 0.8 m/s. In addition, the size of the spatter is larger and the amount of the spatter is fewer in SS316L compared with Ti6Al4V. This can be explained by the fact that SS316L has a lower surface tension force and lower dynamic viscosity, therefore a high fluidity. Moreover, the instant velocity of spatter can be up to 6 m/s which can be used to estimate the splash height. Furthermore, the shape of spatter can be like spheroidal shape and elongated shape depending on sputtering velocity. It also can be found that the size and the amount of spatter are reduced when increasing the laser scanning velocity or reducing the laser power. The results provide a good understanding of spatter formation mechanism during SLM process.

Keywords: Selective laser melting; spatter formation; Ti6Al4V and SS316L.

High Efficient Process Monitoring and Intelligent Defect Detection for Powder Bed Laser Melting Process

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Additive manufacturing brings tremendous freedom for design and manufacturing. However, the lack of defect detection and therefore a way to control the repeatability and stability makes additive manufacturing irrelevant to many industry applications.

In this paper, a fast in-situ 3D sensing device based on high resolution laser is integrated into a self-developed powder bed laser melting equipment. Machine learning and data compression methods implemented as highly efficient automated defect detection algorithms are explored. It provides a novel intelligent approach to overcome the common environment influences such as light and shadow to detect various defects during laser printing.

The Study and Clinical Application of Additive Manufacturing Based on Tissue Digital Analysis and Reconstruction

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Critical defects remain as the major clinical challenge, resulting in a growing demand for the efficacious implants. The breakthroughs in biomaterials and regenerative medicine have made artificial tissue a possible source for implants instead of natural tissue from donors. However, most artificial implants lack of bio-activity and integrating ability with the host body. To solve the problem, we have developed the bone implants with bionic microstructure simulating trabecular bones, and fabricated the customized implant specifically for each individual patients using additive manufacturing. To verify the feasibility and efficacy of our implants, we have fabricated the bionic microstructural implants using polycaprolactone/hydroxyapatite (PCL/HA), measured their similarity with natural cancellous bones and tested the osteoconductivity using murine osteoblasts. Our study showed that the fabricated bionic structure had significantly high similarity (more than 95%) with natural trabecular bone, and this bionic microstructure could provide the osteoblasts supportive microenvironment for cell growth and functionality. Our technology and research prove that the digital reconstruction of tissue microstructure can enhance the implants' bioactivity, which may lead the way to the future of artificial implants.

Numerical simulation on powder-spreading process of selective laser melting via discrete element method: packing density of powder layer

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Powder-spreading is an essential process of selective laser melting (SLM). The packing density of powder layer, which is determined in the powder-spreading process, has considerable effects on the mechanical properties of final

parts. With the objective to improve the packing density of the powder layer, we conducted a particulate scale numerical simulation on the powder-spreading process of SLM using discrete element method (DEM), where the physical properties of particles such as particle shape and particle size were taken into account. The dynamic flowing behaviors of powder particles during the powder-spreading process were analyzed in terms of particle velocity and motion trajectory. It is preliminarily found that the packing density of the powder layer is determined by the combined affections of particle properties (particle size distributions and particle shape) and spreading parameters (spreading speed and layer thickness). Our simulation gives a novel insight to the flowing and packing behavior of powder material during the powder-spreading process at particulate scale and is helpful for improving the packing density of the powder layer.

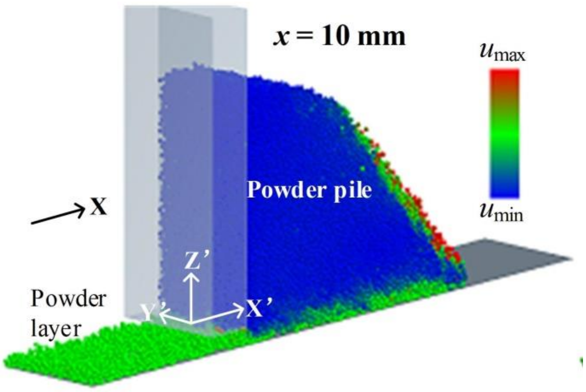

Figure 1. Powder-spreading of SLM via DEM simulation

Development of Perfusion Culture Media for Continuous Biomanufacturing

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It is generally understood that the development of platform-specific cell culture media is required for economical, productive performance in biomanufacturing. Heightened criteria for production media have driven suppliers to develop new high-efficiency, chemically defined and animal-product free basal formulations. Despite the use of perfusion methods by some for many years, implicit in these products generally has been the intention that they would be employed in batch or fed-batch applications. With some identified exceptions, this assumption included attached, suspension and microcarrier-based culture. The increased popularity of perfusion culture has inspired suppliers to develop formulations specifically designed for perfusion applications.

Many commercial production media will support successful culture in most perfusion applications, yet many unique challenges to optimal performance in perfusion application have been reported. The first observation made by most operators is that the culture-medium volumetric productivity of a perfusion reactor at initial conditions is often lower than the that productivity in fed-batch. This has been demonstrated to be often due to the culture disproportionately demanding some sub-set of the formulation's primary nutrients, and the reactors medium exchange rate having been adjusted to maintain the supply those few components. Secondly, as intensified perfusion culture determines such distinct operating conditions that the behavior/ characteristics of cells has been reported to often be quite different than in batch culture. Differences in the operating conditions include a much higher cell-density, equilibrium culture conditions (eliminating gradients of metabolite-to-cell ratios over time) and exposure to one of many medium exchange apparatus/technologies.

Each platform and clone can present a unique functional phenotype in this regard, yet some general observations have been noted. They include a differential consumption rate between individual amino acids; a differential consumption rate between glucose and other primary metabolites; a reduction in the requirement for proteins or factors in the formulation; an alteration in the use of identified amino acids/glutamine and consequent lactate/ammonium generation; differences in clumping potential; an increased or decreased demand for particular vitamins; a new identified optimum in primary (feeding) osmolality; and a change in average size of the cells. Also of note is that there are a few distinct styles of perfusion culture, each determining their own unique media design criteria. For example, the ultra-high density, static culture environment of a hollow-fibre perfusion bioreactor (HFPB) presents concerns distinct from a wave-action based suspension culture perfusion reactor. These include that sheer protectants and antifoams are not required in HFPB and albumin secretion by hepatocytes grown in a HFPB was reported to be 15-fold higher than cells grown in traditional culture. Mode-specific secreted product residence time within a reactor, and its consequence, is another consideration.

Methods employed to develop perfusion media include blending of existing formulations, measurement of metabolite gradients during operation, concentration of unnecessary-component depleted formulations to reduce volumetric addition and custom-design of mini-perfusion apparatus to reduce cost and increase throughput in DoE directed experimentation. Finally, development of perfusion culture-specific media is occurring at a time when the importance of composition-determined post-translational properties (e.g. glycoform pattern) and in toto trace material contaminant (e.g., metals) effects is being revealed, complicating the endeavor. Nevertheless, culture media manufacturers are now addressing perfusion-specific production formulations supporting the popular manufacturing platforms, perfusion types and product entities.

Three Dimensional Monolayer Culture of Epithelial Cells on Electrospun Poly(vinyl alcohol) Nanofibrous Membrane

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Adherence of epithelial cells cultured on traditional two-dimensional (2D) culture dish may induce aberrant cell functions, including epithelial-mesenchymal transition. In this study, three-dimensional (3D) culture system of epithelial cells was developed to maintain long-term survival, adherence, and function of cultured epithelial cells. Poly(vinyl alcohol) (PVA) is one of the most prevalent and versatile synthetic polymers abundantly used in tissue engineering as biomaterials, but high hydrophilicity of PVA results in water soluble and poor cell adhesion. The novel combination of PVA/polyacrylic acid/glutaraldehyde crosslinked with combination of heat, HCl, and dimethylformamide as an electrospun membrane showed promising characteristics of water stability and cell adhesion. In addition, peptides, which are derived from domains of cell binding in extracellular matrix proteins, such as fibronectin, laminin, and collagen, could be blended in PVA nanofibers. When mouse primary hepatocytes and lung epithelial cell line, MLE-12 cells were cultured on PVA nanofiber membrane, these cells adhered to the cross-linked PVA/PAA/GA nanofiber membrane but formed cell aggregate and discoidal shaped spheroid. In comparison, the epithelial cells adhered to and formed monolayer on cell-adhesive peptide-blended PVA nanofibers. The expression of E-cadherin in culture cells and tight junction were maintained during culture time. Therefore, epithelial cells cultured on PVA nanofiber membrane grow three dimensionally in monolayer and maintain their functions for long time.

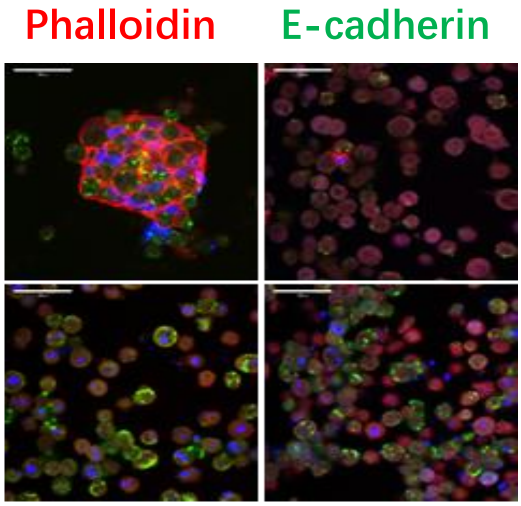

Figure 1. Culture of primary hepatocytes for 5 days on PVA and RGD-PVA membrane

Microfluidic system for modelling 3D tumour invasion into surrounding stroma and drug screening

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Tumour invasion into the surrounding stroma is a critical step in metastasis, and it is necessary to clarify the role of microenvironmental factors in tumour invasion. We present a microfluidic system that simulated and controlled

multi-factors of the tumour microenvironment for three-dimensional (3D) assessment of tumour invasion into the stroma. The simultaneous, precise and continuous arrangement of two 3D matrices was visualised to observe the migration of cancer cell populations or single cells by transfecting cells with a fluorescent protein. A vascular endothelial layer was formed to simulate transendothelial transport of nutrients, and its endothelial barrier function was verified by the diffusion of 70-kDa fluorescein isothiocyanate (FITC)-Dextran in 3D matrices. Through high-throughput cell migration tracking observation and statistic evaluation, we clarified that cell density of the tumour directly determined its invasiveness. The results suggested that increased secretion of IL-6 among both cancer cells (MDA-MB-231) and non-cancerous cells (MCF-10A or HDF-n) after co-culture contributes to cancer cell invasiveness, and this was verified by an IL-6 inhibitor assay. Finally, the drug efficacy of paclitaxel was reflected as changes in cancer cell migration ability, viability, and morphology. Together, our microfluidic devices could be a useful tool to study the mechanism of tumour invasion into the stroma and to screen anti-metastatic drugs.

Decellularized Extracellular Matrix Bioinks and the External Stimuli to Enhance Cardiac Tissue Development *in vitro*

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Successful development of an engineered heart tissue (EHT) holds potential as a model for *in vitro* tissue modeling or tissue regeneration. Different systems have been described to fabricate EHT; however its efficacy is currently limited by inferior functional properties of the cultured cardiomyocytes. Specifically, the surrounding matrix microenvironment such as appropriate bioink composition plays an imperative role in modulating cardiomyocyte differentiation. Recently, the use of tissue-derived extracellular matrix (dECM) hydrogel is considered as one of the most promising candidates because of their functional and structural similarities to native tissue. Nevertheless difference in its matrix modulus as a result of varied concentration may affect the gross cardiomyocyte behavior and its subsequent gene expression. In this study, we fabricate 3D printed EHT using a biomimicry approach and addressed the phenotypical changes in cardiomyocyte maturation with respect to varying bioink composition having different degrees of stiffness; and the culturing condition.

We demonstrated a correlation between synthesis of cardiomyocyte specific proteins and the surrounding bioink and its stiffness regardless of the similar material chemistry. Notably, 3D bioprinted EHT using 0.6% hdECM having reduced matrix stiffness significantly modulated redifferentiation of NRCM by enhancing synthesis of cardiac specific proteins as compared to other experimental group. Furthermore, confocal microscopic examination showed development of aligned sarcomeres for NRCM encapsulated in hdECM unlike collagen group that did not display sarcomeric alignment under similar dynamic condition.

A remarkable difference in cardiomyocyte behavior could be observed with respect to bioink composition and culturing conditions. This highlights that matrix modulus and culturing condition can be a decisive factor for cell-material interaction, thereby affecting cardiomyocyte morphology and governing its subsequent gene expression. Hence, this study provides an experimental insight towards the establishment of a 3D printed cardiac tissue model with respect to varied matrix mechanics and culturing conditions.

Acknowledgements: This work was supported by the National Research Foundation of Korea (NRF), funded by the Ministry of Education (No. 2015R1A6A3A04059015) and under the "ICT Consilience Creative Program"(IITP-R0346-16-1007) supervised by the IITP (Institute for Information & communications Technology Promotion).

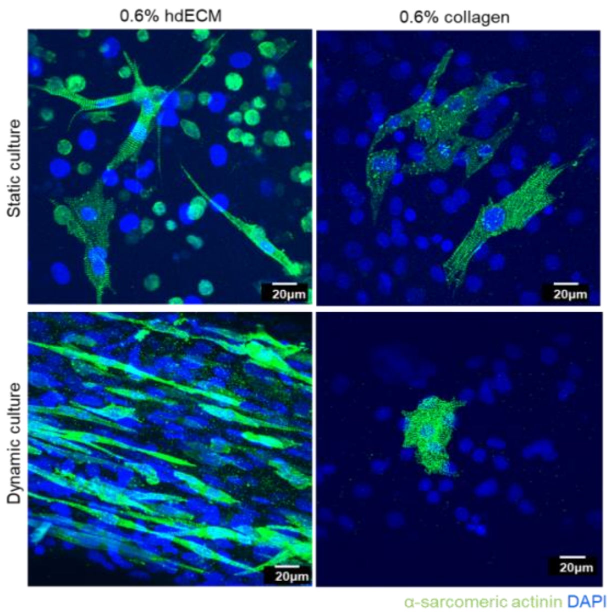

Figure 1. Immunofluorescent images of α-sarcomeric actinin expressed by NRCM encapsulated in 0.6% hdECM and collagen cultured under static and dynamic condition at day 14, respectively.

An in vitro brain-like drug screen model based on advanced 3D bioprinting technology

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Introduction: Brain is the most complex organ of human beings due to its role of being the instruction center that governs the whole body as well as the material carrier of all ideology. The formation and development of brain diseases can seriously damage the health of the brain and bring great stress to patients' life. At the beginning of the twenty-first century, brain science and neuroscience have become the leading trend of science and technology in the field dedicating to discovering functional mechanisms of brains and exploring accumulated development of diseases. Meanwhile, in biomedical engineering, 3D bioprinting as an emerging biofabrication technology has been widely applied in in vitro tissue research [1,2], and this making 3D bioprinting has a great potential in Neuroscience by constructing in vitro brain like structure. Many research groups have successfully constructed brain like structure in vitro [3,4]. However, none of them report neural signals detected in the fabricated structure. In this work, neural signals detected in the 3D bioprinting brain like structure are investigated. Firstly, the current 3D bioprinting technology will be further designed and improved for constructing in vitro layered brain like structure. Then, the layered brain like structure is directly cultured on 4 4 multiple electrode array up to Day 31 in vitro. Finally, the neural signals are collected by using the Med64 recording system. Our layered brain like structure is very sensitive to input signals. The goal of this work is to construct drug screen model for brain disease study by using the 3D bioprinting to print out layered brain like structure.

Materials and Methods: Multiple electrodes arrays (MED64) are coated poly(D-lycine) (PDL) one day ahead of experimental day. On the experimental day, neural cells are dissected from P1 Wistar pups brains. Cell-laden bioink is prepared by mixing neural cells with concentration of 1 ´106 /ml and gel materials including 4% alginate, 15% gelatin and 12 mg/ml fibronectin. Layered brain like structure is printed out according to a designed program at 10 oC. The fabricated layered brain like structure is then crosslinked and solidified successively by 1% CaCl2, glutamine transaminage and thrombin, and cultured fresh culture media at 37 oC incubator. The culture media is changed biweekly media. On day 31, the sample is connected to the MED64 recording system to collect neural signals in a perfusion system. After half an hour recording, the sample is marked by live/dead assay to check the survive rate. The laboratory animal facility has been accredited by AAALAC (Association for Assessment and Accreditation of Laboratory Animal Care International) and the IACUC (Institutional Animal Care and Use Committee) of Tsinghua University approved all animal protocols used in this study.

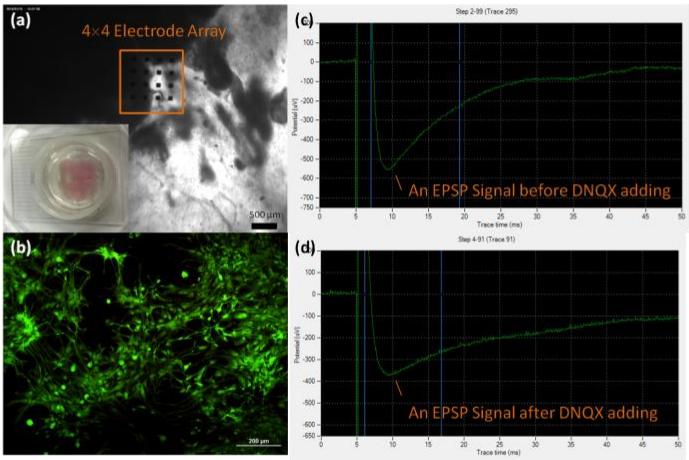

Fig 1. (a) Image of layered brain like structure cultured on a multiple electrode arrays on Day 31, and the inset is the image of a sample cultured on a multiple electrode array; (b) Live/Dead imaging of neural cells on Day 31; (c) Electrophysiological recording of the layered brain-like structure on Day 31 before and after DNQX adding.

Results and Discussion: Layered brain like structure is cultured directly on a multiple electrode array and maintained up to 31 days in vitro, as shown in Fig.1 (a), and the inset is the image of a culturing sample on a array of electrodes. Fig. 1(b) shows that Live/Dead cells marker is used to image neural cells cultured to 31 days. Large survive rate of neural cells after 31 days culturing in vitro promotes the formation of neural circuits. The neural signals of the sample is collected by using MED64 recording system. DNQX are added into the sample culture successively and a negative decreasing amplitude is observed as shown in Fig.1 (c) and (d). The sensitive responding signals indicate that the constructed brain-like structured layers is suitable as a drug test model.

Conclusions: Functional layered-brain-like structure is firstly constructed in this project. Neural cells in this structure can survive up to 31 days in vitro. This promotes the formation of the neural circuits and hence makes this structure greatly potential in drug test model for brain disease investigation.

References:

1. Khademhosseini A and Langer R. A decade of progress in tissue engineering, Nature Protocol, 2016, 11: 1775-1781.
2. Kang HW, Lee SJ, Ko IK, Kengla C, Yoo JJ and Atala A. A 3D bioprinting system to produce human-scale tissue constructs with structural integrity. Nature Biotechnology, 2016, 34: 311-319.
3. Lozano R, Stevens L, Thompson BC, Gilmore KJ, III RG, Stewart EM, Panhuis MIH, Romero-Ortega M and Wallace GG. 3D printing of layered brain-like structures using peptide modified gellan gum substrates. Biomaterials, 2015, 67: 264-273.
4. Gu Q, Tomaskovic-Crook E, Wallace GG, and Crook JM. 3D bioprinting human induced pluripotent stem cell constructs for in situ cell proliferation and successive multilineage differentiation. Advanced Healthcare Materials, 2017, 1700175

Control of the formation of vascular network in 3D bioprinted tissue by tensile forces

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3D bioprinting is an attractive method for fabricating viable tissues and organs that could be used to treat and restore function in the case of compromised and dysfunctional tissue. Tissue vascularization is a major prerequisite for the long-term survival and function of these constructs post-implantation. Tensile forces are understood to play a critical role in vasculogenesis. We used a simple 3D bioprinted tissue model to further understand the role of tensile forces in vascular network formation. The components used to produce the 3D architecture included polycaprolactone (PCL) polymer for the supporting scaffold and composite cell-laden fibrin hydrogel containing normal human dermal fibroblasts (NHDF) and human umbilical vein endothelial cells (HUVEC). The PCL supports were first printed and then the fibrin cell-laden hydrogel within the PCL supports. All constructs were stained with CD31 15 days after printing. The results showed that vessel formation in 5mg/ml fibrinogen scaffolds was better than others, and vessel-like structures grew parallel to the direction of the tensile force with very few branches. Vessel lumen formation was observed with collagen deposition around the vessels. The vessels and actin grew in the direction of tensile force and were found to be aligned. Inclusion of Y27632, a rho-associated protein kinase (ROCK) inhibitor, reduced cell-generated forces resulting in damaged networks and less-elongated vessel-like structures. Also, cultures treated with blebbistatin, which inhibits Myosin-II, displayed reduced network quality. This suggests that vascular network formation is regulated by tensile forces that result due to the interaction between the 3D bioprinted PCL support scaffold and the printed cell-laden hydrogels. Further understanding of the mechanisms underlying these tensile forces will enable better control on formation of vascular networks in bioprinted tissue.

3D Printing Smart Soft Robotics

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Soft robotics is currently a hot topic in robotic research mainly due to soft robots' in- herent property of compliance to environments and safe interaction with humans. This article presents the development of 3D printing of soft robots with sensors and actua- tors without the need of assembly. Shape memory Polymers (SMP) have the ability to return from a deformed state (temporary shape) to their original (permanent) shape induced by an external stimulus (trigger), such as temperature change. This property of SMP has been tapped for the design of soft robots. The design of a soft robot, nor- mally has complex shapes, could be fabricated by a 3D printing process.

