AET2025

PROCEEDINGS OF THE 6TH AET SYMPOSIUM ON ACSM AND DIGITAL MANUFACTURING JOINTLY WITH EUSPEN SIG MEETING IN MICRO/NANO MANUFACTURING

International Academy of Engineering and Technology

European Society for Precision Engineering and Nanotechnology

THE 6TH AET SYMPOSIUM ON ACSM AND DIGITAL MANUFACTURING JOINTLY WITH EUSPEN SIG MEETING IN MICRO/NANO MANUFACTURING

AET2025

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Preface

On behalf of the organising committee, I would like to warmly welcome you to the 6th AET Symposium on ACSM and Digital Manufacturing (AETS2025) and Euspen Special Interest Conference Micro/Nano Manufacturing which is organised by the International Academy of Engineering and Technology (AET), the European Society for Precision Engineering and Nanotechnology (Euspen) and the Paris-Saclay University.

A new round of industrial digital revolution is currently being nurtured worldwide, thanks to breakthroughs in emerging Industry 4.0 technologies. With continuous shrinking of feature size for the next-generation products, manufacturing is clearly advancing to a new paradigm, namely Manufacturing III, towards both atomic scale precision and atomic scale functional feature size. The series AETS Symposia started in 2018 and have provided a platform for fostering collaborations between Academia and Industry and cover a broad spectrum of areas with multi-disciplinary interests, in the field of Atomic and Close-to-atomic Scale Manufacturing (ACSM) and Digital Manufacturing, ranging from fundamental research to real-world applications. To make the symposium more effective and efficient, keynote speeches and oral presentations are scheduled, while poster presentations are allocated into a compact program.

There are 5 keynote addresses that will be given by Prof Fred Roozeboom from University of Twente (Netherlands) addressing current status and future outlook in atomic-scale processing technologies, by Prof Kazuya Yamamura from the University of Osaka (Japan) who will introduce plasma-assisted polishing technology to obtain atomically smooth diamond substrates, by Prof Martin Booth from the University of Oxford (UK) presenting adaptive laser writing technique for three-dimensional precision fabrication of functional devices, by Prof Seeram Ramakrishna from National University of Singapore (Singapore) highlighting electrospinning of intelligent and sustainable materials and by Prof U.D. Zeitner from Opto-Mechanical Systems, Fraunhofer (Germany) focusing on advanced fabrication technologies for scaling optical micro- and nano-structures to application relevant areas.

I would like to take this opportunity to thank the organizing committee and all those who have contributed to this conference, as well as the scientific committee members for their valuable support. My thanks go to the conference sponsor for their suggestions and support.

Sincere thanks also go to Prof Nabil Anwer, the Organizing Committee Chairman, Prof Xichun Luo, the AET Secretary General and Ms Dish Philips, the CEO of Euspen for their dedication throughout the conference. Finally, but not least, I want to thank the many volunteers for their diligent work for the conference.

I wish you all have a remarkable success in participating the conference and have a pleasant stay in Paris!

Professor Kornel Ehmann

President, the International Academy of Engineering and Technology

1 September 2025

euspen SIC Micro/Nano Manufacturing and AET Symposium in ACSM and Digital Manufacturing 17th -19th September 2025
École Normale Supérieure Paris-Saclay, France, FR