In this article, critical extrusion process parameters have been experimented to deter- mine an appropriate set of parameter values so that good quality SMP filament could be made for FDM. In the FDM process, effects of different printing parameters such as extruder temperature and scanning speed on object printing quality are also studied. In all the process studies, we aim to achieve good quality parts by evaluating part den- sity, tensile strength, dimensional accuracy and surface roughness. Based on these studies, sample SMP parts such as that in Fig.1 have been successfully built. Due to the thermal sensitive nature of the printed SMP part in Fig.1(a). it can be used as a gripper stimulated by thermal stimulation as in Fig.1(b).

The novel design and 3D printing of a bio-inspired soft robotic finger as shown in Fig.2 is also presented in this article. The robotic finger is co-printed with two materi- als, one for sensors (pressure and angular position) and the other for actuator. Its char- acterization and performance will be presented and discussed.

Fig.1 3D printing of a gripper

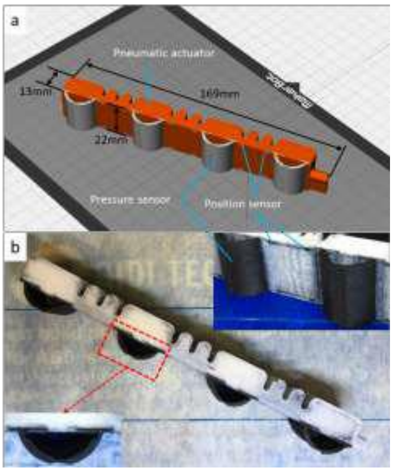

Fig.2 Bio-inspired robotic finger (a) Original (b) Thermal activated

Biomimetic 3D hydrogel-based cell culture model of human ovarian cancer: implications for novel therapeutic targets in ovarian cancer

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Ovarian cancer is one of the most deadly malignancies in women because of its poor prognosis and that a majority of patients are diagnosed at advanced stage. Therefore, chemotherapy becomes the most important treatment option in most ovarian cancer cases. Current *in vitro* drug testing models based on 2D cell culture lack natural tissue-like structural organization and result in disappointing clinical outcomes. The development of efficient drug testing models using 3D cell culture that more accurately reflects *in vivo* behaviors is vital. Our aim was to establish an *in vitro* 3D ovarian cancer model that can imitate the *in vivo* human ovarian cancer microenvironment. Using this model, we explored strategies to evaluate tumor progression and malignancy. Ovarian cancer cells grown in this model exhibited excellent biomimetic properties compared to conventional 2D culture including (1) enhanced chemotherapy resistance, (2) suppressed rate of apoptosis, (3) upregulated expression of drug resistance genes (MDR1 and MRP1), (4) elevated levels of tumor aggressiveness factors including Notch (Notch, VEGF and MMPs), and (5) enrichment of a cancer stem cell markers (Sox-2 and Nanog). Therefore, our data suggest that our 3D ovarian cancer model is a promising *in vitro* research platform for studying ovarian cancer biology and therapeutic approaches.

3D cell printing of pluripotent stem cells

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Pluripotent stem cells (PSCs) derived from either the embryo or reprogramming processes have the capacity to self-renew and differentiate into various cells in the body, thereby offering a valuable cell source for regenerative therapy of intractable disease and serious tissue damage. Traditionally, methods to expand and differentiate PSCs are mostly confined to 2D culture through the use of biochemical signals. The need for models that recapitulate 3D natural human tissue physiology is urgent for drug testing and development, study of disease mechanism and regenerative medicine applications. We make the first attempt to bioplotting embryonic stem cell-laden hydrogel into 3D structure. Printing process standardization was systematically studied to ensure both good printability and cell viability. Large quantities of uniform and pluripotent embryoid bodies with tunable properties were obtained with simple process. We also make the first attempt to bioplotting human iPSCs-laden hydrogel into 3D structure with a novel hydroxypropyl chitin bioink that facilitated the printability as well as iPSCs viability. With long-term culture (10 days), formation of hiPSC aggregates with uniform sizes was observed and demonstrated the improved efficiency of further induced differentiation.

Fabrication Of Three-Dimensional Organic/Inorganic Scaffold by Direct Ink Writing Technology

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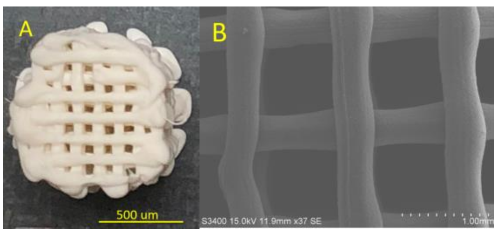
The repairing of post-traumatic bones is a major problem in clinical surgery. Autologous bone-repair methods are often limited by donors and cannot meet the requirement of a large number of clinical applications. Corals, mainly composed of calcium carbonate ($CaCO_3$), is promising in bone repairing [1]. However, as an endangered marine organism, its exploitation and use are restricted and no longer available as artificial bone materials. A kind of 3D printing technology, Directly Ink Write (DIW)[2] has several advantages such as high precision, and can be used to print a variety of different materials, build complex 3D models, and is widely used in tissue engineering research.

In this paper, nano-scale $CaCO_3$ is used to form coral-like artificial bones. An amount of 10-30wt% of biocompatible and degradable L-polylactic acid (PLLA) is used as a binder to construct artificial coral-like bone by DIW technology. The calcium carbonate on the surface of the scaffold is replaced by hydrothermal reaction into hydroxyapatite(HA) as it has better osteoinductivity. 3D porous structures of PLLA/$CaCO_3$ were produced (as shown in Fig.1). The cell culture showed that the cells can successfully attached and proliferated on the surface of the scaffold.



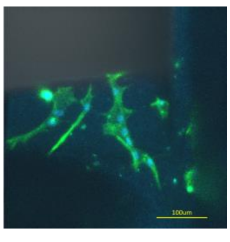


Figure 1. (A) Top View of PLLA/$CaCO_3$/HA Scaffold; (B) SEM observation of the Scaffold
Figure 2. The attachment of human bone marrow mesenchymal stem cells on the scaffold

Reference:
[1] Cui L, Liu B, Liu GP, Zhang WJ, et al. Repair of cranial bone defects with adipose derived stem cells and coral scaffold in a canine model, Biomaterials 28 (2007) 5477–5486
[2] Jakus AE, Rutz AL, Jordan SW, et al. Hyperelastic "bone": A highly versatile, growth factor-free, osteoregenerative, scalable, and surgically friendly biomaterial, Science Translational Medicine 28 Sep 2016:Vol. 8, Issue 358, pp. 358ra127

Fabrication and in vitro evaluation of 3D-printed biodegradable stents

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Statement of Purpose:

Drug-eluting stents are the gold standard for interventional treatment of coronary artery disease to date. Although they address some shortcomings and limitations of bare-metal stents, the permanent presence of the stent struts apply restriction of vascular vasomotion due to inflammation, and the risk of late and very late stent thrombosis [1-3]. It is worth mentioning that the shape of human coronary artery is approximately conical, which means the profiles of different position are not uniform. Nevertheless, the stents used in clinical are all cylindrical, leading to mismatching with the physiological structure of vessels. The development of personalized biodegradable stent, which is tailed to the shape of cornory, is a new approach that attempts to circumvent these drawbacks. It has been observed that 3D-printing has evolved into a versatile technology for personalized fabrication.

In this work, we reported a novel study of fabricating a personalized completely biodegradable stent with fused deposition modeling (FDM) by 3D-printing. The material, structure and forming method of personalized biodegradable stents were investigated to achieve adequate strength and toughness. Furthermore, the fabrication of FDM equipment has been performed. A variety of styles of cylindrical and conical stents with well-molded quality and suitable radial strength were developed with biomaterials, such as poly-caprolactone (PCL).

Methods:

Commercially available PCL (Mw 80 kDa) was purchased from Sigma-Aldrich (St. Louis, MO, USA), with a low glass-transition temperature of -60℃ and a low melting temperature of 60℃. We propose to use fused deposition modeling (FDM) as the method of molding BDS. The monolayer vascular stent 3D printing process based on the cylindrical coordinates was adopted. The molten polymer filament was attached to the surface of the rotating axis, and the stent was formed with the linkage of the platform. Meanwhile, high-precision 3D printing nozzles were designed and fabricated. We analysis the forming method and choose the material and structure of personalized biodegradable stent. Then, we complete design, selection and assembly of the molding equipment. This equipment consists of four systems: motor system, heating system, injecting system and cooling system.

Results:

With this 4-axis linkage (XYZ, rotation axis) equipment as a coronary stent 3D printing platform and precision extrusion deposition technology, a variety of styles of cylindrical and conical personalized completely biodegradable stents with well molding quality and suitable radial strength are fabricated with PCL, respectively.

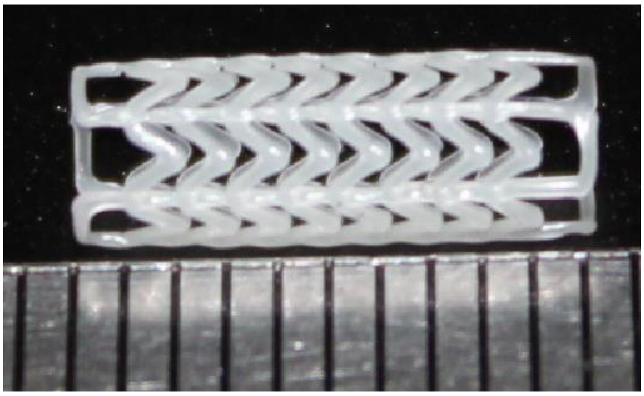

Figure 1. Cylindrical stents fabricated by 3D-printing

Conclusions:

Personalized completely biodegradable stent adapts to the physical structure of blood vessels, meets the needs of individualized treatment, and provides new ideas to reduce the incidence of coronary intervention complications, and provide experimental support for the development and popularization of innovative biodegradable conical coronary stent.

In this paper, the function and technical route of the forming equipment are analyzed, and the design, selection and erection of the equipment are finished. At the same time, the material and structure of personalized BDS are analyzed, and the suitable degradable materials are selected. The stent structure is designed to meet the requirements of 3D printing and strength. The forming of cylindrical and conical stents were completed, all of which had good quality of molding. The method of personalized BDS based on cylindrical coordinate is explored, and the preliminary forming target is basically realized, which lays a foundation for further study.

References:

[1] Ang H Y. International Journal of Cardiology, 2017, 228:931-939.
[2] Kim H K.. Chonnam medical journal, 2012, 48(3): 141-149.
[3] Wiebe J. Journal of the American College of Cardiology, 2014, 64(23): 2541-2551.

Additive manufacturing of ceramics and its potential applications

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Ceramic components are expected to be widely used in various fields due to their excellent properties, including high strength, high-temperature capability and corrosion resistance, etc. However, there are some restrictions in preparing ceramic components with complex structures by traditional manufacturing methods. Additive manufacturing has shown great advantages in fabricating ceramic components of high geometrical design freedom and structure complexity without molds. Nevertheless, there are still many issues in the preparation of ceramic components via additive manufacturing. In this respect, lots of related researches on additive manufacturing of different kinds of ceramics have been successfully done by Prof. Yu-Sheng Shi's group in Huazhong University of Science and Technology. Firstly, the present research status of ceramic parts fabricated by additive manufacturing is systematically introduced, such as selective laser sintering (SLS), selective laser melting (SLM), fused deposition modeling (FDM), laminated objected manufacturing (LOM) and stereo-lithography apparatus (SLA), etc. Secondly, our recent research works on additive manufacturing of porous/dense ceramic components and related manufacturing equipments are introduced. Finally, the applications and challenges for additive manufacturing of ceramics are elaborated. The preparation of high-performance ceramic components by additive manufacturing shows promising application in the fields of aerospace, marine equipment, biomedical and electronics industries, etc.

Microstructure evolution of porous SiC with low residual silicon content fabricated by direct laser sintering method

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Due to its high strength, good chemical stability and thermal conductivity, porous SiC was widely applied in many situations such as catalyst, heat exchanger, gas filtration and water treatment. Recently, SiC heat exchanger with gradient micro-structures and complex shapes got more and more attentions. Traditional manufacturing methods such as dry pressing, extrusion, gel casting, injection molding and tape casting are either difficult to obtain the gradient structures or difficult to fabricate parts with complex shapes. Direct selective laser sintering is a promising way to solve all the problems with more efficiency and more convenience. However, due to the decomposition of SiC under laser irradiation, direct laser sintering of SiC is still a big challenge. In this study, additives(15 wt.% boron carbide with a D50 about 3 μm) was introduced into the SiC raw powder(5 μm, 10 μm and 20 μm respectively) to improve the laser sintering process of SiC. The effect of particle size were investigated in this study. The powder was irradiated under Nb-YAG laser with a laser power 300W, laser scanning speed 2500 mm/s and span space 0.5 mm. The laser spot size diameter is 20 μm. The results showed that when the particle size is about (10 μm), the microstructure showed a interlocked grid microstructure. When the powder particle size is about 20 μm, a near parallel line structure could be obtained. This phenomenon should be attributed to the vaporization caused by the decomposition of SiC and plasma process during the laser irradiation process. XRD results showed that due to the existence of boron carbide particles, the residual silicon content was limited to about 20 wt.%.

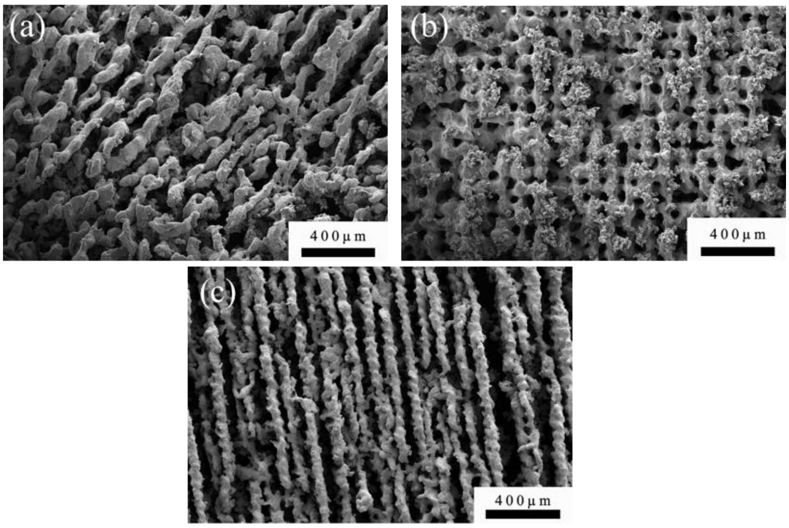

Figure 1. The Effect of SiC particle size on the microstructure of porous SiC: (a)5 μm SiC raw powder, (b)10 μm SiC raw powder and (c) 20 μm SiC powder

A study of 3D-printable reinforced composite resin: PMMA modified with TiO_2/PEEK micro- and nano-composite

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Polymethyl methacrylate (PMMA) composite resins have been used as important raw materials in dental 3D printing application for years. However, drawbacks such as large shrinkage size, low degree of one-time curing, poor mechanical strength, low bacterial resistance, limit the long-term performance of PMMA in clinical dentistry.

Antimicrobial nanocomposites have generated interest in dental composite resins research. Ag and TiO_2 nanoparticles were demonstrated to have good antibacterial characteristics against not only gram-negative but also gram-positive bacteria. Furthermore, TiO_2 nanoparticles can provide extra toughening mechanisms of PMMA composite resin.

Compared to pure nanoparticles, micro- and nano-composite were demonstrated to have better load transfer ability to effectively improve mechanical properties of PMMA composite resin. Herein, PEEK microparticles were subsequently conducted to enhance mechanical properties. The resulting TiO_2/PEEK micro- and nano-composite were envisioned promising fillers for 3D-printable PMMA composite resin, to improve their mechanical properties, impact resistance, biocompatibility and bacteria activity.

Hierarchical structure of soft materials: A cathodic writing approach to control the function and properties of polysaccharide hydrogel

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We used a dual-responsive interpenetrating polysaccharide network as our dynamic medium: agarose is thermally responsive, and chitosan is pH responsive. The initial medium was made by cooling an acidic blend of chitosan and agarose to form agarose network. The medium was placed on a conductive surface which was used as an anode, and a stainless steel wire used as a cathode contacting the surface of the medium. Cathodic writing was achieved using the stainless steel wire as an electrode pen to locally perform cathodic electrolysis reactions that generated high pH-regions that neutralized the interpenetrating chitosan chains and induced their self-assembly into crystalline regions. Surprisingly, the gradients in structure induced by cathodic writing were stable even after the pH gradient dissipated. Then, we developed a model to explore the deposition thicknesses with varying deposition time and the intensity of the electrical input signal (i.e., the current density). The changes in structure generated by cathodic writing altered the medium's mechanical, chemical and biological properties. The tensile test demonstrated that writing systematically enhanced the tensile strength of the films. Cathodic writing converted chitosan's ammonium groups into neutral state with enhanced abilities to chelate metals and served as nucleophiles for chemical modification reactions. The photomicrographs and XPS analysis showed the existence of Ag nanoparticles on the written region. The fluorescence images indicated that covalent conjugation of fluorescently labeled BSA and biotin preferentially occurred on the written region. The photographs illustrated that the quinone-chitosan grafting reaction was preferentially localized to the written region. The confocal fluorescence images showed that fibroblast cells preferentially adhered to the surface of written region. In essence, cathodic writing provides a simple approach to pattern selectivity reactive regions to the hydrogel. Broadly, this work demonstrates the use of top-down electrical inputs to induce bottom-up structural changes in a biopolymer-based medium and these structural changes fundamentally alter how this medium interacts chemically and biologically with its environment.

A noval method of 3D printing for continuous fiber reinforced thermosetting polymer composites

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Although great advancement is shown in the process aspect of 3D printing technology, problems are still existed in the material aspect, which limit its further developments and applications. The most direct and effective improvement method is to use the polymer materials as a resin matrix, and use the high performance fiber as a reinforcement. Then the fiber-reinforced resin-based composites are formed as the 3D printing filaments. In this paper, a new 3D printing technology for continuous fiber reinforced thermosetting polymer composites was proposed and investigated, which was divided into three separated modules, including impregnating, printing and curing, as shown in Fig. 1 (a, b, c). The relevant equipments were built and several mechanical tests were conducted. The results showed that the tensile strength and tensile modulus of these printed samples were 1325.14 MPa and 100.28 GPa, respectively; the flexural strength and flexural modulus were 1078.03 MPa and 80.01 GPa, respectively; and the interlaminar shear strength was 58.89 MPa. The mechanical performance had been greatly improved, which were more than twenty times that of CCF/ABS (3D printing) and more than 60% of UD composites (laminate). Finally, the interlaminar defects of fiber damages and resin cracking, as well as the insufficient combinations along the printing direction were discussed, through the analysis of the destructional forms, micro interface and void distribution.

Keywords: 3D printing, Continuous fiber, thermosetting composites, Mechanical performance

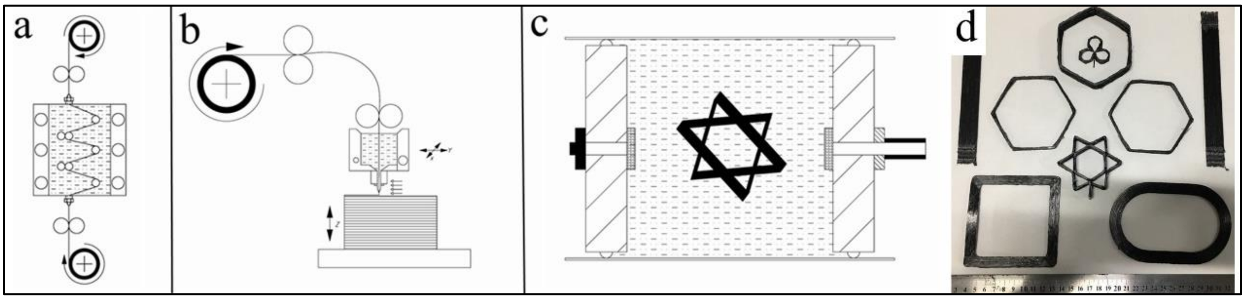

Fig. 1. Schematic representation of the impregnating, printing and curing modules, (a) schematic representation of the impregnating process, (b) schematic representation of the printing process, (c) schematic representation of the curing process, (d) cured samples of CFRTPCs.

Digital Hybrid Forming Manufacturing Technology & Equipment Based on Patternless Casting

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Green Manufacturing is a kind of the advanced manufacturing technology with the environment implications and resource efficiency. Many developed countries have focused on the intelligent green technology innovation. The characteristics of the green hybrid forming manufacturing are as follows, near-net & precision shaping, short cycle & high efficiency, lightweight forming and non-pollution emission & clean manufacturing, and so on. How to manufacture metal castings with digital, low-cost, high-quality, high-efficiency and green? Multi-material and multi-process hybrid patternless casting forming method was put forward. It realizes the transform from pattern sand casting to patternless sand casting for foundry industry. Series of digital precision forming Pattern-less Casting machines such as sand mould digital flexible extrusion equipment, digital sand machining forming machine, sand cutting & printing machine, have been developed. To improve the machining accuracy and surface roughness, avoid the collapse of thin wall sand mold, the sand cutting force model has been created. And the influence law of sand cutting mechanism and cutting performance is obtained. By testing and analysis different extrusion strength, spindle speed, feeding speed, cutting width and depth, the optimal process parameters of compound forming have been studied. Case Studies of Hybrid Forming Technology were listed. Type SMM5000 - CAMTC forming machine has forming sand mould with 5000 mm × 3000 mm × 2000 mm. The method realizes the fast, efficient, environmentally friendly, precision forming manufacturing of metal parts with complex shape.

Keywords : Hybrid Forming, Green Manufacturing, Digital Casting, Rapid Manufacturing

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Ceramic Mold for Casting Single-crystal Superalloys Based on Stereolithography

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The fabrication of alumina-based ceramic molds for rapid casting of single-crystal (SX) superalloy parts based on stereolithography additive manufacturing and gelcasting technology was investigated. To our knowledge, this is a promising approach to fabricate SX superalloy parts with internal structure, such as gas turbine blades, via current additive manufacturing technology. The main fabrication procedures of the mold are: preparing resin molds by stereolithography, ceramic gelcasting, freeze drying, and sintering. The mold properties were enhanced through the addition of kyanite to the raw materials. The bending strength and creep deformation were assessed at 1550 ℃, to determine the performance of the mold under the conditions required for the casting of SX superalloy parts. Additionally, the sintering shrinkage and apparent porosity were evaluated. The results showed that the fabricated molds with suitable amounts of kyanite addition exhibited superior high-temperature mechanical performance and dimensional stability. The high-temperature mechanical performance was attributed to the mullitization of the raw materials. Moreover, the volume expansion that accompanied kyanite decomposition enabled well-controlled sintering shrinkage and apparent porosity. A SX hollow turbine blade sample was fabricated via directional solidification by grain selection method, demonstrating the feasibility of the proposed technique for rapid-casting SX superalloy parts.

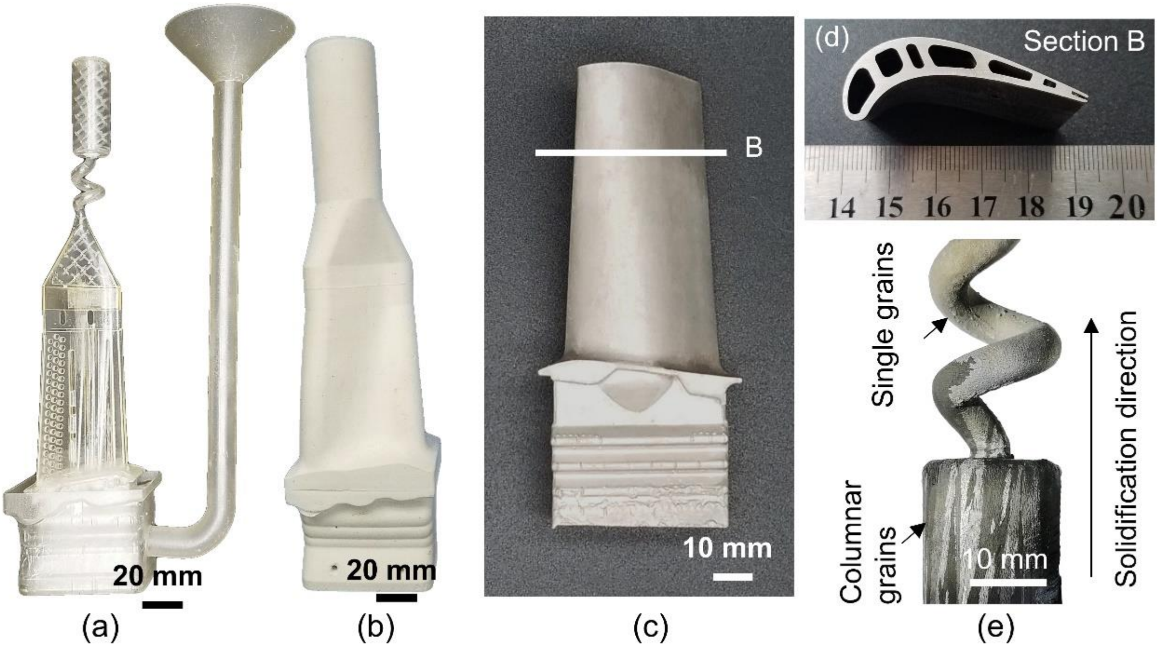

Figure 1. (a) Turbine blade resin mold, (b) ceramic mold, (c) SX blade sample, (d) hollow structure of the blade, and (e) grain selector for the SX blade.

Rapid Precision Casting of Complex Pipeline Based on Stereolithography Prototype

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Gypsum mold is widely used in light alloy casting because of its advantages of strong replication ability, good surface precision and easy removal. The rapid manufacturing of complex structural parts can be realized by combining gypsum mold casting with SL prototype. However, due to the limitation of the gypsum mold's characteristics, the filling and maintenance capacity of the structures like complex and slender tubes is insufficient during manufacture of the gypsum mold with complex pipeline structure. Aiming at the difficulty of surface treatment of complex pipeline inner wall, this research optimizes the surface waxing process to ensure the surface quality of SL prototype inner wall. Through the analysis of typical pipeline structure in this process, the influence of negative pressure on the filling effect of gypsum slurry was studied. Complete filling of complex pipeline was realized by controlling the pressure difference between inlet and outlet of pipeline. By strengthening with the calcium sulfate whisker, the high temperature(350℃-750℃) strength of the gypsum core can be effectively

improved without obviously influencing the slurry viscosity, and the maintenance capacity of the slender tube structure during the roasting process can be enhanced. The dissolution characteristic of gypsum core was promoted by the optimization of gypsum formula, ultrasonic vibration and thermal vibration.

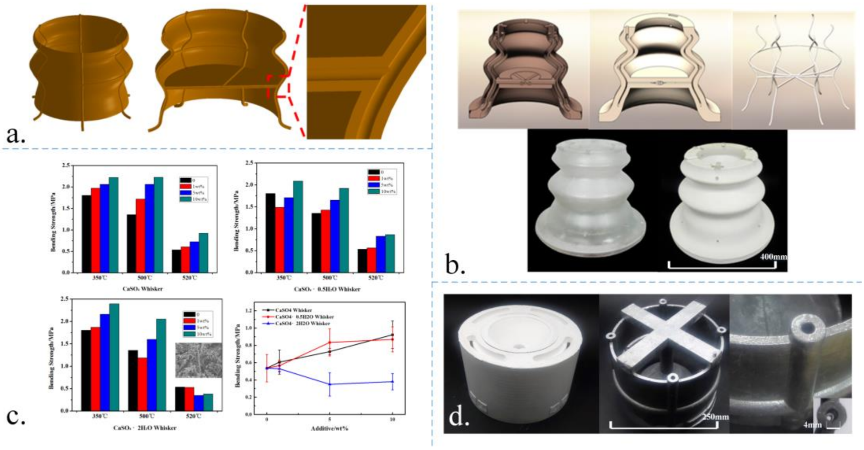

Figure 1. (a) complex pipeline in an aero-engine casing (b) numeric model/SL prototype/gypsum mold (c) strengthening effect of calcium sulfate whisker
(d) gypsum mold and metal castings with complex pipelines

Additive Manufacturing of Topology Optimized Landing Gear Fabricated With Continuous Carbon Fiber Reinforced Thermoplastic Composite

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The need to have lightweight yet strong structures, which has always been the primary concern in aerospace industry, has spurred the research on developing better materials and better structural designs. The search for better materials for aerospace applications has led to the development of composite materials. Composite materials, having special characteristics such as high strength-to-weight and stiffness-to-weight ratios, have since slowly replaced the heavier alloys in aircraft structures. In order to obtain better structural design, various methods have been used to obtain optimized structural design which includes topology optimization. In this work, a full list of mechanical properties of additively manufactured continuous fiber reinforced thermoplastic required for structural simulation are reported and discussed. The list includes poisson ratios, compression properties and shear modulus in x-, y-, and z-directions that are hardly found in available literatures. The list of mechanical properties will be useful for product designers who are interested in using this FFF technique to produce continuous carbon fiber composite structural parts to perform structural simulation before the production of a design. Apart from that, the use of FFF technique to fabricate a topology optimized landing gear of UAV with continuous carbon fiber composite is demonstrated showcasing the ability of FFF technique to print geometrically-complex high-performance structural parts. Successful landing of UAV demonstrates the superior performance of continuous carbon fiber reinforced thermoplastics fabricated using FFF techniques.

High-density bio-glass ceramics fabricated by stereo-lithography

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In this paper, a ceramic slurry which can be used for photo-curing was prepared. Based on this, the factors influencing the separation force in the process of photocurable manufacturing were tested. In the factors that affect the separation force, according to the significance of the level of sorting: forming size(0.002)> separation speed(0.017)> single layer thickness(0.043)> single layer curing time(0.5). With the increasing diameter, the separation force is increasing linearly, while the area is increasing faster than the force. With area increasing, the average stress is decreasing.Stretched diaphragm will change the process of separation from stretching to peeling.The green bodies are subjected to sintering treatment according to the data obtained by thermogravimetric analysis.The relative density of DLP and 3DP sintered parts were compared. The result shows that if the volume fraction is 60%, the relative density of the parts is 98.2%. But the relative density of 3DP parts is only 83.8%. At the same time, with the increase of solid content, the density and strength of the parts have also increased significantly.The energy spectrum analysis shows the entire manufacturing process didn't introduce impurity elements by using FESEM, so the biological properties of bone scaffolds were not influenced by the manufacturing process. Preparation of cell experimental scaffolds made by AP40mod and β-TCP. L929 cells(mouse fibroblasts) are cultured in DMEM high glucose medium and 5% fetal bovine serum. The relative survival rate of cells was obtained by measuring the OD value of cells in different concentrations of extract and the OD value of the control group. Although the proliferation of L929 cells in AP40mod scaffolds is better than the control group,but the difference was not statistically significant.From the current animal experiments, we can conclude that AP40mod has a good osteogenic characteristics, and arteriovenous vascular bundle combined with ectopic transplantation can hopefully achieve large segment of bone vascularization.

Development of PLA/BF composites and their feasible evaluation for 3D printing applications

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The objective of this work is to develop KH550-treated basalt fiber (KBF) reinforced polylactide (PLA) composite as a potential 3D-printed feedstock. Herein, PLA/KBF feedstock filaments are successfully fabricated and printed to variable shape and size parts via FDM technique. 3D-printed specimens exhibit similar tensile strength in contrast with compression-molded counterparts. Compared with short carbon fiber reinforced PLA printed specimens, mechanical results suggest that PLA/KBF exhibit comparable tensile properties and superior flexural properties to those of PLA/CF control, which can be attributed to high complex viscosity of PLA/CF affect the interlayer adhesion. Furthermore, the optimized fiber content and fiber length of KBF are evaluated and observed by CT scans. It is demonstrated that low infill and micro-defects are shown with increasing fiber length and content, resulting in a deteriorated mechanical performance of PLA/KBF filaments. The present work proves PLA/KBF as a mechanical improved and low-cost feedstock for 3D printing applications in complex design and variable sizes.

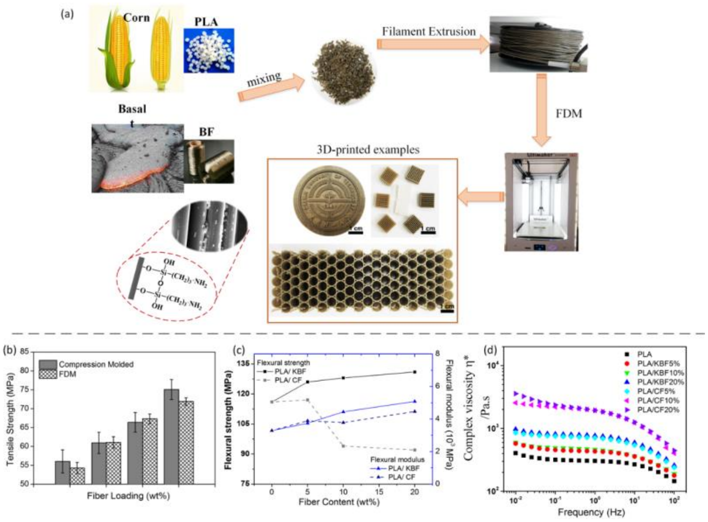

Fig.1 (a) Manufacturing steps of PLA/KBF printed filaments, (b) tensile strength of FDM and compression-molded PLA/KBF specimens, (c) flexural strength and modulus and (d) complex viscosity of PLA/KBF and PLA/CF printed specimens.

Building a World Class 3D Printing Research Centre: Strategies and Lessons

Chee Kai Chua

3D printing or additive manufacturing is one of the key elements in industry 4.0. Building a world class 3D printing centre is necessary and essential for any country that intends to catch up with or even take the lead in industry 4.0. However, establishing a successful world class 3D printing centre is not obvious. Getting sufficient initial funding and maintaining fruitful and sustainable development are the two greatest challenges. In this talk, I would like to share Singapore's unique experience in building a world class 3D printing – Singapore Centre for 3D Printing. I hope that the strategies we have developed and tested and the lessons we have learnt could be useful to other countries.

Development of high performance titanium-copper alloys through laser metal deposition

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Titanium alloyed with a certain amount of copper is reported to have excellent anti-bacterial properties, good biocompatibility and corrosion resistance for dental applications. However, conventionally cast Ti-Cu alloys are not strong enough even after artificial aging. Given the unique advantages of very high cooling rates and multiple thermal cycles, additive manufacturing (AM) opens a new opportunity to produce high performance Ti-Cu alloys. In this study, a series of Ti-xCu binary alloys ($4 \leq x \leq 10$ wt. pct.) were produced by laser metal deposition (LMD). The effect of Cu concentration on the microstructure, porosity and mechanical properties of the AM Ti-Cu alloys has been comprehensively studied. In addition, the performance of AM Ti-Cu alloys was also compared with their cast counterparts in terms of the mechanical properties and anti-bacterial capability.

Suppressing Effect and Mechanism of Titanium Oxide Doping on Cracking Behavior of Directed Laser Deposition of Alumina Structure

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Alumina ceramics prepared by directed laser deposition (DLD) is expected to have excellent oxidation resistance and high temperature mechanical properties due to the absence of binder doping, but excessive cracking during the depositing process limits the practical application of this technique. The reaction of titanium oxide with alumina produces aluminum titanate with low thermal expansion coefficient, thereby reducing thermal stress during deposition and reducing cracking. In this paper, alumina ceramic structure was prepared by the DLD technique. Suppressing effect of titanium oxide doping on the cracking behavior of the fabricated structure was discussed, and the suppressing mechanism was analyzed. The results show that alumina and titanium oxide form a composite microstructure with aluminum titanate as the matrix and alumina as the discrete phase. As the doping amount of titanium oxide increases, the number of cracks in the formed structure decreases continuously. When the doping amount reaches the eutectic ratio of alumina/aluminum titanate, the cracking phenomenon disappears. The formation of aluminum titanate reduces the coefficient of thermal expansion of the fabricated sample, and the coefficient of thermal expansion decreases as the doping amount of titanium oxide increases, which directly reduces the thermal stress during the depositing process and reduces the generation of cracks. In addition, the formation of the composite microstructure reduces the size of the original defects in the microstructure of pure alumina and increases the energy required for crack propagation. The mismatch of the thermal expansion coefficient of alumina and aluminum titanate forms residual compressive stress in the aluminum titanate matrix,

has a trapping effect on the crack tip, and also has the effect of crack suppression. Through the doping of titanium oxide, large-sized crack-free ceramic structures were successfully fabricated.

Figure 1. Alumina/aluminum titanate samples fabricated by DLD

Microstructure, mechanical and magnetic properties of soft magnetic Fe-Ni-Si by using selective laser melting from nickel coated high silicon steel powder

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Given to its high permeability, low coercivity, and low hysteresis loss, the soft ferromagnetic material is usually used to amplify the flux density generated by a magnetic field. In this work, Fe-Ni-Si soft magnetic parts, using Ni coated high silicon steel powder, were manufactured by selective laser melting process. The type of defect changes from porosity to cracks and the relative density increases, from 50 % to 99 %, with the decreasing laser scanning speed. The microstructural analyses indicate that the low laser scanning speed fully melted the nickel coating and high-silicon steel core. The EBSD study showed that the separated island and lamellar mesostructures appeared on the top and side view respectively. Moreover, no apparent texture were observed. The magnetization saturation of SLM processed sample decreased, as the laser scanning speed was increased. Consequently, the magnetic properties of SLM processed Fe-Ni-Si alloy also showed anisotropic feature in building and scanning directions, which can be attributed to their different mesostructure.

Furthermore, the hot isostatic pressing (HIPing) was employed to densified the SLM processed soft magnetic Fe-Ni-Si component. Go through the HIPing process, the crack and porosity of SLM processed sample were reduced. Moreover, the X-ray diffraction phase analysis indicates that only fcc γ (Fe, Ni) phase was observed in both samples before and after HIPing. In detail, a slight movement of XRD pattern appears after HIPing process, which can be attributed to the release of residual stress and elemental precipitation. The results indicates that both the coercivity and retentivity increased from 23Gs and 0.57emu/g to 36Gs and 0.86 emu/g after the HIPing process. Lastly, the compressive properties were also investigated with focus on the densification and isotropic features.

Keywords: Additive manufacturing; Soft magnetic materials; Anisotropic mesostructured; Hot isostatic pressing; compression.

Effects of deposition strategy on residual stress and deformation in additive manufacturing

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The present study investigated the influences of deposition strategy on residual stress and deformation in additive manufacturing process. Six representative deposition strategies were studied in by numerical simulations of additive manufacturing process. The results suggested that the deposition strategy showed a strong impact on heat transfer during the deposition process, inducing different residual stresses and deformation after venting to ambient. The largest and smallest temperature gradients were resulted from the zigzag path and the alternate-line path, respectively. The temperature gradient was reduced with the increasing of layers. The alternate-line path can be considered as the optimum path since it induced the smallest residual stress and deformation.

Keywords: Additive manufacturing; Deposition strategy; Residual stress; deformation; Simulation

In Vitro Alternatives in Drug Discovery and Safety Evaluation

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Safety and efficacy are two key factors determining the success of the R&D of innovative drugs and drug withdrawal. Traditional drug toxicity testing and safety predictions are facing great challenges. In recent years, with the development and development of the 21st century toxicity test strategy (TT21C), drug toxicity test based on toxic mechanism has become an important development direction of drug discovery and safety evaluation. In the past decade since the release of TT21C by the US National Research Council, a group of new approach methods has been developed and applied in drug discovery and safety evaluation. In particular, the complete ban on animal testing for cosmetics in Europe and the Lautenberg Chemical Safety Act in the United States have provided strong incentives to develop alternative strategies, which also brings significant impacts on pharmaceutical industry. In facing the challenges of traditional animal-based toxicity testing methods, TT21C has been widely developed and applied in drug discovery and safety evaluation, with emphasis on using in vitro alternatives that formed human originated cell- and mechanisms-based testing strategies. A group of case study chemicals (including doxorubicin, diclofenac, troglitazone, phenoxyethanol, niacinamide and caffeine) was assessed using a panel human originated cell- based, high content imaging assays designed to detect effects on several different cell stress pathways including mitochondrial toxicity and oxidative stress. For materials where initial work indicates a potential for mitochondrial toxicity, higher tier investigations may be appropriate. In some cases, many different cell models are applied and compared such as human originated cell lines and hiPSC-derived cells and compared to both measured human systemic levels of tested drugs in patients undergoing treatment as well as systemic levels predicted from Physiologically Based Kinetic modelling. In silico modelling approaches have also been taken to describe the inter-relationship between the biomarkers tested. Our results indicate that a tiered approach integrated with in vitro alternatives and a mechanisms/pathways-based strategy can be incorporated into drug discovery and safety evaluation.

Electrohydrodynamic Printing Process Monitoring by Microscope Image Identification

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With the rapid development of micro/nano manufacturing technologies, electrohydrodynamic printing (EHDP) has drawn great attention. This technology can align micron to nano scale fibers and fabricate multi-scale multi-pattern scaffolds using biocompatible polymer materials. Fibrous bioscaffolds are architecturally characterized by fiber diameter, pore size and internal configuration. To ensure scaffolds with required morphology, it is very necessary to monitor EHDP fabrication process which can be easily affected by environment factors.

In this paper, we propose to capture EHDP cone image by a digital microscope as shown in Figure 1. The monitoring images are collected under varied process parameters (voltage from 2.6 to 3.4kV and the nozzle-to-substrate distance from 3 to 4mm), with concentration of 65 % PCL and 70 % PCL in acetic acid. Various features are extracted to quantify the EHDP cone shape, such as centroid of cone, fiber width, ratio of long axis to short axis, ratio of perimeter to area, and top angle of cones.

A convolutional neural network (CNN) is used to classify cone shape and identify their suitability for scaffold fabrication. TensorFlow which is an open-source deep learning library developed by Google Brain team, is applied for coding this CNN. Firstly, 5000 EHDP cone images are labeled into eight categories according to their characteristics: fine cones, broken cones, dry cones, huge cones, tiny cones, meniscus cones and multi-jet cones. These images are divided into: training, validation and test set. In training process, 16 or 32 randomly chosen images with labels are input into the network in each step.

To achieve accurate classification, continuous 15 frames of images are used for classification and this cone category is eventually decided by the maximum vote of classification results. Our classification model accuracy on the test set is about 94.8%.

Figure 1. Formation of coiled fiber when collector is stationary.

Towards Intelligent Precision Additive Manufacturing – a case study on interferometry sensor data mining for in-process 3D measurement of photopolymerized part dimensions

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Real-time process measurement and control is one prominent technology node to advance additive manufacturing (AM) processes towards being intelligent precision systems for fabricating high-standard components of demanding properties (e.g., high dimensional accuracy). As in-situ sensors have been increasingly employed in various additive manufacturing systems to monitor the 3D printing processes, capable data techniques are desired to interpret sensor data online and extract measurands information which can enable real-time feedback control for achieving target properties.