Day 1: Wednesday 17th September 2025

Time (CET)	Programme
08:30-09:00	**Registration**
09:00-09:10	**Welcome address by meeting chairs**: Prof. Nabil Anwer, Paris-Saclay University, FR and Dr Oltmann Riemer from LFM (Bremen)
09:10-09:20	**Welcome address by AET Vice-President**, Prof Lihui Wang, KTH Royal Institute of Technology
09:20–09:50	**Keynote 1**: **Current Status and Future Outlook in Atomic-Scale Processing** Prof. Dr Fred Roozeboom, Faculty of Science & Technology, University of Twente, NL
	Session 1: ACSM
09:50-10:10	**Session Keynote:** Preliminary introduction to atomic and close-to atomic scale manufacturing, *Xichun Luo, University of Strathclyde (MNAET25190)*
10:10-10:25	**Oral 1**: Two-Photon Laser Oxidation as a Promising Technique for Area-Selective ALD on Graphene: A Review of Surface Modification Approaches *Atiye Khosravi, Strathclyde University (MNAET25126)*
10:25-10:40	**Oral 2**: Deformation behaviour of monocrystalline silicon under AFM dynamic lithography *Yang He, University College Dublin (MNAET25128)*
10:40-10:55	**Discussion**
10:55-11:10	**Coffee and networking**
11:10-11:25	**Oral 3**: Atomic Features Characterisation using Conductive Atomic Force Microscopy under Ambient Condition at Atomic and Close-to-atomic Scale *Wenhao Zhang, University College Dublin (MNAET25142)*
11:25-11:40	**Oral 4**: Atomic Layer Etching: A Review *Hifza Hafeez, University of Strathclyde (MNAET25173)*
11:40-11:55	**Oral 5**: Manufacturing of silicon dioxide nanodots using rolling nanoelectrode lithography *Zhengjian Wang, University of Strathclyde (MNAET25187)*
11:55-12:10	**Discussion**
12:10-12:25	**Exhibitor presentations**
12:25-13:30	**Lunch**

13:30-14:00	**Keynote 2: Achieving atomically smooth diamond substrates by plasma-assisted polishing** Prof. Kazuya Yamamura, Research Center for Precision Engineering, Graduate School of Engineering, The University of Osaka, Japan
	Session 2: Micro and Nano Machining
14:00-14:20	**Session Keynote**: Effect of near-surface gas flow on surface roughness in atmospheric plasma chemical vaporization machining *Xinyang Wei, University of Osaka (MNAET25130)*
14:20-14:35	**Oral 1:** Investigation of Ultrasonic Vibration-assisted Polishing of Reaction-Sintered Silicon Carbide *Zhichao Geng, University College Dublin (MNAET25127)*
14:35-14:50	**Oral 2**: Reactive Ion Beam Figuring of optical materials *Thomas Arnold, Leibniz-Institut für Oberflächenmodifizierung (MNAET25165)*
14:50-15:05	**Oral 3**: Atomic-Level Stress-Free Precision Machining of Fused Silica via Electrochemically Induced Chemical Etching *Sizhou Chen, Dalian University of Technology (MNAET25167)*
15:05-15:25	**Discussion**
15:25-15:40	**Coffee and networking**
	Session 3: Metrology
15:40-15:55	**Oral 1:** Advancements in Scanning Probe Microscopy for Characterizing Solar Cell Materials *Chuanxiao Xiao, Ningbo Institute of Materials Technology and Engineering (MNAET25131)*
15:55-16:10	**Oral 2:** High-speed lateral-scanning white-light interferometry with vertical off-axis compensation *Hang Zhao, Huazhong University of Science and Technology (MNAET25135)*
16:10-16:25	**Oral 3**: The Molecular Dynamics Simulation of the Damage Mechanism of Ni/Graphene Composite Dynamic Sealing Layer *Yongbo Guo, Harbin Institute of Technology (MNAET25150)*
16:25-16:40	**Oral 4:** Design of Triaxial Robust Repetitive Control for Fast Atomic Force Microscopy Imaging *Qi Yu, Shanghai Jiaotong University (MNAET25152)*
16:40-17:00	**Discussion**
17:00-17:15	**Oral 5**: A Point Cloud Analysis-Based Surface Characteristic Method for Directed Energy Deposition (DED) Additive Manufacturing *Hao Xue, University of Edinburgh (MNAET25162)*

17:15-17:30	**Oral 6**: Mating Surface Contact Behavior Analysis and Assembly Accuracy Prediction for Precision Mechanical Products *Nan Shao, Paris-Saclay Universite (MNAET25175)*
17:30-17:45	**Oral 7**: Design of an Abbe Error Free Three-Dimensional Coordinate Measuring Machine *Ali Rugbani, Cape Peninsula University of Technology, CPUT (MNAET25178)*
17:45-18:00	**Oral 8:** On the use of B-spline reconstruction for roughness evaluation of complex profiles *Ahmed Bachir, LNE (MNAET25185)*
18:00-18:20	**Discussion**
	Close Day 1 – free evening