In this presentation, an example case of mining sensor data to measure the height profile of an additively manufactured part will be discussed with a lab-designed AM system as shown in Figure 1. The Exposure Controlled Projection Lithography (ECPL) is an in-house additive manufacturing process that can cure microscale photopolymer parts on a stationary transparent substrate with a time sequence of patterned ultraviolet beams delivered from underneath. The in-situ interferometric curing monitoring and measurement (ICM&M) system is developed to measure the ECPL process output of cured height profile. As the photopolymerization phenomena occur continuously over a range of space and time scales, the sensor data analysis is complicated with computation speed and cost. The large amount of video data, which is usually noisy and cumbersome, requires efficient data analysis methods to unleash the measurement capability. Algorithms are strengthened by incorporating empirical values obtained from experimental observations to guarantee realistic solutions for online computation. Experimental results indicate that the data-enabled interferometry method could estimate the height profile of cured parts with accuracy and precision. Furthermore, the study exemplifies that data mining techniques can help unveil more insights about the real-time dynamics for advanced process modeling and control.

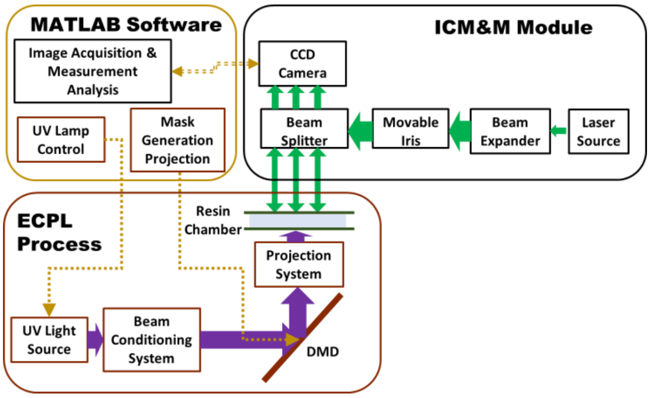

Figure 7. A Lab-scale Cyber-Physical System for Photopolymer Additive Manufacturing Equipped with in-situ Measurement and Real-time Control Capabilities

The presentation will be concluded with a brief introduction about a new AM research lab propelled by precision engineering and artificial intelligence in the University of Pittsburgh (Pitt). Research opportunities on advanced additive manufacturing are available with a strong body of faculties and state-of-the-art facilities at Pitt.

Generative Design of Robot Component

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The mass inertia of the robot mechanical component, and the harness of the electric, pneumatic or hydraulic systems represent fundamental difficulty for robot motion accuracy and repeatability.

With the help of additive manufacturing examples, this study is to demonstrate the generative design of bionic components to reduce weight and improve mobility for robot. The ongoing work of this study is actively on the design and manufacturing of flexible and autonomous robot, multiple axis lathe or mechanical arm, and medical implant.

3D-Printed Polymeric Structures for Tunable Wideband Acoustic Absorption

WenjingYang

In acoustic engineering, noise reduction and sound damping have received considerable attention. The quality of the noise control is measured by the absorption frequency bandwidth and the absorption coefficients. To achieve

effective absorptions in wide bandwidths with high absorption coefficients, the micro-perforated panel (MPP) is focused as one of the most promising acoustic absorption devices. This study aims to design and develop MPPs with higher absorption efficiency in wider frequency ranges compared to the conventional single-layer MPP. MPP structures including multi-layer MPPs and the single-layer MPP with non-circular perforations are designed. The effective absorption frequency ranges are tuned by geometric variations of the structures. Additive Manufacturing (AM) is newly introduced in MPP manufacturing via selective laser sintering (SLS). The acoustic test results show that the absorption frequency bandwidths are broadened and tuned by the designed structures, which agree with the numerical simulation resutls. This research work demonstrates the potential of artificial acoustic designs using AM approaches without constrains in design and manufacturing.

In-situ capture of spatter signature of SLM processing using maximum entropy double threshold segmentation method

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The process stability of selective laser melting (SLM) is still affected by spatter. However, there is still a lack of methods for processing spatter image to automatically detect the onset of spatter. In this paper, we propose the maximum entropy double threshold segmentation method to obtain spatter image contour. The experimental setup with high speed camera is used to capture spatter images. Then, our novel maximum entropy double threshold segmentation method which combines maximum entropy and genetic algorithm algorithm, can extract the contour of spatter accurately and rapidly. Three parameters (processing time, spatter number and area) are used to evaluate the performance of algorithm. Results show that our method has a better accuracy for recognition of spatter than previous algorithms. Its average processing time can be shortened to 37 ms.

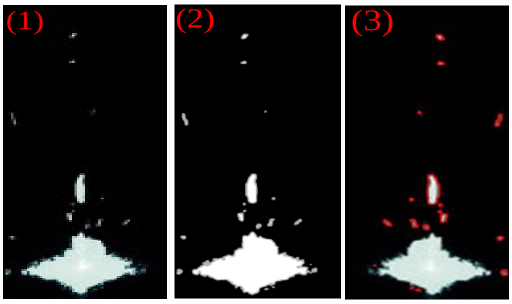

Figure 1. (1) Spatter original image (2) New algorithm (3) Comparison of results

E-Jet Bioprinting of Hierarchical Scaffold for Esophagus Tissue Repair

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Esophagus is a muscular tuber in which food and drink are transported from pharynx to stomach. However, the function of esophagus could be damaged due to diseases. To rebuild the damaged esophagus, a suitable replacement is needed to re-establish the function of esophagus. The muscular wall of esophagus was found in bilaminar arrangement: an inner layer where fibroblasts oriented circumferentially to lumen axis and an outer layer where cells aligned parallel to lumen axis. This arrangement is essential in propelling food boluses or fluid. In detail, the sequential contraction of the circular muscle layer occludes the lumen to push the ingested bolus longitudinally along the esophagus, and the sequential contraction of the longitudinal muscle shortens the esophagus tract. The contraction of longitudinal muscle layer also increases the density of the circular muscle fibers and, in turn, increases the efficiency of the circular muscle contraction.

Recently, artificial biopolymers such as Poly(L-lactide-co-caprolactone) (PLLC) and polycaprolactone (PCL) were applied to fabricate esophageal tissue engineering scaffolds. However, due to the intrinsic defects of fabrication, the structures of previous scaffolds are not regular. Hence, they can hardly orient cells regular alignment, which provides poor replicate to the natural esophageal structure.

Porous scaffolds could facilitate cells connections as well as nutrition exchange, hence, promoting cells' growth and proliferation. However, the pores also influence cell seeding efficiency. When cells are pipetted on top of scaffolds, many cells could go through the pores directly and left on the bottom of culture plate. Subsequently, it takes a long time for these cells to proliferate and adhere onto the fibers of scaffold, which leads to a waste of cells seeding and culturing time.

The objective of this study is to fabricate hierarchical esophageal tissue engineering scaffold to guide cellular regular orientation as well as to increase cell adhesion, growth and proliferation hence, mimicking the structure of natural esophagus. Electro-hydrodynamic jetting (E-jetting) and electro-spraying (e-spraying) were adopted to fabricate the scaffold (Figure 1). Furthermore, human esophagus fibroblasts (HEF) were cultured on this scaffold to determine the function of fibre cell alignment.

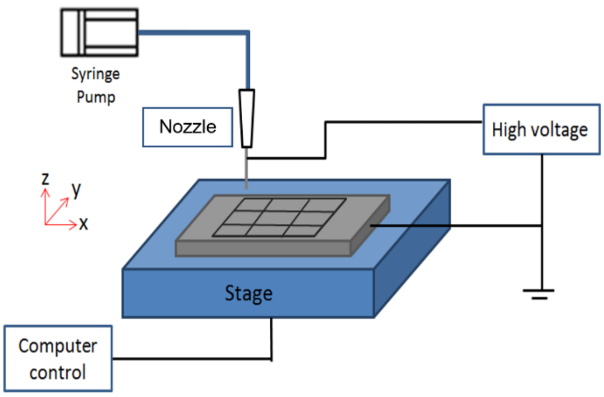

Figure 1. Schematic of E-jetting and E-spraying process

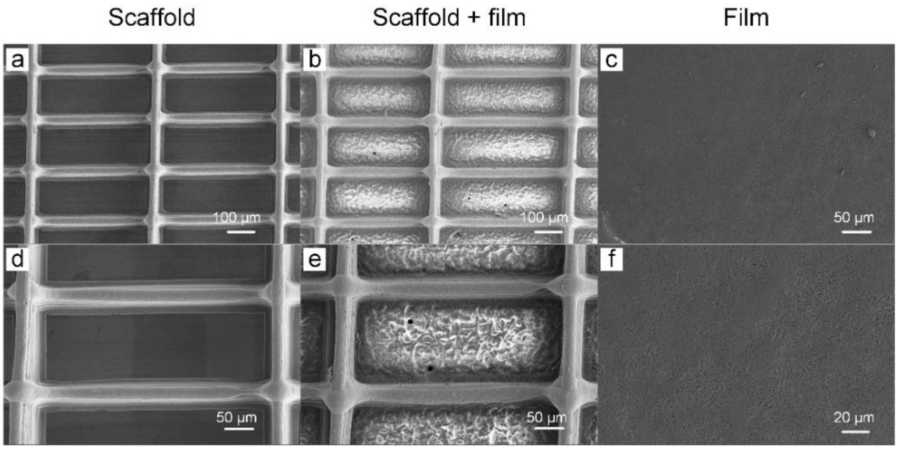

Figure 2. SEM images of (a, d) e-jetted scaffold, (b, e) hierarchical scaffold and(c, f) e-sprayed film.show that hierarchical scaffold enhanced cell alignment and adhesion, indicating its potential in the applications to esophageal tissue and other tissues with similar structures such as tendon.

Primary human esophagus fibroblasts (HEsF #2730) were seeded on the scaffolds (Figure 2). There are only few dead cells on all three kinds of scaffolds in all time points, which proves the good biocompatibility of all scaffolds. Furthermore, with the increase of culturing time, HEsF spread and proliferated on the surface of scaffolds gradually. On the hierarchical scaffold, fibroblasts covered the inter-fiber area, while there were some round HEsF cells on the film (Figure 3).

The effects of different scaffolds to influence cellular orientation was demonstrated through cytoskeletal staining tests. Figure 4(a) shows the F-actin and nucleus morphology of HEsF on different scaffolds. The orientations of HEsF on the e-jetted scaffold were mainly oriented along the longitudinal fibers. On the other hand, the HEsF on hierarchical scaffolds and e-sprayed film orientated in random directions. The HEsFs with nuclei angles between 0 - 20 °and 160 - 180 °were designated as aligned cells. Figure 4(b) shows the nuclei angles distribution on each group. On e-jetted scaffolds, the fibroblasts nuclei angles were mainly between the range of 0-20 ° and 160 °-180 °. On the hierarchical scaffold, however the nuclei angle distributed more evenly. Meanwhile, the nuclei angle was focused more on the range of 60 °-80 °.

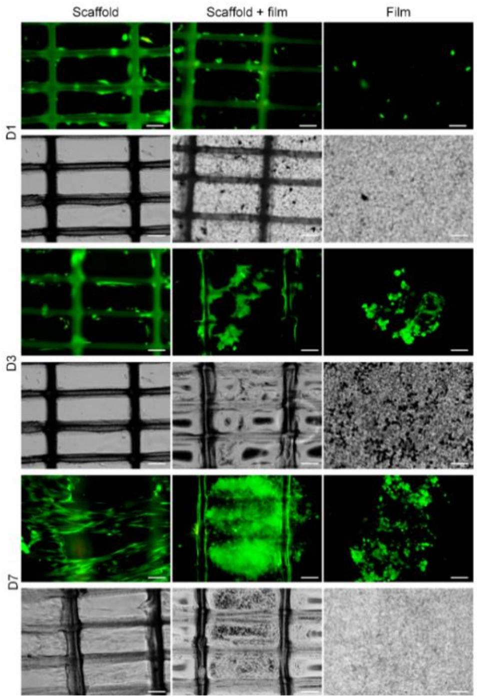

Figure 3. Viability of HEsF on esophageal tissue engineering scaffolds after culturing for 1, 3 and 7 days. Live cell: green color, dead cells: red color. Scale bar: 100 μm

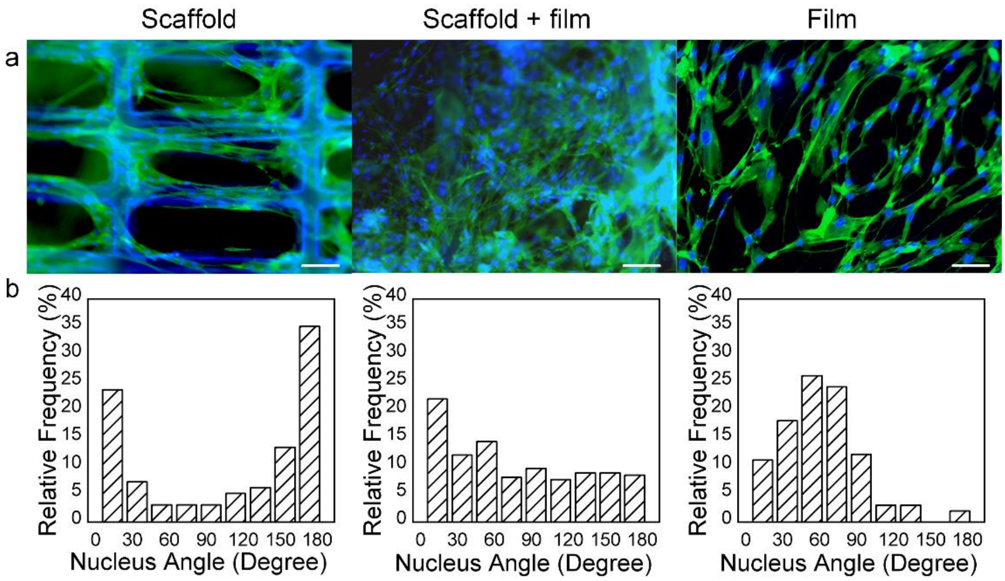

Figure 4. (a) Cytoskeletal staining of HEsF on three kinds of scaffolds after 7 days. Phalloidin: green color, F-actin; DAPI: blue color, nucleus. (b) Nucleus angle distribution.

3DP of bioceramics with accurate hierarchical porosity for bone tissue repair

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Hierarchical porosity, which includes micropores and macropores in scaffolds, contributes to important multiple biological functions for tissue regeneration. However, most of these conventional methods are difficult to control the scaffolds' pore arrangements and dimensions. 3D printing technique with a super ability to fabricate 3D complicated architecture with customized pores. It could produce highly complicated implants with personal-customized architectures for different patients in accordance with their CT data. Concerning the biological function importance of hierarchical macro-/micro-porosity, this study seeks to construct hierarchical porous HA bone tissue engineering scaffolds with rigid porous structures using 3DP[1].

HA with nano-sized crystals of 30–50 nm with lengths of 50–100 nm were modulated by polyvinyl alcohol, cellulose, and pure water to form the printing “ink”. The first-level macropores of HA scaffolds were designed by CAD molding with considering of 20% linear shrinkage, and fabricated by the 3DP technique. The second-level micropores of scaffolds were obtained by the freeze and sintering process.

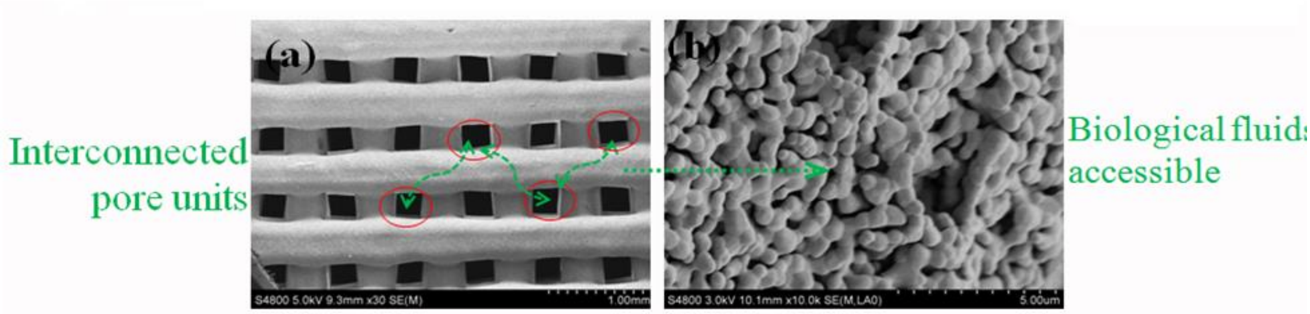

Figure 1. SEM images of the printed CaP scaffolds with hierarchical porous architectures and porosity. (a) is the scaffolds with macro pore sizes of 300 μm and (b) is the scaffolds with micro pores, respectively.

Fig. 1 showed the hierarchical microstructure of 3DP bioceramics. The scaffolds showed highly open, well-interconnected, and uniform pores. The pore units of the scaffolds are cubic pores with side lengths of 300, 425, and 550 μm. An ideal scaffold for bone tissue engineering should have accuracy porosity to provide different biophysical and biochemical effects. The bioceramics with precise porosity showed obvious osteoinductivity in the animal experiments. This research may provide a versatile way to modulate biological function of biomaterials through optimized design and fabrication of scaffolds.

Acknowledgments
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References

[1] Zhou C.C., Ye X.J., Zhang X.D. et, al. Biomimetic fabrication of a three-level hierarchical calcium phosphate/collagen/hydroxyapatite scaffold for bone tissue engineering. Biofabrication, 2014,(6):035013-25.

Bioinks for 3D Bioprinting of Biomimetic Tissue Models

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3D Bioprinting has gained attention in tissue engineering due to its ability to spa- tially control the placement of cells, biomaterials and biological molecules. The development of new hydrogel bioinks with good printability and bioactive proper- ties has made it possible to 3D bioprint and accelerate the maturation of complex 3D tissue-like models. Bioprinting technologies developed by CELLINK, including 3D bioprinters and bioinks , are being applied to regenerative medicine to address the need for tissues and organs suitable for transplantation, cell-based sensors, drug screening models, and tumor models. These bioinks are optimized for print- ability, cell viability, and cellular expression, and are made from a range of syn- thetic, natural, and ECM based biomaterials. The current design strategy for bi- oinks is to create environments that support specific cell types or functionalities, while mimicking natural tissues.

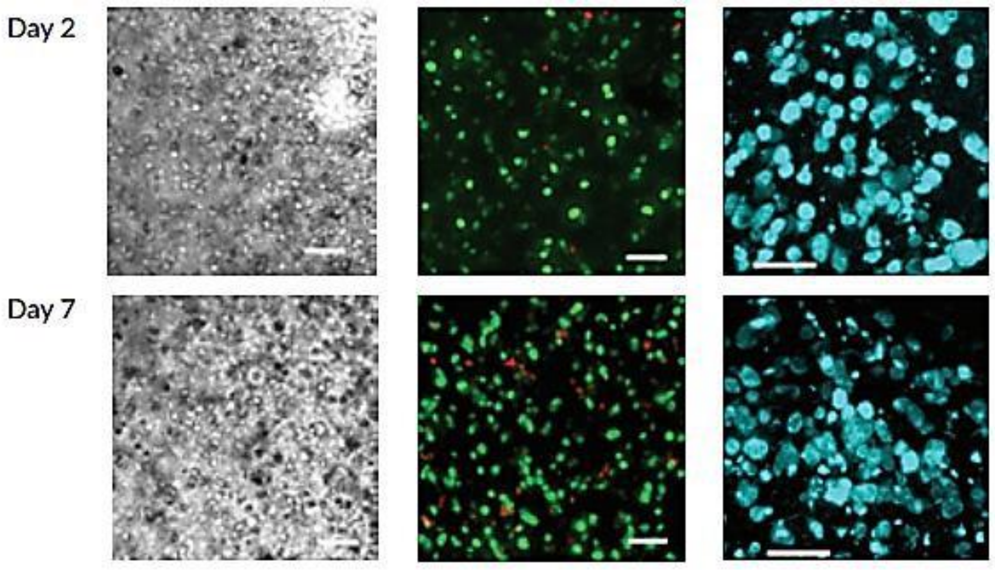

Figure 1. Indicated for day 2 and 7. Left: Brightfield images of cells evenly distributed within the LAMININK 121 cell-laden. Center: Live/dead staining images show minimal dead cells (red). Right: label-free microscopy images of Hep G2 (cyan, multiphoton microscopy). Scale bar 100 μm.

This includes our CELLINK LAMININK series, which contains five tissue- specific bioinks based on laminin proteins that mimic the basal lamina of natural tissue. More information will be demonstrated during the presentation, including CELLINK's latest advances in bioinks and biomaterials, and data from our research collaborators.

3D printing for peripheral nerve regeneration

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Artificial nerve conduits provide an advanced tool for repairing the injured peripheral nerve. However, the efficacy of the artificial nerve conduits to bridge the defects in peripheral nerve needs significant improvement. Functionalization of nerve conduits promotes peripheral nerve regeneration and functional restoration. Here, we show a functional nanoparticle-enhanced conduit that can promote the regeneration of peripheral nerve. This conduit, which consists of designer hydrogels with drug loaded nanoparticles decorated in the hydrogel matrix, is rapidly fabricated by a continuous 3D printing process. While the 3D-printed hydrogel conduit with personalized size, shape and structure provides a physical microenvironment for the peripheral nerve repair, the nanoparticles offer drug release to promote the regeneration of the injured nerve. Our results indicate that this conduit can efficiently induce the recovery of sciatic injuries in morphology, histopathology and functions in vivo, showing potential clinical applications.

Electro-fabrication of polysaccharide films with biomedical applications

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Membrane materials can be used for wound care, tissue isolation, and tissue-induced regeneration. Traditional film-making techniques such as solution casting, freeze-drying phase separation, electrospinning, and 3D printing are inefficient, and their ability to control the structure of the material and improve its functionality is insufficient. Electrochemical technique outputs signals rapidly and accuratly, and also these signals can be used to trigger material shaping and material functional modifications.Here we report a series of functional membrane materials that were prepared using electrochemical methods. Firstly, we electrolyzed water to induce a local pH change around the electrode that triggered in situ electrodeposition of alginic acid, and thus a free-standing Ca2+-alginic acid membrane with controllable structure was rapidly prepared for wound treatment.Further using this technique, a free-standing antibacterial film of Cu2+-alginic acid, which has a controlled structure, was prepared in one step.We further combine electrochemical deposition and electrochemical oxidation techniques to prepare a chitosan antimicrobial dressing containing a haloamine structure. In addition, we used a step-by-step electrodeposition technique to prepare a structurally asymmetric multi-functional artificial periosteum for the regeneration of bone defects.

Reference:

Qu X*, Liu H, Zhang CC, Lei Y, Lei M, Xu M, Jin DW, Li P, Yin M, Payne GF, Liu CS* Electrofabrication of Functional Materials: Chloramine-based Antimicrobial Film for Infectious Wound Treatment ***Acta Biomaterialia*** 2018,73:190-203
Liu H, **Qu X***, Kim E, Lei M, Dai K, Tan X, Xu M, Li JY, Liu YP, Shi XW, Li P, Payne FG, Liu CS* "Bio-Inspired Redox-Cycling Antimicrobial Film for Sustained generation of Reactive Oxygen Species"***Biomaterials*** 2018,162:109-122.
Liu XL, Liu H, **Qu X***, Lei M, Zhang CC, Hong H, Payne GF, **Liu CS***"Electrical signals triggered controllable formation of calcium-alginate film for wound treatment" ***Journal of Materials Science Materials in Medicine*** 2017, 28:146

Electrofabrication of Biomaterials: A Bio-mimetic Electrochemical Approach to Fabricate Hydrogel and Confer Functions

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Biology routinely uses redox (reduction-oxidation) reactions to perform important biological functions including tissue matrix assembly (e.g., disulfide bond formation for mucus assembly and oxidative crosslinking of collagen). Inspired by this, we employed electrochemistry and diffusible redox mediators to mimic the oxidative crosslinking of tissue matrices to fabricate bio-mimetic and biofunctional hydrogels.

Our results show that:

(i) the electrochemical approach allows oxidative assembly of 4-arm thiolated polyethylene glycol (PEG-SH) and gelatin into transparent hydrogels on Indium Tin Oxide (ITO) coated glass electrodes (as shown in **Figure 1a**);

(ii) the deposition facilitates the spatial assembly of PEG-SH and gelatin as indicated by the highly localized hydrogel on patterned electrodes in **Figure 1b**;

(iii) the assembled matrix allows reagent-less protein conjugation through reactions between activated hydrogels and proteins with engineered fusion tags (**Figure 1b**);

(iv) the approach allows the co-deposition of cells (e.g., the breast cancer cells MDA-MB-231) that are mixed into the deposition solution, and the entrapped cells maintained high viability after 48-hr incubation (**Figure 1c**).

In summary, this bio-mimetic electrochemical approach provides a versatile, tractable and inexpensive way to extend the capabilities of electrofabrication to functional biomaterials fabrication.

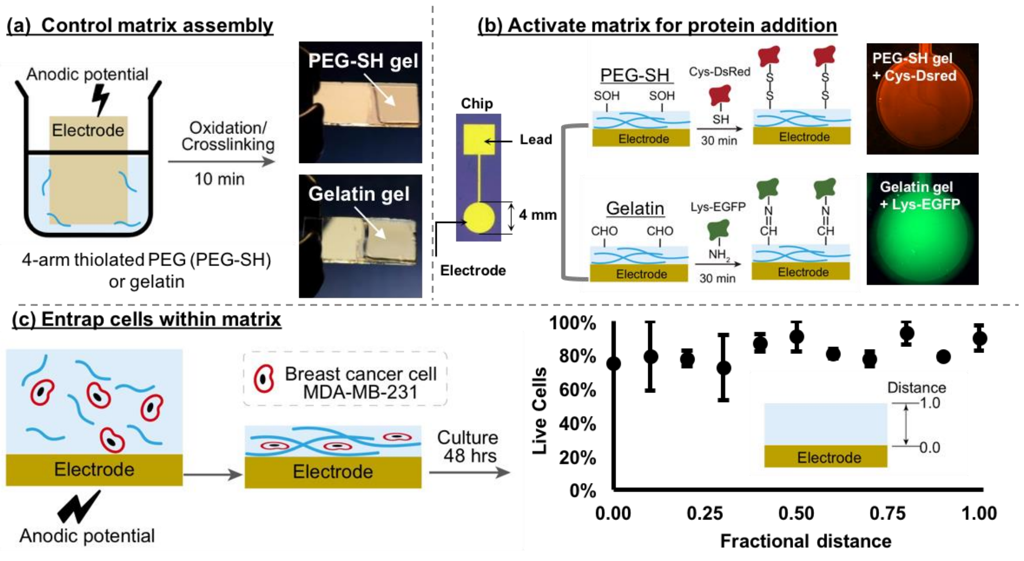

Figure 1. A bio-mimetic electrochemical approach for biofabrication.

Oxygen transfer-based design of 3D scaffolds for large metabolic tissues: an integrative methodology based on a branching/joining flow channel network and micro-tissue assembly

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In large liver tissue engineering, ensuring good mass transfers of oxygen, nutrients or metabolic wastes between the cells and culture medium or blood is the most fundamental issue, but attentions are not so seriously paid when compared with 3D cellular organization or biological optimizations. To ensure oxygen transfer from micro- to macro-scales, we proposed a mew methodology integrating 3D fabrication-based “Top down approach” giving a special scaffold having a branching/joining flow channel with a small chamber which are further filled with various micro-tissue in a random manner as an ”Bottom-up approach”. On the basis of this concept, we fabricated a special 3D scaffold (culture chamber volume 11.63 cm^3) by selective laser sintering (SLS) process using poly- -caprolactone powders. Perfusion culture of model micro-tissue elements, liver cell aggregates, demonstrated the high possibility of scaling up to a clinically relevant size. We also designed and fabricated Raschig ring-like hollow and macroporous micro-scaffolds (1.1 mm in diameter and 1.5 mm in height) to have better stability of the shapes during culture. Perfusion culture of randomly-packed such micro-scaffolds showed better cell growth and functions with very high cell density of the order of 10^7 cell/cm^3. These integrative improvements in terms of oxygen supply in different scales show a promise to engineer large liver tissues through the integration of different approaches according to the scales.

Emulsion Inks for 3D Printing of High Porosity Materials

Osgriff-Hernandez Elizabeth

Our lab has developed a new solid freeform fabrication (SFF) technology capable of printing curable emulsion inks to print materials with hierarchical porosity. Briefly, an emulsion ink based on a high internal phase emulsion (HIPE) is deposited layer-by-layer using an open source 3D printer equipped with a syringe and motor-actuated plunger. Emulsions inks are rapidly cured after deposition by constant UV irradiation to form rigid constructs with interconnected porosity in a method we term Cure-on-Dispense (CoD) printing, **Figure 1**. 3D printed polyHIPE constructs benefit from the tunable pore structure of emulsion templated materials and the fine control over complex geometries of 3D printing that is not possible with traditional manufacturing techniques. Overall, the demonstrated ability to print porous materials using emulsion inks and CoD technology advance current additive manufacturing efforts to generate custom porous materials for tissue engineering and drug delivery applications.

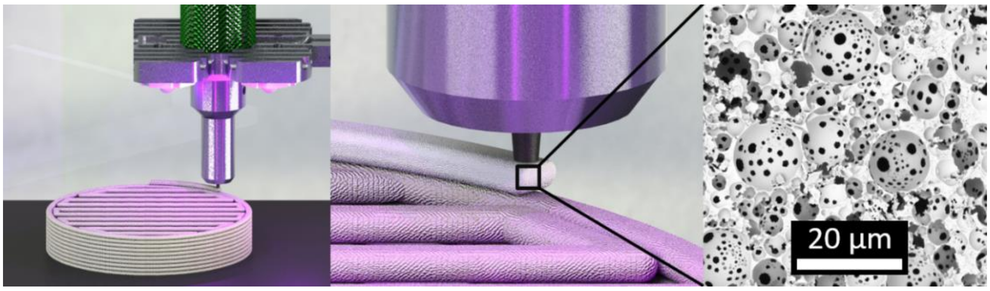

Figure 1. Schematic of UV Cure-on-Dispense (CoD) HIPE printing system

Microengineered hydrogels for tissue fabrication and organ-on-a-chip application

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Tissue engineering holds great promise as an alternative therapy by creating functional tissue constructs that can reestablish the structure and function of injured tissue. However, a major challenge in tissue engineering is recapitulating the *in vitro,* three-dimensional (3D) hierarchical microarchitecture comprised of multiple cell types and the extracellular matrix (ECM) components of native tissues, along with achievement of continuous function and viability of engineered tissues after implantation. Specifically, survival of implanted cell-laden scaffolds is fully dependent on the oxygenation derived by its connection to blood circulation of the host body. The physiological process of angiogenesis is time-consuming, which results in the failure of clinically sized implants due to starvation-induced cell death, especially in thick and large constructs. Therefore, the incorporation of functional vasculature is important for maintaining thick and large complex tissue constructs, particularly in cardiac and skeletal muscle tissues that require highly vascularized networks to support the large metabolically activity in muscle cells. To address these challenges, 3D bioprinting is emerging as a powerful technique for the development of highly organized and complex 3D constructs. Its use offers a versatile means to optimize tissue constructs by providing flexibility in modulating the composition, structure, and architecture of the scaffolds. To achieve *in vivo*-like biological functions in 3D tissue constructs, ECM-based biomaterials are required to mimic biological and physical properties that will enhance the resulting tissue function. We envision that developing hybrid bioinks that are functionalized by growth factors or nanomaterials could be useful in creating more customized and biomimetic 3D-printed tissue constructs for various biomedical applications.

In addition, the engineered 3D tissue constructs can be used for toxicity assays based on organs-on-a-chip platforms, which have become increasingly important for drug discovery. The organs-on-a-chip system allows for the testing of cytotoxic effects of pharmaceutical compounds and nanomaterials on physiologically relevant human tissue models prior to moving forward with expensive animal testing or clinical trials. To successfully establish organs-on-a-chip platforms, it is critically important to continuously monitor the dynamic behaviors of human organ models interacting with drugs *in situ* for an extended period of time. We introduce a fully integrated and automated platform of microfluidic, label-free, resuable, biosensing technology combined with a human organ-on-a-chip system, which jointly allows for long-term and accurate measurements of the concentrations of the biomarkers secreted by both tissues in response to a panel of drugs. When combined with an automated microfluidic system, the electrochemical biosensing chip will demonstrate a built-in capability for regenerating its sensor surface, allowing for continual kinetic studies over extended periods of time. We believe that this novel platform technology may be further extended to a wide variety of applications in academia and pharmaceutics for personalized screenings of drug toxicity, efficacy, and pharmacokinetics in the future.

Design of Conforming Surface for Human Skin at Highly-Stretched Joint Areas with Additive Manufacturing

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In this study, a computational method was proposed to design 2D conforming surfaces for human skin at highly-stretched joint areas during the rotation of the joints between two pieces of bone. Considering the auxetic deformation behavior of the skin around the joint area during joint movement, the designed conforming surface should also have the similar Poisson's ratio (PR) distribution. By mapping unit cells with different PR to the skin

surface, the obtained conforming surface would have the same mechanical property and deformation behavior as the human skin at the joint. With the complexity of such conforming surfaces, additive manufacturing (AM) has to be used for the fabrication. New generation wearable electronics with superior conformability could be developed based on this conforming surface. Besides, the proposed method has the potential to design novel biomaterials, such as smart bandage, skin scaffold, *etc.*

The proposed design method was composed of six steps as shown in **Figure 1**. To start the method, 3D scanning was conducted to get the point cloud data of the skin surface around the joint at two positions: fully-straightened (initial state) and fully-bended (objective state). From the initial state to the objective state, the deformation behavior of the skin can be analyzed. The skin surface was discretized into finite subsurfaces to analyses how the strain and deformation was distributed over the surface area. Next, PR of each subsurface could be computed based on the deformation. Unit cell was selected to achieve tunable PR by manipulating parameters of each unit cell. Considering the relative large deformation, geometrically nonlinear FEA was applied to get the relationship between unit cell's PR and the parameters. With this relationship, unit cells with the various PR values were mapped to cover all subsurfaces. Both computational and experimental tests with 3D printed surfaces were conducted to validate the conformability of the designed conforming surface to the skin surface.

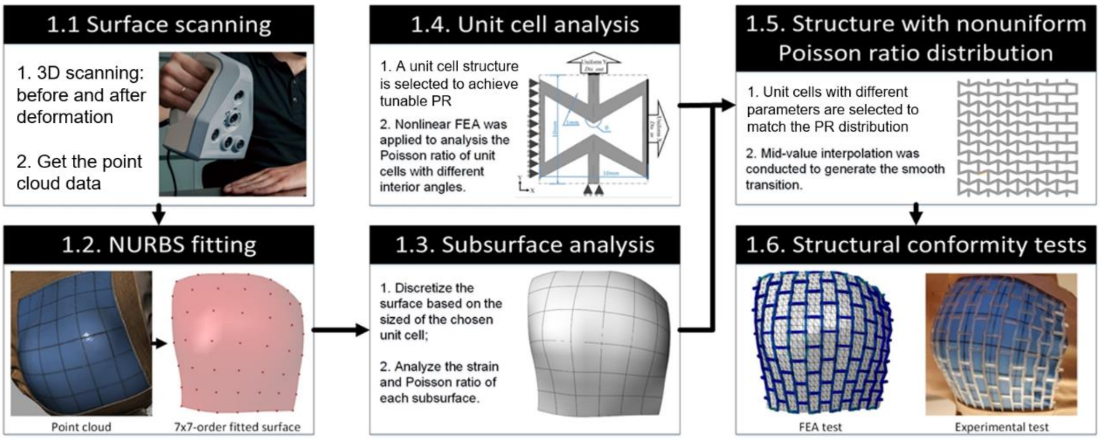

Figure 1. General process of the proposed design method

Investigation of Ink Properties on the Printability and Stability in Electrohydrodynamic Printing System

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Electrohydrodynamic printing (EHDP) is an additive manufacturing process with great potential in fabricating micro- and nano- scale fibrous structure through using highly viscous polymers solution. This work investigates the influence of properties of polycaprolactone (PCL) solution to the formation of the Taylor cone and solidification of fibrous structure. The results give a guide on the development of new ink in the perspective of viscosity and demonstrate printing process with inks of different viscosity. First, the intrinsic viscosities of PCL with different molecular weights were characterized by Ubbelohde viscometer. Then, the printability of these inks was evaluated through analyzing the images of Taylor cones, and scanning electron microscopy (SEM) images of printed fibrous structure. Results show that optimum intrinsic viscosity range of PCL based ink is estimated as 0.7 to 0.9 dL/g. Our findings suggest that scaffolds fabricated by the solution-based EHDP within this intrinsic viscosity range have uniform fibers and rapid solidification during printing process, which provide a standard when preparing the printable materials for EHDP systems.

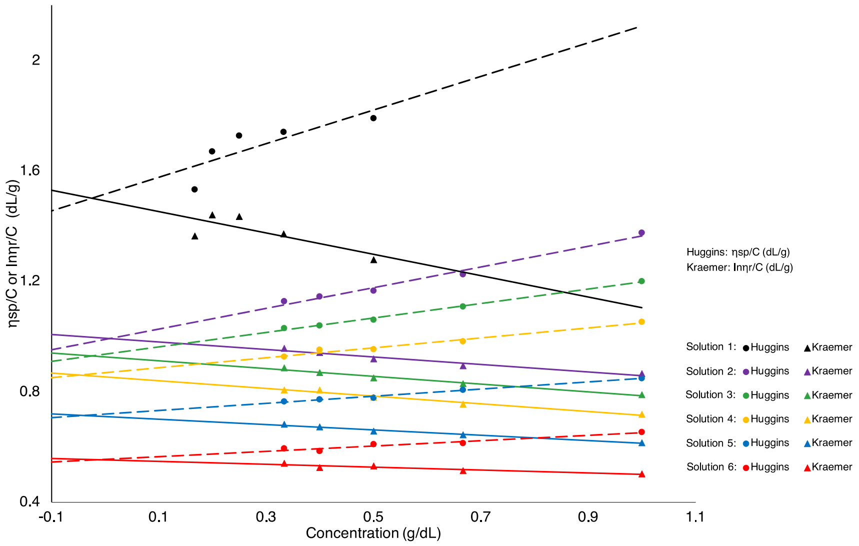

Figure 1. Intrinsic viscosity plot of solutions with different viscosities

Bioinks for 3D Printing Tissue Engineered Vascular Grafts

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3D bioprinting enables developing tissue constructs with heterogeneous compositions and complex structures. It has been adopted for printing multicellular tissues. Bioengineered vascular constructs have gained increased interest as a promising alternative to autologous vessel grafts. 3D printed vascular constructs promise to be a customizable, patient specific alternative but the question of whether to use synthetic or natural materials remains. In this work, we characterized an additive biomanufacturing method that allows the use of a soft biomaterial, fibrinogen, but enhances its printability to be compatible with extrusion bioprinting using a thermosreversible gelatin. With a 3D rotatory bioprinter developed in our lab, we demonstrated the feasibility of on-demand printing tissue engineered vascular grafts. We interrogated a number of biomaterials and developed a blend bioink that possesses essential rheological properties for rotatory bioprinting. We showed that the printed constructs increased in elastic modulus and ultimate tensile strength over time with viable cells observed up to 2 months. Histological analysis revealed increased collagen deposition in 3-week old construct. This study opens a new venue of using favorable biomaterials for biofabricating tissue engineered vascular grafts that possess mechanical and biological properties comparable to small diameter human blood vessels.

Micro-Assembly Exploiting SofT Robotics (MAESTRO)

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There is an urgent need for miniaturized actuators, and their control schemes, capable of accomplishing micro-scale robotic assembly. Due to the difficulty in fabricating nanoscale motors and developing microscale power sources, actuation and control are two significant challenges in micro-scale robotics. We seek to combine microscale cell-like actuators, termed *artificial cells*, and novel swarm control algorithms for micro patterning. Specifically, we use artificial cell actuators, encapsulating targeted materials, which are organized into complex configurations using only global control signals. Our recent project is to develop a new type manufacturing by combining soft robotics and swarm control to construct assemblies (e.g. living cells, inorganic particles) in 2D and 3D. The approach seeks to use the soft robots themselves as building blocks for desired patterns. Their microrobotic artificial cells excel in encapsulating a wide range of micro- and nanosized particles, for example, living cells and magnetic nanoparticles. Furthermore, artificial cells can efficiently release their payloads using external stimuli (e.g. optical). This microrobotic system has been complemented with novel swarm control algorithms using obstacle-based particle computations. This obstacle-based positional control makes the position of microrobots fully controllable using just a single control input. Actuation of the stimuli-responsive artificial cells in microfluidic obstacle-laden environments presents a paradigm shift in fabrication technology.

Effects of Cross-linkers Concentration on the Thermal and Shape Memory Properties of a New Acrylate-based Polymer Printed by Digital Light Processing

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Shape memory polymers (SMPs), a type of promising smart material, are commonly applied into stereolithography apparatus (SLA) to realize 4D printing. However, the influence of different cross-linkers concentration in photosensitive resin on the properties of formed parts is rarely studied. In this research, we present a novel photosensitive acrylate-based shape memory polymer serving as forming raw materials for digital light processing (DLP) that is a kind of UV curing technology equipped with projection light source. The SMPs are amorphous and keep thermally stable when no more than 200℃. DMA tests prove that glass transition temperature (T_g) can be adjusted by changing the concentration of crosslinking agent and decreases with the increment of cross-linker, and the storage modulus reach up to 1484MPa as the cross-linker concentration is 50 wt%. Shape memory cycle tests and fold-deploy experiments were performed to evaluate their shape memory properties. The SMP with 10 wt% cross-linker can withstand 16 consecutive cycles and have extremely high shape recovery ratio of 100% after 14 cycles. The one of 20 wt% cross-linker possesses the best shape fixity ratios of 96.39%±0.92% yet its cycle life declines to 10 cycles. The cycle life of SMPs with high crosslink degree has been improved compared with previous studies. The process of a 180° shape recovery takes only 7~13s, indicating pretty good shape recovery rate. Due to their high storage moduli and excellent shape memory performance, the DLP printed SMPs can be potentially applied into many areas as shape memory materials.

Material Extrusion Additive Manufacturing of Polycaprolactone–Magnesium Composite for Bone Tissue Engineering

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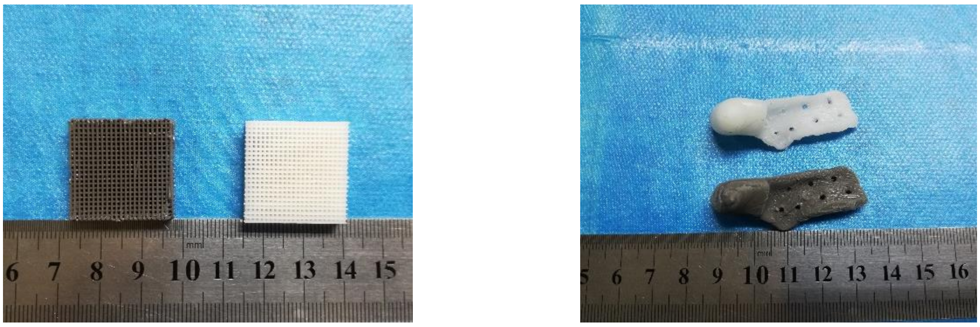
Polycaprolactone (PCL) and magnesium (Mg) both two kinds of materials have a long history in the biomedical application area. PCL and Mg both are biodegradable and bioresorbable as well as PCL is a FDA approved polymer and Mg element mainly exists in the bone system helping bone strengthen and grow. However, the low mechanical strength with intrinsic hydrophobic properties of PCL and the rapid corrosion with hydrogen evolution in the human body fluid of Mg limit their use in bone substitutes. Our group incorporated Mg micro-particles into the PCL matrix after which producing PCL/Mg composite filament for material extrusion. The tensile, bending and compression samples are made to verify the influence of printing perimeters to the mechanical properties of PCL/Mg with a consequence of 60%-80% improving in the flexible modulus which is closing to those of human cancellous bone and 11%-25% improving in the bending strength comparing to the pure PCL. Using the material extrusion technology, we fabricate the bone tissue engineering scaffolds with the pore size of 300μm-500μm and strut size of 600μm which is appropriate to the cell growth and customized dog mandible prosthesis with 20% and 100% infill rate. The PCL/Mg scaffold has a faster degradation time than the pure PCL and released Mg^{2+} is benefit to the cell proliferation and differentiation. The SEM images show a rougher surface morphology in contrast to the pure PCL with Mg micro-particles inserted on the PCL matrix surface indicating that the improvement of hydrophilicity which is contribute to cell attachment and growth.



(a) (b)

Figure 1. (a) PCL/Mg (left) and PCL (right) scaffold and (b) the PCL (top) and PCL/Mg (down) dog mandible prosthesis

The Design and Verification of A FDM 3D Printer with Double Nozzles Working Synchronously

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In order to better utilize the advantage of FDM 3D printer to fabricate parts in multi-variety and small batch, a double-wire extrusion mechanism is designed to improve printing efficiency and reduce manufacturing cost, which consist of a main extruding component and a vice one. Two nozzles on the mechanism can print synchronously, the efficiency of printing same parts is doubled than before. The double-wire extrusion mechanism has two nozzles and only one electric-motor, which works synchronously by synchronous belt transmission. The distance between two nozzles can be adjusted by sliding the vice-extruding component in a horizontal groove, which makes the machining range more flexible. A prototype of FDM 3D printer with double nozzles working synchronously is produced and a series of experiments are carried out by using PLA material. Two samples are fabricated by synchronous printing, which precision is in ±0.2mm. Finally, the design is optimized according to the disadvantage. By adding preloaded spring between heating aluminum block and radiator, the height of the nozzles can be regulated accurately within small range by screwing the heating aluminum block.

Fabrication of Graphite/mullite Composite via Indirect Selective Laser Sintering and Gelcasting Process

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Graphite/mullite composite was successfully fabricated by combining with indirect selective laser sintering and aqueous AM/MBAM gelcasting process, which exhibited both low and adjustable thermal conductivity (0.8~1.1 $W\ m^{-1}\ K^{-1}$) and sufficient compressive strength, and it had broad application in foundry industry. The indirect selective laser sintering process was chosen to prepare graphite scaffold with trimodal pore structure for better interlayer bonding, and then it was filled with fused mullite powder slurry. After post processes involving polymerization, vacuum drying and high temperature sintering, a graphite/mullite composite was obtained. The advantages of graphite and ceramic materials, such as low thermal conductivity, sufficient compressive strength, good thermal shock resistance and so on were fully exploited. The graphite scaffold acted as three dimensional thermal conductive network could be varied and optimized thus resulting in varying thermal conductivity values, and mullite matrix provided sufficient compressive strength.

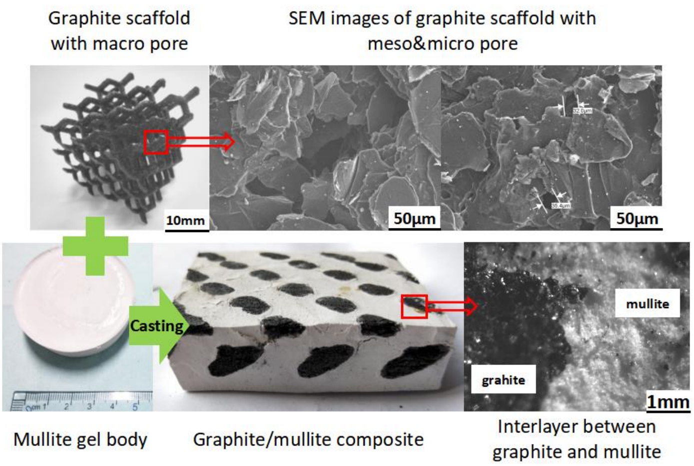

Figure 1. Graphical Abstract of Fabrication and Micrographs of Graphite/mullite Composite

Based on that, the effect of processing parameters and graphite-binder ratio on the pore size of graphite scaffold was investigated, results showed with optimized laser beam energy density (0.15 J/mm^2) and increment of binder/graphite ratio (8:2 to 6:4), the pore size and open porosity increased. In addition, effect of varying solid loading, and sintering temperature on thermal conductivity and compressive strength was investigated as well, the maximal value of thermal conductivity (1.1 $W\ m^{-1}\ K^{-1}$) and compressive strength (10MPa) occurred when solid loading and sintering temperature were at 55 vol.% and 1550°C respectively.

Present works were mainly focused on fabrication processes, further study will focus on effect of varying scaffold structure, post processes of scaffold on interlayer bonding behavior and properties of composite.

Electro-biofabrication to create complex materials systems for emerging life science applications

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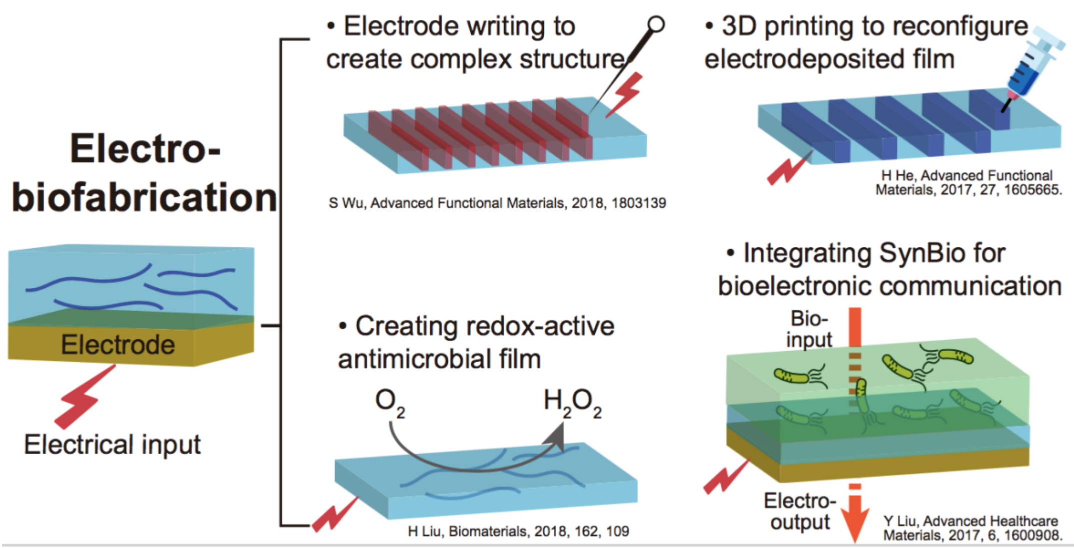
Compared to conventional materials fabrication that focused on shape and strength, biofabrication methods will need to satisfy an entirely new and more subtle set of requirements to meet the needs of emerging life sciences applications. A common emerging fabrication goal is to recapitulate complex biological contexts (e.g., tissue) for applications that range from animal-on-a-chip to regenerative medicine. In these cases, the materials systems will be required to: (i) present appropriate surface functionalities over a hierarchy of length scales (e.g., molecular features that enable cell adhesion and topographical features that guide differentiation); (ii) provide a suite of mechanobiological cues that promote the emergence of native-like tissue form and function; and (iii) organize structure to control cellular ingress and molecular transport to enable the development of a cellular community actively participating in cell-cell signaling. And these requirements will not likely be static but vary over time and space which will require capabilities for the material systems to dynamically respond, adapt, heal and reconfigure. Electrofabrication is an emerging method for hierarchical assembly that provides capabilities that are both unique and complementary to existing biofabrication methods (e.g., lithographic or printing). Specifically, electrofabrication enlists quantitatively controllable electrical signals to promote the migration, alignment, self-assembly and functionalization of material systems. Previous studies have shown that electrofabrication can be coupled with conventional synthetic chemistry and biofabrication methods to confer molecular and mesoscale functions. Increasingly, electrofabrication is being applied to guide the hierarchical assembly of biological materials (e.g., chitosan, alginate, collagen and silk) and this electro-biofabrication enables access to the biotechnology toolbox (e.g., enzymatic-assembly and protein engineering) to offer exquisite control of structure and function. Here, we highlight recent progress from various labs to demonstrate the potential of electro-biofabrication.



Collagen based biomaterials and its application in biopriting

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The collagen family is one of the most abundant groups of proteins as principal protein component of all connective tissues. Due to its vital role in tissue, collagen is regarded as one of the most useful biomaterials, either as native, unmodified tissue grafts or as manufactured products for use in various medical areas. The excellent biocompatibility and safety due to its biological characteristics, such as biodegradability and weak antigenicity, made collagen the primary resource in medical applications. Collagen stability under different conditions is different, based on which, we established a collagen extraction process. Collagen type I and II was prepared with industrial scale. A method for collagen type identification and characterization was developed with marker peptide as an index using HPLC-MS/MS.

Among the existing collagens, collagen type I is the most abundant and also the most important for use as a biomaterial. However, The properties of collagen change with embryonic growth and development, for example, embryonic dermal collagen contains a high proportion of type III collagen but is predominantly type I in the adult, similarly endochondral ossification involves the replacement of type II collagen by type I. Theoretically, preparation of articular cartilage of cell scaffold to be used for articular should use type II as raw materials. Thus, we investigated the difference of cell behaviors on scaffold prepared with type I and II. Cell migration and differentiation is associated with ECM formation and degradation. The interaction between collagen and fibronectin, further with integrin play vital role in regulating cell behaviors. Thus, collagen and acellular matrix were used as matrix for bio printing. The protein map were profiled using proteomic method.

Acknowledgement: this research was supported by National key research and development program (2018YFA0108202, 2018YFC110147) and Guangdong Sci-Tech Program project (201803010086).

Design considerations of high temperature FDM technology for PEEK materials

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With favorable biological properties, polyether-ether-ketone (PEEK) material has been widely used as artificial bone in the field of medical transplantation. Due to its adaptability and individuation, additive manufacturing (AM) is one of the best chooses for artificial bone molding. The main difficulty of peek material AM process lies in the internal stress of the formed parts caused by the large temperature change during the forming process. Herein, we describe several design improvements over regular fused deposition modeling (FDM) that take into account the high melting temperature and large thermal expansion coefficients of PEEK materials. It was found that the performance of formed PEEK parts can be improved by augmenting the nozzle with a heat collector module, which significantly improves the interlayer bonding of PEEK polymer. To tackle the high thermal expansion of PEEK materials, a two-degree-of-freedom platform was specially designed to mitigate the expansion deformation of the bottom plate caused by the high temperature forming environment. The newly designed FDM equipment was capable of forming complex PEEK parts with improved mechanical properties. Our mechanical experiments show that PEEK's average warpage rate reduces from 20.1% to 6.10%, while the tensile modules increased by 10%.

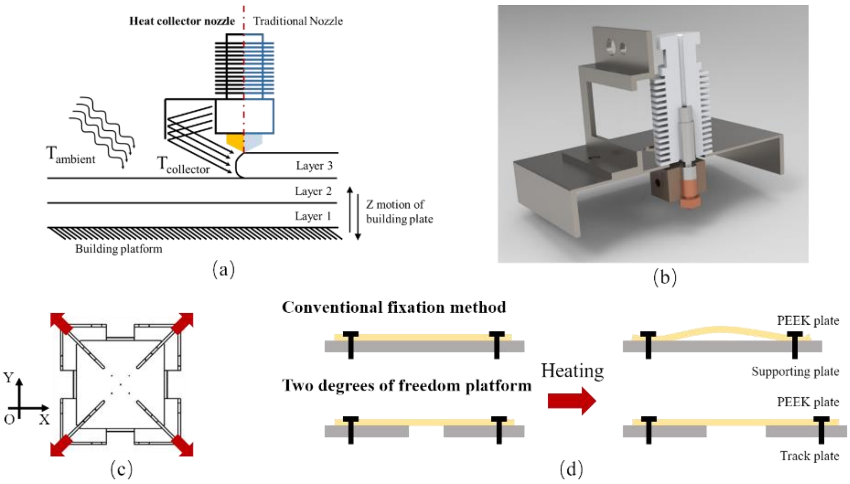

Figure 1. The design of printing, (a) Schematic diagram of temperature influence factors via forming new with equipment, (b) Three-dimensional virtual half-section diagram of heat collector nozzle, (**c**) is the top view of two degrees of freedom platform (**d**) show the different phenomenon of conventional fixation method and new design platform.

References

[1] 史长春, 胡镔, 陈定方, 陈蓉, 单斌. 聚醚醚酮 3D 打印成型工艺的仿真和实验研究[J]. 中国机械工程, 2017.

High-porosity Mullite Ceramics with Enhanced Properties Prepared by Selective Laser Sintering using Fly Ash Hollow Spheres as Raw Materials

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Ceramic components are expected to be widely used in various fields due to their excellent properties, including high strength, high-temperature capability and corrosion resistance, etc. However, there are some restrictions in preparing ceramic components with complex structures by traditional manufacturing methods. Additive manufacturing has shown great advantages in fabricating ceramic components of high geometrical design freedom and structure complexity without molds. Nevertheless, there are still many issues in the preparation of ceramic components via additive manufacturing. In this respect, lots of related researches on additive manufacturing of different kinds of ceramics have been successfully done by Prof. Yu-Sheng Shi's group in Huazhong University of Science and Technology. Firstly, the present research status of ceramic parts fabricated by additive manufacturing is systematically introduced, such as selective laser sintering (SLS), selective laser melting (SLM), fused deposition modeling (FDM), laminated objected manufacturing (LOM) and stereo-lithography apparatus (SLA), etc. Secondly, our recent research works on additive manufacturing of porous/dense ceramic components and related manufacturing equipments are introduced. Finally, the applications and challenges for additive manufacturing of ceramics are elaborated. The preparation of high-performance ceramic components by additive manufacturing shows promising application in the fields of aerospace, marine equipment, biomedical and electronics industries, etc.

Recent Development in Additive Manufacturing for Drug Delivery and Testing

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Additive manufacturing (AM) emerges as a rapid prototyping technology and has gained its popularity recently due to its simple concept and various applications. In pharmaceutical applications, it can be used to develop drug delivery and testing systems. The US FDA approval of first 3D printed tablet in 2015 has ignited growing interest in 3D printing for pharmaceutical applications. Beyond just a novel method for rapid prototyping, 3D printing provides advantages over traditional manufacturing. These advantages include the ability to fabricate complex geometries to achieve variable drug release kinetics and personalising pharmacotherapy for patients. Furthermore, 3DP allows fabrication of complex and micron-sized tissue scaffolds and models for drug testing systems.

New Process for Customized Patient-Specific Aortic Stent Graft using the Additive Manufacturing Technique

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Endovascular aneurysm repair (EVAR) has been widely used as an effective means for the treatment of descending aortic disease. However, the majority of the existing coating stents are of a standard design, which may be unable to meet the size or structural requirements of different patients. Therefore, using 3D printing and controlled deposition, a customized patient-specific aortic stent graft manufacturing technique is proposed in this paper. This project adopts the rapid prototyping sacrificial core–coating forming (RPSC-CF) technique; the aortic stent graft consists of a film and metallic stent. Polyether polyurethane (PU) and nickel-titanium (Ni-Ti) alloys were chosen due to their shape memory ability and good biocompatibility properties. The results show that the customized stent grafts can meet the demands of personalized therapy, and they demonstrate good performance in the blasting pressure test and radial support force test. The stent graft meets the requirements for invasive surgery, laying the foundation for precise aortic dissection treatment.

Key words: 3D Printing, Personalized Aortic Stent Graft, Aortic Dissection, RPSC-CF technique

References

[1] Daniele P, Emanuele F, Andrea V, et al. Abdominal aortic endograft collapse due to false lumen radial force of an acute type B aortic dissection.[J]. Annals of Vascular Surgery, 2014, 28(8):1931.e9-1931.e12.

[2] Demanget N, Duprey A, Badel P, et al. Finite element analysis of the mechanical performances of 8 marketed aortic stent-grafts[J]. Journal of Endovascular Therapy, 2013, 20(4):523-535.

[3] Van Lith R, Baker E, Ware H, et al. 3D-Printing Strong High-Resolution Antioxidant Bioresorbable Vascular Stents[J]. Advanced Materials Technologies, 2017, 1(9):1600138.

[4] Lee V K, Kim D Y, Ngo H, et al. Creating perfused functional vascular channels using 3D bio-printing technology.[J]. Biomaterials, 2014, 35(28):8092-8102.

[5] Zhang, L., Fabrication and fundamental research of multi-branched blood vessel scaffolds with multi-layered wall. 2006, Tsinghua University.

Biomimetic anti-slipping surface design of surgical instrument

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Prevention of soft tissue injury is very necessary for surgery, especially minimally invasive surgery. Clipper or scalpel, in general, is hold tightly to prevent slipping of soft tissue, which usually leads to tissue injury. Several researches have demonstrated that surface micro-pattern have great impact on their functions such as anti-slipping and anti-adhesion. How to design and fabricate upon surgical instrument is gradually becoming an important research topics. Nature surface has been evolved to hierarchical structures with superior function, which is regarded as treasure vault for inspiration of biomimetic surface. In this paper, we investigated the anti-adhesion and anti-slipping of Nepenthes mirabilis and pad of tree frog on basis of SEM images, and unveiled the structural effect on their surface function. Especially, the unique microscale fluid behaviour was discovered by investigation on the bio-inspired surface structure. Apart from the design of biomimetic surface, their fabrication of complicated surface structure of surgical instrument was exploited and their efficiency was validated by performing experiments of soft tissue.

Medicine and bioengineering integration to solve clinical problems—the story of the combination of bio-manufacturing and orthopedic biomaterials

Quanyi Guo

Throughout the reality of the rapid development of medicine at home and abroad, we can clearly see that most of the laws are lying in the fruits of the integration of medicine and bioengineering. The concept of integrating medicine and bioengineering often appears in the cross-disciplinary field of medicine and bioengineering. It has also become the theme of many medical academic conferences, bio-manufacturing forums, and medicine and bioengineering transformation seminars. Unfortunately, this concept is very difficult to apply to clinical practice as we don't know where to start it.

The topic of “Medicine and bioengineering integration to solve clinical problems—the story of the integration of bio-manufacturing and orthopedic biomaterials” reveals the clinical problems of the treatment of common diseases osteoarthritis in the Institute of Orthopedics, Chinese PLA General Hospital. It also shows that the cooperation methods and results in artificial joints, articular cartilage damage and meniscus repair are combined through the integration of medicine and bioengineering under different conditions and levels of science and technology.

The PLA General Hospital is one of the earliest research institutions to develop artificial joints. In the 1970s, artificial joints such as knees, hips, and shoulders were developed in China through the integration of medicine and bioengineering. It improved life quality of many patients with severe osteoarthritis during its clinical application. However, with the clinical application of artificial joints, it could be found that young patients’ artificial joints are prone to loosening after joint replacements. Therefore, the research team carried out research on cartilage tissue engineering in the 1990s. Through the medical background researchers selecting materials and the engineering background researchers assisting in the preparation, the construction of the leading cartilage tissue engineering stent at home and abroad, applied to the clinical solution to the repair problems of articular cartilage injury in young patients. In the aspect of joint meniscus injury, the 3D printed tissue engineering meniscus for the meniscus regeneration has also made a great breakthrough.

[Team members’ introduction]

The Department of Orthopedics of the PLA General Hospital was established in 1953 and the Institute of Orthopedics of the PLA General Hospital was established in 1995. The Institute of Orthopedics is dedicated to the diagnosis and treatment of orthopedic diseases under the leadership of Lu Shibi-- member of the Chinese Academy of Engineering. In the development of nearly sixty years, it has achieved the following honors: "Top Priority" unit of the military and PLA Key Laboratory in 2001; National Key Disciplines in 2002; Department of Orthopedics in

PLA General Hospital in 2007; National Army Key Laboratory of Orthopedic Trauma in 2010; Beijing Key Laboratory of Orthopedics Regenerative Medicine in 2012. The total property of its instruments and equipment is 21 million yuan. The Orthopedics Institute covers an area of 2,000 m^2 and has a ward where a new clinical technology can be applied in. Its research fields lie in the research and development of repair materials and therapeutic techniques such as stem cells, bones, nerves, tendons, cartilage and meniscus.

Additive Manufacturing of ultralow modulus, biocompatible Ti-Nb-Ta-Zr alloy with controllable porosity & Young's modulus

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Mismatch in Young's modulus between implant and human bone easily leads to the so-called stress shielding effect, which may result in the failure of implantation. Lower modulus, biomedical materials like β-Ti alloys are therefore being widely pursed. Additive manufacturing such as Selective Laser Melting (SLM) is rapidly developing which is capable to directly fabricate metallic materials into desirable morpholo-gy/structure and therebya potent approach to solving the issue. To manufacture bio-medical Ti-30Nb-5Ta-3Zr (TNTZ) with proper Young's modulus which meets re-quirements on implant's mechanical properties and bioactivity and, simultaneous-ly,avoids the so-called stress-shielding effect, SLM has been employed in this detailed study. We have examined the effects of various cellular lattice structures/architectures created by SLM on the Young's modulus and biocompatibility. Conclusions are made as follows: (a) The highest density (99.3 %) as-printed samples were prepared using a laser power of 230 W and a scanning speed of 800 mm/s. After 600 ℃ ×4 h stress relief annealing, acicular martensite (average size ~ 0.8 μm) is retained in the micro-structure; (b) The elastic modulus, tensile strength and fatigue strength of the lattice structures manufactured in this work can reach ~2.14 GPa, ~170 MPa and, ~18.3 MPa, respectively; (c) Based on the Gibson–Ashby model and the experimental results of this work, the relationships among porosity, modulus and yield strength of the TNTZ lattice structures with BCC archetecture are developed, which can bemanipulate the Young's modulus of the TNTZ alloy and similar materials as well;; (d) In the bio-compatibility tests, all lattice samples exhibit no cell cytotoxicity, measured by the Relative Growth Rate (RGR) value.

Keywords: Selective Laser Melting, Ti-Nb-Ta-Zr, Biocompatibility, Young's modulus, Microstructure.

An image-guided technique for intra-scaffold cell printing

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To create thick and heterogeneous scaffold-based tissue structures, deep and precise multi-cellular deposition is required. Traditional seeding strategies lack ability to create multi-cellular scaffold-based tissue structures with high cell penetration and cell distribution, whilst emerging strategies aim to simultaneously combine cell-laden tissue segments with scaffold fabrication. We describe a technique that allows for 3D intra-scaffold bioassembly using direct cell deposition. Scaffolds are first fabricated and treated separately, followed by cells being accurately populated within the scaffold using an image-guided technique. This two-step process yields less limitation to scaffold material choice, additional treatments, allows for deeper and easier cell seeding, as well as less potential harm to cells.

A camera system and image processing algorithm was used with existing heterogeneous printing platforms. Parts of the algorithm involve grayscale transformation, threshold segmentation, and boundary extraction processes to accurately locate the pore centroids of the scaffold. Coupled with a camera calibration algorithm, suitable and accurate print path plans are designed. Technique precision was demonstrated using collagen-coated PLGA scaffolds of varying pore shape and diameter size (≥230μm) together with NIH3T3 cell-laden hydrogels. LIVE/DEAD and PrestoBlue® analysis showed high cell viability (>92%) and cell proliferation over seven culture days. The technology provides a precise method to aid cell deposition with variant depth of simple and complex 3D scaffold-based constructs using multi-nozzle platforms with multiple bio-inks. Since the technique can be used with any existing printing platform, it shows potential and capability to facilitate direct spatial organization and hierarchal 3D assembly of cells and/or drugs for both further research and clinical study.

Keywords: intra-scaffold cell printing; image-guided cell printing; bioassembly; heterogeneous cell seeding; image processing

Implantable cervix uterus with protein sustained release functionality by 3D printing

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Cervical cancer is the fourth most common cancer (528 000 new cases) and the fourth most common cause of cancer death (266 000 deaths) in women worldwide, as estimated in 2012. Traditional treatment of cervical conization leads to partial tissue defect in the cervix with significant pain points, and increases the risk of reproductive tract infection. What's worse is leading to miscarriage and premature rupture of membranes. In view of the current situation of the worldwide cervical disease and the unrepair of damaged organs, we aim at the development of an implantable cervix uterus with drug-laden based on 3D printing technology.

This cervix uterus was designed as a cone-shaped scaffold according to the conization tissue (3000 μm in bottom diameter; 1500 μm in height). Polyurethane(PU) was selected as the raw material for fabrication using low-temperature deposition manufacturing (LDM). As followed by freeze drying process, multilevel pores were obtained in the fabricated structure and further applied to drug loading. Anti-HPV protein was loaded onto the porous scaffold through negative pressure. The biocompatibility, structural stability and protein release of the 3D printed PU-based structure was analyzed.

The results showed that the cervix constructs with three hieratical pore distribution were successfully engineered by LDM technology and freeze drying process. Loading anti-HPV protein was achieved in the constructs via those hieratical pores. The 3D printed cervix constructs were expected to function as accurate, structured and tailored tissue elements as well as controlled-release drug delivery systems towards individual treatment.

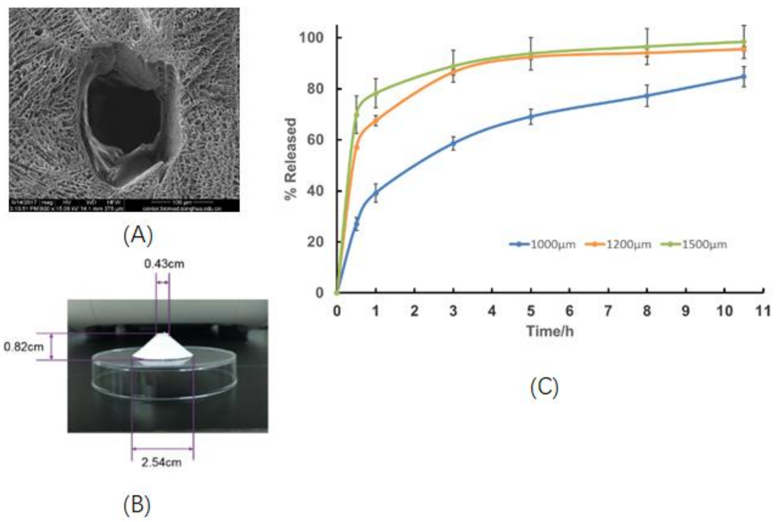

Fig. 1 A. SEM view; B. LDM printed porous construct; C Release of protein

Preparation and Properties of Biopiezoelectric Coatings Prepared by RF Magnetron Technology

Zhongyu Zhang

In order to make the bone tissue engineering scaffold have bone repair function and simulate the bioelectrical phenomenon in human body, a barium titanate-hydroxyapatite bio-piezoelectric coating was prepared on the surface of the bone tissue engineering scaffold. Hydroxyapatite, polyvinyl alcohol and graphene oxide composite bio-bone tissue engineering scaffolds were prepared by self-designed mechanical extrusion device. The barium titanate-hydroxyapatite bio-piezoelectric coating was obtained on the surface of the stent by RF magnetron technology. The morphology and composition of the coating surface were characterized by electron microscopy and energy spectrum analyzer. Cell culture experiments were carried out to evaluate the cytotoxicity. The results show that the hydroxyapatite-barium titanate composite coating with certain adhesion strength can be prepared by magnetron sputtering, and the bio-induced activity of hydroxyapatite can be improved by the piezoelectric effect of piezoelectric ceramics for further development. It provides a reference for further development of high performance bioactive materials.

Multiscale Mechanobiology and Engineered Construction in Liver Sinusoids

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Liver sinusoid consists of multiple types of cells including liver sinusoid endothelial cells (LSECs), Kuppfer cells (KCs), hepatic stellate cells (HSCs), and hepatocytes (HCs), together with blood flow in main stream and interstitial flow in Disse gap. Reconstruction of liver sinusoids is critical for understanding the mechano-biological coupling between residing hepatic cells and flowing leukocytes or tumor cells, as well as for applying these modules in drug screening or bioartificial liver supporting system.

Here we developed an *in vitro* 3D model to recapitulate key features of liver sinusoids and to elucidate the roles of cellular interactions and shear flow in liver-specific PMN recruitment and LSEC fenestrae regulation. Two microfabricated polydimethylsiloxane (PDMS) layers were bonded together, forming two fluidic channels separated by a permeable polyethylene (PE) membrane to mimic a liver sinusoid with an endothelium separating microvenule and Disse Space. To replicate the physiological structure and cellular composition, LSEC monolayer with sparsely distributed KCs and HSCs was integrated on either side of extracellular matrix (ECM)-coated PE membrane and HC monolayer was immobilized in lower compartment. Typical liver specific functions and multi-typed cell interplay in protein secretion, drug metabolism and immune responses were analyzed. Data indicated that shear flow fostered albumin secretion for HCs alone or even higher when co-culturing with nonparenchymal cells, implying that co-culture and shear flow could work cooperatively. Shear flow enhanced dramatically CYP1A2 activity when HCs were cultured alone or co-cultured with NPCs. Co-culture of LSECs with respective HSCs, KCs, or HCs, or with all cell types increased PMN accumulation, implying that each type of hepatic cells may contribute to PMN recruitment differently. Thus, this 3D microfluidic device can replicate the key architecture of liver sinusoids by integrating four major types of cells into two separated flow channels, serving as a potential platform to investigate hepatic cellular interplay, cytotoxic metabolism, and inflammatory cascade under physiologically-like microenvironment.

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Organization of liver organoid using Raschig ring-like micro-scaffolds and triple co-culture toward modular assembly-based scalable liver tissue engineering

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Addressing the remaining issues of fragile structure and insufficient mass transfer in modular assembly-based tissue engineering, a Raschig ring-like micro-scaffold was proposed and fabricated using poly-ε-caprolactone with 60% porosity and 11.4 mm^2 efficient surface area for cell loading. By investigation on the inoculation process, the extracellular matrix was found necessary to establish the hierarchical co-culture of Hep G2 and endothelial cells, and the triple co-culture with fibroblast (Swiss 3T3 cells) were recognized most efficient for attempting to higher cell attachment, proliferation and hepatic function. The equipped intersecting hollow channels in the micro-scaffold functioned as flow paths after randomly packed into a bioreactor for perfusion culture. The hollow structure promoted the mass transfer to the immobilized cells, as turned out the advanced albumin production and well maintained cellular viability. *In vivo*-comparable cell density was obtained in the perfused construct with

well-preserved rigid structure, which suggested the great potential of current micro-scaffolds as modular tissues towards scaling up in the organization of liver organoid.

Fabrication of PLA Scaffolds with Photo-active Controlled Properties by 3D Fiber Deposition

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An ideal behavior of the tissue engineering scaffold is that it degrades and reshapes at a rate that matches the formation of new tissues. However, this idea situation may not occur in real applications. Therefore, how to actively control the properties of the scaffolds during tissue growth is highly desired. In our previous study, to test the promise of the active control of scaffold degradation, a photo/water dual-degradable porous scaffold was designed and fabricated using a 3D fiber deposition system from a linear biopolymer (named PLANB) that combined the o-nitrobenzyl linkages and hydrolysable ester bone in the polymer chains [1]. During degradation process, the SEM image and the mass loss profile demonstrated a porous-void microstructure along the strands of scaffolds and an apparent increase of the mass loss amount compared with the control group without photo-irradiation. The results demonstrated such scaffolds have great potential in offering a diverse range of control over degradation kinetics of tissue engineering scaffolds.

To further demonstrate the practicability of photo-active control, in this work, PLANB was printed by mixing with PLLA in molten state. Figure 1 indicates the crystallinity of PLANB, PLLA and the mixture, which can guide the printing parameters setting. Figure 2 shows the SEM image of mix-printing of PLANB and PLLA with the weight ratio of 5:1. The mix-printing requires a small difference between the flowability of the mixed polymers at the printing temperature. Otherwise, the extrusion of melted polymers will be ununiform and lead to the failure of mixture printing. Although the strands here are not as smooth as the PLANB scaffold, it shows the possibility of scaffolds printing by mixing PLANB with other mixable polyesters. The morphology of the mix-printed scaffold could be improved by carefully selection of printing parameters. This study enables various possibilities for the construction of PLANB-based scaffolds according to application requirements.

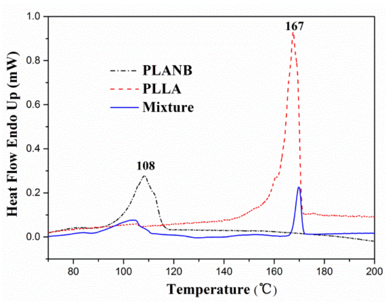

Figure 1. DSC curves of PLANB, PLLA and their 5:1 mixture.

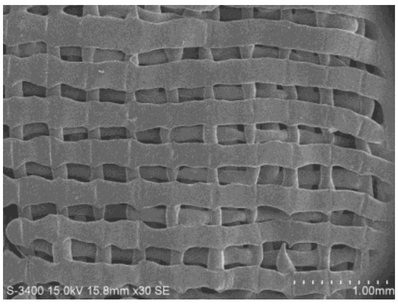

Figure 2. SEM image of mix-printing scaffold made by PLANB and PLLA.

Reference

[1] Ruixue Yin* et al., Journal of Materials Chemistry B, 2017, 5, 329-340.

Biofarbication of Complex Multilayered Tubular Hydrogels Using Diffusion-induced Gelation and 3D Printing

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Multilayer hydrogels are useful to achieve stepwise and heterogeneous control over the organization of biomedical materials and cells. There are numerous challenges in the development of fabrication approaches towards this, including the need for mild processing conditions that maintain the integrity of embedded compounds and the versatility in processing to introduce desired complexity. Here, we report a method to fabricate heterogeneous multilayered hydrogels sequentially based on diffusion-induced gelation. This technique uses the quick diffusion of ions and small molecules (i.e., photoinitiators) through gel-sol or gel-gel interfaces to produce hydrogel layers. Specifically, ionically (e.g. alginate-based) and covalently (e.g. GelMA-based) photocrosslinked hydrogels are generated in converse directions from the same interface. The multilayer (e.g. seven layers) ionic hydrogels could be formed within seconds to minutes with thicknesses ranging from tens to hundreds of micrometers. The thicknesses of the covalent hydrogels are also greatly determined by the reaction time (or the molecule diffusion time). Multiwalled tubular structures (e.g. mimicking branched multiwalled vessels) are mainly investigated in this study based on a removable gel core, but this method can be generalized to other material patterns. The process is also demonstrated to support the encapsulation of viable cells and is compatible with a range of thermally reversible core materials (e.g., gelatin and Pluronic F127) and covalently crosslinked formulations (e.g., GelMA and MeHA). This biofabrication process enhances our ability to fabricate a range of structures that are useful for biomedical applications.

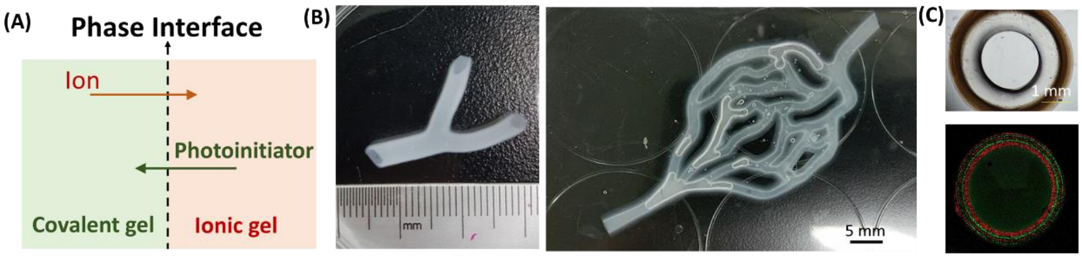

Figure 1. (A) Schematic of diffusion-induced gelation process for ionic and photo-crosslinkable hydrogels. (B) Representative tubular structure based on custom 3D printed mould. (C) Cross-section of multilayered heterogenous tubular structures.

Reference

[1] Ouyang L, Burdick JA, Sun W. ACS Appl Mater Interfaces. 2018, 10(15):12424-12430.

3D bio-printer with special add-on extruder compatible with FFF (Fused Filament Fabrication) based 3D Printers, with extensive software platform for soft tissue engineering applications

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The development of first 3D printing happened in 1983 with the promise of revolutionizing the rapid prototyping industry. Along the years this technique has garnered a huge attention of researchers from all over the world. Based on the fundamentals of 3D Printing over the time 3D Bioprinting emerged with the capability of revolutionizing the entire medical industry. It has the potential to facilitate organ transplantation, drug testing and repair of damaged skins, bones or cartilage. But the real challenge apart from the delicacy of this process is that a large number of 3D Bioprinters available in the market are not affordable for researchers, life science companies and innovators who work with bioprinting industry. Not only this, the limitation of currently available 3D Bioprinter is that most of them are for tissue engineering of hard structures like bone and cartilage and a few for limited lab-on-chip experiments. Apart from this, the conventional pneumatic based 3D printer also poses a challenge of perfect control over the Bioink extrusion. In this paper, keeping above challenges into consideration, authors leading an engineering team have developed a 3D Bioprinter in their lab which has affordability and just perfect controllability over extrusion. Equipped with Artificial Intelligence and Image processing this 3D Bioprinter solves fundamental problems researchers face using this technology. This Bioprinter uses a stepper motor and a complex version of the "rack and pinion" mechanism instead of the conventional pneumatic extruder. It provides perfect control over the volumetric flow rate of Bioink through the extruder along with retraction settings. It works on one of the most used technology in the commercial 3D printing i.e Fused Filament Fabrication (FFF). Although the material properties of 3D Bioprinting and FFF are different they both have similar fundamental dynamics which provides us with an edge on building well-developed algorithms.

Keywords: 3D Bioprinting, FFF, Motor Extruder, Algorithms, Software, Artificial Intelligence, Image Processing

Choice of bioinks: synthetic or natural materials or combination

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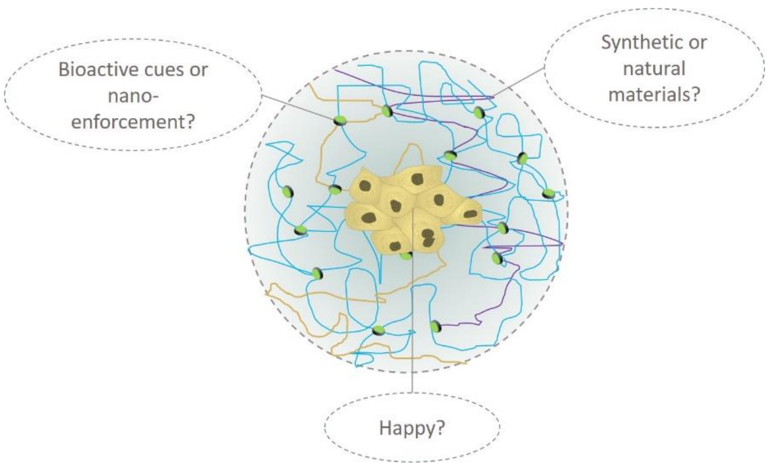
3D bioprinting has provided particular cellularized constructs for human tissues regeneration. This technology enables the process flexibility, versatility and all-in-one manufacturing through the design of smart and advanced biomaterials and proper polymerization techniques [1]. An ideal bioink should possess proper mechanical, rheological, and biological properties of the target tissues, which are critical to ensure correct functionalities. Therefore, it heavily relies on biomaterials for structural support and sites for attachment of biological and mechanical cues of the laboratory-engineered tissue constructs and organs.

Hydrogels are the most adequate candidates of biomaterials because they have many similar features of the natural extracellular matrix and could also provide a highly hydrated environment for cell proliferation. However, the vast majority of bioinks present limitations in the printing of chemically defined 3D constructs with controllable biophysical and biochemical properties. In this field of bio-fabrication, particularly in bioprinting, the lack of suitable hydrogels remains a major challenge [2]. Thus, choosing appropriate hydrogels for bioprinting is the key to print self-supporting 3D constructs.



Hydrogels in tissue engineering are classified into two groups: naturally-derived hydrogels such as gelatin, fibrin, collagen, chitosan, and alginate and synthetically-derived hydrogels such as Pluronic® or polyethylene glycol (PEG) [3]. Naturally-derived hydrogels generally possess inherent signaling molecules for cell adhesion, while synthetically-derived hydrogels stand with bioprintability and mechanical support for shape maintenance and load bearing.

A comprehensive of understanding of pros & cons gives you the best choice of your bioink for your particular tissue applications.

Reference:
[1] Jinah Jang a, 1, Ju Young Park b, 1, Ge Gao b, Dong-Woo Cho b*, Biomaterials 156 (2018) 88e106
[2] Huijun Li, Cavin Tan, Lin Li, Materials and Design 159 (2018) 20–38
[3] Monika Hospodiuk a,b, Madhuri Dey b,c, Donna Sosnoski a,b, Ibrahim T. Ozbolat a,b,d,e,*, Biotechnology Advances 35 (2017) 217–239

Biomimetic design and fabrication of pre-vascularized myocardial tissue

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Cardiovascular diseases, as well as some exogenous drugs, may both cause a variety of complex pathophysiological damages to the cardiovascular system, resulting in cardiac function changes or myocardial infarction, further impairing the health and lives of patients. Due to the high metabolic demand and beating behavior of native myocardium, the ability to fabricate three-dimensional (3D) vascularized myocardial tissue that leads to further angiogenesis and cardiac tissue level function could enable scientific and technological advances in different biological and clinical applications, such as tissue engineering, regenerative medicine, drug toxicity, and drug screening studies.

In this study, we will report our newly developed approaches for the design and fabrication of pre-vascularized myocardial tissue with indirect and direct 3D printing techniques. In the indirect technique, scaffolds with oriented microporous structure and built-in vascular-like channel network were fabricated, by freezing the hydrogel - that embedded a 3D printed sacrificial vascular template - with unidirectional temperature field, and then dissolving the template after freeze-drying and crosslinking. In the direct technique, cells/hydrogel inks were directly extruded through a coaxial nozzle to form hollow hydrogel fibers containing double-layer-cell types. After perfusion of HUVEC cells within the channel network with a customized bioreactor, the results demonstrated that endothelial cells attached well to the channels walls and confluent elongated within the channels, and cardiac myocytes had a high viability and showed specific connection within the pre-vascularized structure.

This research developed a reproducible platform for fabricating thick pre-vascularized myocardial tissue and had the potential for further applications in both fundamental biological studies and translational research. Challenges, opportunities and future trend of the techniques will also be discussed.

Keywords: myocardial tissue engineering, pre-vascularization, 3D printing, biomaterials,

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Gyroid cellular structures used in biomedical application: Mathematical design, additive manufacturing and mechanical properties

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Materials used for hard tissue replacement should match the elastic properties of human bone tissue. Therefore, cellular structures are more favourable for the use of implants than solid materials for their custom-designed

mechanical properties. In this work, a mathematical method used to generate Gyroid cellular structures with different volume fraction and gradient counter maps. The mechanical response of these structures under compressive loads was investigated throughout experimental, finite element and analytical methods. The relationship between Young's modulus and volume fraction, gradient effect, as well as the orientation dependence of the mechanical responses for GCS loaded in various orientations were discussed. Novel deformation properties of the Graded cellular structure with enhanced stiffness and strength were acquired by optimizing density distribution. Further investigation shows that the mechanical properties of graded cellular structures can be customized by optimizing the different proportion of each layer. These significant findings illustrate the high application prospect of Gyroid cellular structures in the biomedical application.

A rapid Micro-MRI nerve scanning method for three-dimensional reconstruction of peripheral nerve fascicles

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The most common methods for three-dimensional reconstruction of peripheral nerve fascicles include histological and radiology techniques. Histological techniques have many drawbacks including an enormous manual workload and poor image registration. Micro-MRI, an emerging radiology technique, has been used to report results in the brain, liver and tumor tissues; however, Micro-MRI usage for obtaining intraneural structures has not been reported. The aim of this study is to present a new imaging method for 3D reconstruction of peripheral nerve fascicles by 1T Micro-MRI. Freshly harvested nerve samples from an amputated limb were divided into 4 groups. Two different scanning conditions (Mannerist Solution/GD-DTPA contrast agent, distilled water) were selected, and both T1 and T2 phases were programmed for each scanning condition. Three clinical surgeons evaluated the quality of the images via a standardized scale. Moreover, to analyze the deformation of the 2D image, we compared the nerve diameter and total area of the Micro-MRI images with the histological images. The results show that the rapid Micro-MRI imaging method can be used for 3D reconstruction of the fascicle structure. Moreover, the nerve sample is scanned freshly and can be recycled for other procedures. MRI images show good stability and smaller deformation compared to histological images. In conclusion, Micro-MRI provides a feasible and rapid method for three-dimensional reconstruction of peripheral nerve fascicles, which may improve our understanding of neurobiological principles and guide accurate nerve transposition repair.

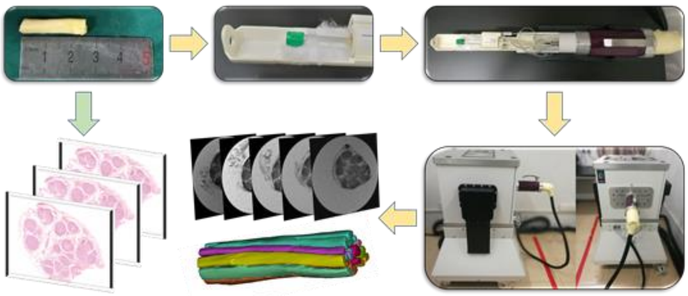

Fig. 1 Schematic views of our Rapid Micro-MRI nerve scanning method used for three-dimensional reconstruction of peripheral nerve fascicles.

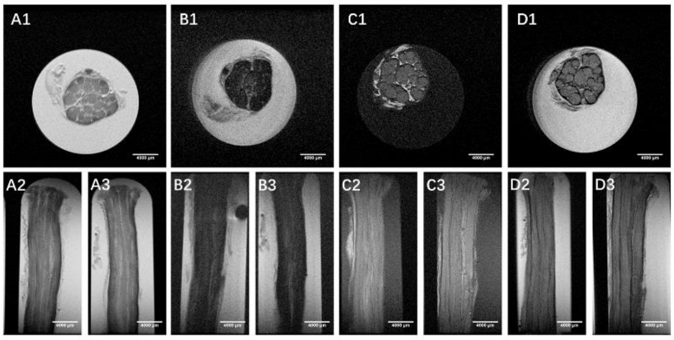

Fig. 2 Micro-MRI scanning images. A group: The nerve sample was immersed in contrast agent (Mannerist Solution) and scanned T1 phase. B group: The nerve sample was immersed in contrast agent (Mannerist Solution) and scanned T2 phase. C group: The nerve sample was immersed in distilled water and scanned T1 phase. D group: The nerve sample was immersed in distilled water and scanned T2 phase. A1, B1, C1, D1: Axial images, A2, B2, C2, D2: Sagittal images, A3, B3, C3, D3: Coronal images.

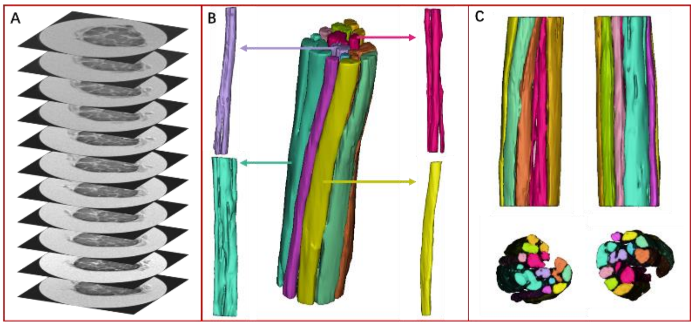

Fig. 3 Three-dimensional reconstruction of peripheral nerve fascicles based on micro-MRI scanning images. A: Original micro-MRI scanning image (T1 phase images of nerve sample Immersed in contrast agent). B: Overall view of the nerve fascicles reconstruction model, every single fascicle can be observed and analyzed independently, clearly showing the morphology, aggregation, distribution. The arrows show the 4 different types of fascicular topography. C: The reconstructed fascicular model presented from different angles (left, right, top, and bottom).

The specificity of motor and sensory nerve architecture in nerve tissue engineering scaffold designing-Histological assessment and three-dimensional reconstruction visualization of the motor and sensory pathways in femoral nerve.

Shuai Qiu

In the successful peripheral nervous system regeneration, beside of the ideal graft of accelerating neural regeneration, the accurate regeneration of axons to their original target end-organs is the major determinant of functional recovery after nerve defect repair. It isconceivable that without effective axonal guidance designing in the nerve graft, the misdirection decreases the precision of reinnervation: the regenerating motor axons are often misrouted to sensory target end-organs, and sensory axons formerly innervating skin are often misrouted to muscle. During the recent years, the use of decellularized allograft and nerve conduits are often used with variable success in nerve defect. However, in complicated peripheral nerve regeneration, there are some remaining deficits and dysfunctions despite regeneration. The main reason for remaining deficits and dysfunctions is the lack of guidance which causing the misdirection to occur in the limited number of axons that succeed in regenerating.

Nowadays, a new challenge will be regeneration across composite nerve that consists of mixed motor and sensory nerve. In mixed nerves with both motor and sensory fascicles, the idea scaffold should be able to allow the regenerating motor and sensory axons grow along the proper pathways. Theoretically, the development of 3D printing technology is promising as it is possible to create bionic scaffold to direct nerve regeneration across motor and sensory pathways independently and efficiently, which significantly improve the motor and sensory functional recovery by limiting the misrouting and misdirection.

Within the context of the femoral nerve model, our results have described the characteristic feature of axon morphology, extracellular matrix structure and three-dimensional magnetic resonance Imaging structure of the motor and sensory fascicles – a conventional model to study the accuracy of reinnervation of motor and sensory axons onto appropriate targets. We also summarize the current knowledge on the molecules correlate to selective regeneration for further discussion. Besides, the femoral nerve can develop into a good study model for verifying the function of the misrouting and misdirection limiting in novel 3D biomimetic printing nerve scaffolds during regeneration. Therefore, we thought the two-dimensional and three-dimensional digital information in femoral nerve might help to expand the knowledge in the neuroscience field for 3D printing scaffold research and developing new strategies to promote functional recovery.

Effect of Freeze-drying on the Properties of Silk Fibroin/Polyvinyl Alcohol/Hydroxyapatite Composites

Xujing ZHANG[1]

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SF/PVA composite hydrogel and SF/PVA/HA composite were prepared by two methods: drying at room temperature and repeated freezing-thawing cycles. A comparative analysis was carried out for the composite material under various conditions, focusing on the properties of SF/PVA/HA composites, studied by FT-IR, SEM, swelling characteristics, mechanical compression, cytotoxicity, in vitro degradation, and drug carrying release experiment. The results revealed that, compared with SF/PVA/HA composites prepared by room temperature drying method, the content of β-sheet structure noticeably increased for the SF/PVA/HA composites prepared by the freezing-thawing cycles of SF/PVA hydrogel at 80 ℃, with HA blended after freeze-drying, which has the best mechanical properties and aqueous solution stability, good cell compatibility, moderate in vitro degradation rate and stable drug release rate, and can also be beneficial for material used in drug-loaded tissue engineering bone scaffold to improve degradation of uniform rate and drug release stability. It provides a significant technique to achieve the treatment of anti-bone tuberculosis and lesion bone defect repair

Poster/Rapid Fire Session

10:45-10:48
RFS01 **The influence of the fitting curve on the performance of knee prosthesis**; Xinyu Li, Peking University, China

10:48-10:51
RFS02 **Simple Fabrication Method of Flexible and Transparent Superhydrophobic Polymer Film**; Seongmin Kim, Pohang University of Science and Technology, Korea

10:51-10:54
RFS03 **Numerical Simulation of Temperature Field and Stress Field in Laser Remelting for Single Crystal Superalloys**; Qiuliang Li, Air Force Engineering University, China

10:54-10:57
RFS04 **Enhancement mechanism of mechanical performance of highly porous mullite ceramics with bimodal pore structures prepared by selective laser sintering**; An-nan Chen, Huazhong University of Science and Technology, China

10:57-11:00
RFS05 **Stability monitoring of melt pool during laser additive manufacturing based on coaxial high-speed camera**; Pei-yu Zhang, Air Force Engineering University, China

11:00-11:03
RFS06 **3D bioprinting of aligned cell-laden polysaccharide constructs with high cell viability**; Guicai Li, Nantong University, China

11:03-11:06
RFS07 **Fabrication of size-controllable nanofibrous concave microwell for cell spheroid formation**; Sang Min Park, Pohang University of Science and Technology, Korea

11:06-11:09
RFS08 **Endothelial monolayer with strong tight junction on collagen-coated aligned nanofiber membrane**; Dohui Kim, Pohang University of Science and Technology, Korea

11:09-11:12
RFS09 **Edge extraction of melt pool during Selective Laser Melting Using Phase Congruency method**; Zefeng Liu, Wuhan University, China

11:12-11:15
RFS10 **A study of controlling metal microstructures using kinetic Monte Carlo Method in additive manufacturing**; Hao Yang , Wuhan University, China

11:15-11:18

RFS11 **The Cloud Service for Laser 3D Printing**; Shaohuang Chen, Hans Laser Smart Equipment Group, China

11:18-11:21

RFS12 **Hybrid Data Processing for fabrication of 3D printed objects with high-resolution cellular structures**; Nan Zhang, Huazhong University of Science and Technology, China

11:21-11:24

RFS13 **A new design of electron beam and laser hybrid selective melting (EB-LHM) system aiming to enhance the performance of laser**; Yefeng Yu, Tsinghua University, China

11:24-11:27

RFS14 **TGF-β induced Epithelial-mesenchymal Transition in advanced cervical tumor model by 3D printing**; Jianyu He, Tsinghua University, China

11:27-11:30

RFS15 **A hybrid 3D-printed aspirin-laden liposome composite scaffold for bone tissue engineering**; Yan Li, Peking University, China

11:30-11:33

RFS16 **A noval method of 3D printing for continuous fiber reinforced thermosetting polymer composites**; Yueke Ming, Xi'an Jiaotong University, China

11:33-11:36

RFS17 **Phase field simulation of γ′ evolution and creep property in nickel-base single-crystal superalloys**; Min Yang, Northwestern Polytechnical University, China

11:36-11:39

RFS18 **In-Situ Skin Wound Healing with One Versatile Thermo-Sensitive Hydrogel**; Jingwen Xu, University of Chinese Academy of Sciences, China

11:39-11:42

RFS19 **Evolution of Crack Defect during Selective Laser Melting Using the Extended Finite Element Method**; Jiantao Zhou, Wuhan University, China

11:42-11:45

RFS20 **Differential Effects of Radiation on Adherence of Cancer and Endothelial Cells to 2D Culture Dish and 3D Nanofibrous Membrane**; Min-Ho Choi, Ajou University, Korea

11:45-11:48

RFS21 **Crystallization of CH3NH3PbI3 in NEP perovskite from Microdroplets at different temperature**; Yunjie Du, Tsinghua University, China

11:48-11:51

RFS22 **Construction of light-driven actuator based on graphene composite hydrogel**; Li-ai Yang, Tsinghua University, China

11:51-11:54
RFS23 **Fabrication of Acellular Biodegradable Small-Diameter Vascular Graft**; Zhen Li, Tsinghua University, China

11:54-11:57
RFS24 **Research on an Efficient Heat Source in WAAM Cylinder Structure Numerical Simulation for Aluminum Alloy**; Mingye Dong, Tsinghua University, China

11:57-12:00
RFS25 **3D Bioprinting of Complex GelMA Scaffolds with fine Porous Structures for Enhancing Cell Migration**; Kang Yu, Zhejiang University, China

12:00-12:03
RFS26 **Hydrogel-based microfluidics mimicking multiscale vascular network**; Jing Nie, Zhejiang University, China

12:03-12:06
RFS27 **3D Bio-printed Compound Material Artificial Vascular Substitute with Electroprinted Polycaprolactone (PCL) and Photo Cross-linked Hydrogel Gelatin Methacryloyl (GelMA)**; Yuan Sun, Zhejiang University, China

12:06-12:09
RFS28 **3D Bioprinted Highly Transparent HCECS-Laden Geometry-Controllable Corneal Stromal Substitute For Corneal Tissue**; Qian Xue, Zhejiang University, China

12:09-12:12
RFS29 **Buckling strength topology optimization of 3D periodic materials**; Wenhao Wang, Taiyuan university of science and technology, China

12:12-12:15
RFS30 **High-efficiency Numerical Simulation on Residual Stress and Deformation for Wire Arc Additive Manufacture of Aluminum Alloy**; Jinlong Jia, Tsinghua University, China

12:15-12:18
RFS31 **Research on a High-Efficiency Engineering Algorithm of Residual Stresses and Distortion Simulation on Wire Arc Additive Manufactured Aluminum Alloy**; Tianyi Zhao, Tsinghua University, China

12:18-12:21
RFS32 **Hydrophobic anodic aluminum oxide by controlling nanopore size and surface roughness**; Jong Seon Choi, Pohang University of Science and Technology, Korea

12:21-12:24

RFS33 **Superhydrophobic surface treatment on micro channel heat exchanger for fungus-cleaning effect**; Jeong Won Lee, Pohang University of Science and Technology, Korea

12:24-12:27

RFS34 **A PEG-Lysozyme Hydrogel harvests Multiple Functions as a Potential 3D Printing Biomaterial for Internal-use of Body**; Haoqi Tan, East China University of Science and Technology, China

12:27-12:30

RFS35 **Effect of Zr on Grain Refinement and Properties of High-Strength Low-Alloy Steel Heat Affected Zone by Wire and Arc Additive Manufacturing**; Yili Dai, Huazhong University of Science and Technology, China

12:30-12:33

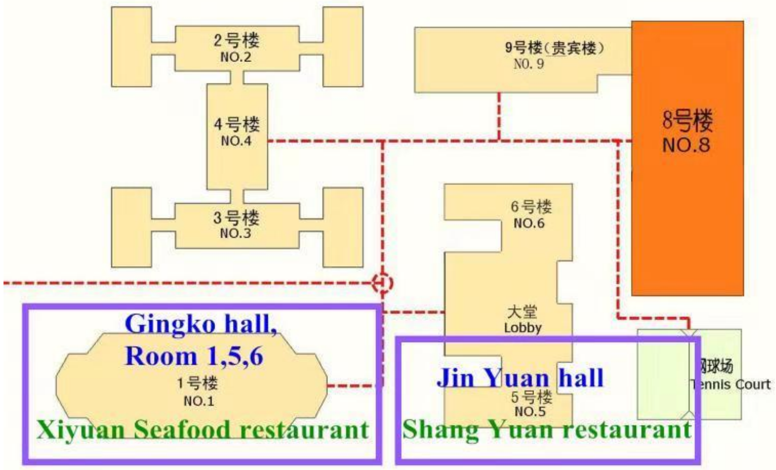
RFS36 **Three Dimensional Growth of Endothelial Cells by VEGF Pro-duced by Cocultured Cancer Cells in Nanofibrous Scaffold**; Ye-Seul Oh, Ajou University, Korea

General Information

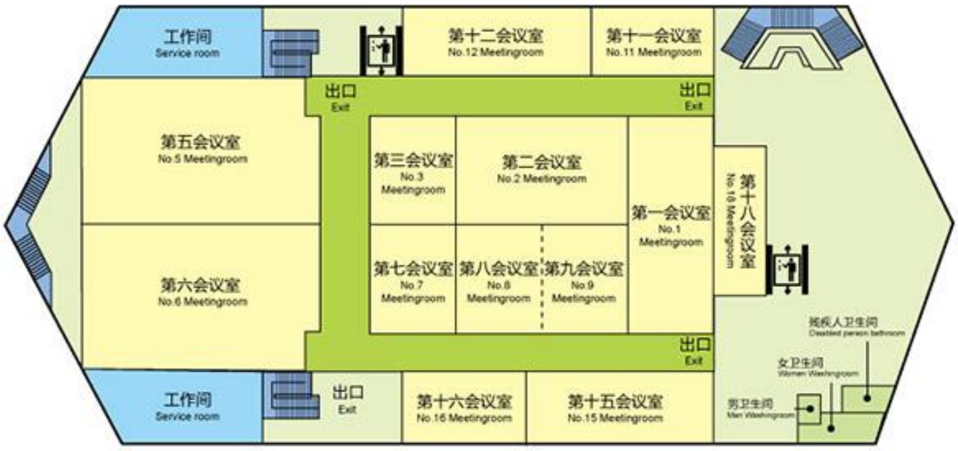
Conference Venue

Beijing Xijiao Hotel locates at the center of Zhongguancun, aka China Silicon Valley, Haidian District, Beijing, China. In this area, it is embraced by the famous universities in China, including, Tsinghua University, Peking University, China University of Mining and Technology, and Beijing Language and Culture University, etc., as well as the pioneered high-tech companies, including, Tsinghua Tongfang, SOHU, and Via Technologies, etc., making it submerged in an academic atmosphere. In addition, 1 mile from the 4th North Ring, 700 m from Wudaokou Subway line 13 Station and 600 m from Qinghuadonglu Subway line 15 station efficiently promote its convenient connecting to the main transportation network of Bejing City. These advantages of spatial location meet the requirements of an ideal social sites for business meetings and academic conferences.

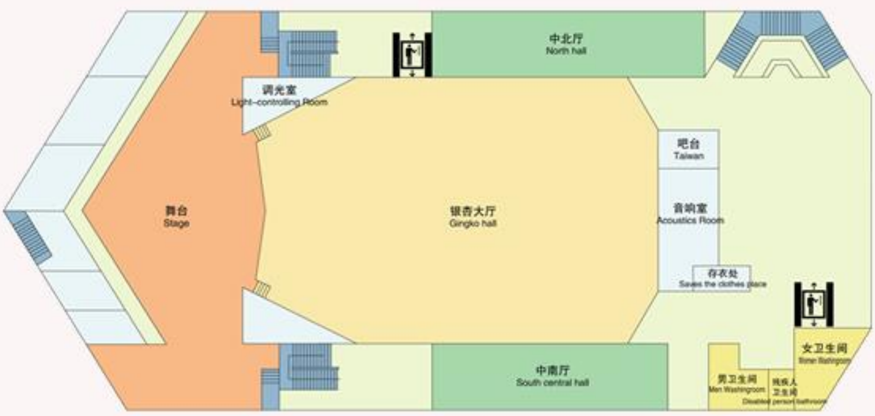
The six-story hotel is opened at 1986 and renovated at 2010. 477 suites are offered for accommodation. Variety of Asian favorites and signatures entrees are provided in the dining center. The luxury Kongle center with perfect facilities is helping guests deal well with their business. The conference center including 22 meeting rooms and one Yinxing hall meets different requirements. Specifically, the YInxing hall can accommodate for 400 people at a time.



西郊宾馆总平面示意图
XiJiao Hotel Plan



西郊宾馆1号楼二层平面示意图
Second Floor Plan of Building No.1



1号楼三层平面示意图
Third Floor Plan of Building No.1

Transportation

Address: No.18 Wangzhuang Road,HaiDian District, Beijing, China

Traffic:

From **capital airport** (30km)

Taxi: about 1 hour, 100RMB

To Taxi driver in Chinese:

师傅，请带我去北京西郊宾馆（北京市海淀区五道口王庄路），谢谢！

Subway: Take Airport Subway to Sanyuanqiao station and then transfer to Subway 10th, next, transfer to Subway 13rd at Xizhimen station, and get off at Wudaokou station.

Shuffle Bus: Take shuffle Bus No.5 and get off at Tsinghua Science Park. Then walk along Chenfu Road for about 10 minutes

From **Beijing Railway Station** (17km):

Take subway No.2 to Xi'zhimen Station and transfer subway No.13 to Wudaokou station.

From **Beijing West Railway Station** (16km):

Take bus No.387/21 to Suojiafen station and transfer bus No.375/562 to Beijing Language and Culture University.

Take subway No.9 to National Library station and transfer to subway No.4 to Xizhimen station, then transfer to subway No.13 to Wudaokou station.

From **Beijing North Railway Station** (16km):

Take subway No.13 to Wudaokou station.

From **Beijing South Railway Station** (16km):

Take subway No.4 to Xizhimen station and transfer subway No.13 to Wudaokou station.

Note