Day 2: Thursday 18th September 2025

Time (CET)	Programme
08:30-09:00	**Keynote 3:** Adaptive laser writing for three-dimensional precision fabrication of functional devices Prof. Martin Booth, University of Oxford, UK
09:00-09:30	**Keynote 4**: **Electrospinning of Intelligent and Sustainable Materials** Prof Seeram Ramakrishna, National University of Singapore, Singapore
	Session 4: Ultra Precision Manufacturing
09:30-09:50	**Session Keynote**: Pattern transfer by atmospheric pressure plasma jet etching for manufacturing hybrid optical elements *Thomas Arnold, Leibniz-Institut für Oberflächenmodifizierung (MNAET25166)*
09:50-10:05	**Oral 1**: Exploring nano/atomic scale removal mechanism of semiconductor materials in energy field assisted ultra-precision machining, *Benny C.F. Cheung, The Hong Kong Polytechnic University (MNAET25183)*
10:05-10:20	**Oral 2**: Optimal Model-Free Iterative Learning Control of Fast Tool Servo for Real-Time Turning Toolpath Tracking of Freeform Surfaces *Wei-Wei Huang, Shanghai Jiao Tong University (MNAET25132)*
10:20-10:35	**Oral 3**: Temperature-Dependent Machinability of Optical Polymers in Diamond Turning *Wei Wang, Leibniz Institute for Materials Engineering IWT (MNAET25188)*
10:35-10:55	**Discussion**
10:55-11:10	**Coffee and networking**
11:10-11:25	**Oral 4**: Insights into the atomic-scale removal mechanism of SiC in plasma-assisted polishing *Congyue Luo, Zhejiang University of Technology (MNAET25148)*
11:25-11:40	**Oral 5**: High-Efficiency Force Rheological Polishing of Hemispherical Resonator Inner Stem *Tao Zhou, Zhejiang University of Technology (MNAET25153)*

11:40-11:55	**Oral 6**: Research on high-efficiency ultra-precision polishing technology of resonant oscillator lip edge *Feng Yingchao, Zhejiang University of Technology (MNAET25156)*
11:55-12:10	**Oral 7**: Achieving ultra-smooth and damage-free surface on deep structure through understanding the material removal mechanism of the modification layer, *Haixiang Hu, Changchun Institute of Optics (MNAET25192)*
12:10-12:30	**Discussion**
12:30-13:30	**Lunch**
13:30-13:45	**Oral 8**: Compact piezo-driven inchworm rotary mechanism for LISA Space mission *Narendra Mahavar, KU Leuven (MNAET25174)*
13:45-14:00	**Oral 9:** Ultra-precision Fly Cutting and Nano-imprinting of Sub-Micron Gratings for AR/VR Applications *Vinod Mishra, CSIO-CSIR (MNAET25180)*
14:00-14:15	**Oral 10**: **Thermal stability analysis and optimization of field-assisted diamond turning,** *Kaiyuan You, University of Electronic Science and Technology of China (MNAET25125)*
14:15-14:30	**Discussion**
	Session 5: Digital Technology for Precision Manufacturing
14:30-14:45	**Oral 1**: Fabrication of Micro-Structured Ceramic Artificial Hip Joints via Digital Twin-Enhanced Ultra-Precision Grinding *Zhenfei Guo, Harbin Institute of Technology & University College Dublin (MNAET25129)*
14:45-15:00	***Oral 2****:* Characterization and experimental study of electromechanical coupling of ball screw servo feeding system *Haitao Liu, Harbin Institute of Technology (MNAET25145)*
15:00-15:15	**Oral 3**: Electrode shape wear prediction in micro-edm with machine learning *Jia Ge, University College Dublin (MNAET25170)*
15:15-15:30	**Discussion**
15:30-15:45	**Coffee and networking**
15:45-16:00	**Oral 4**: Comparing state-of-the-art 2PP to competing processes – a take on precision, accuracy and throughput *Georg Winkler, UpNano GmbH (MNAET25176)*
16:00-16:15	**Oral 5**: Simulation-Driven Design of Ultrasonic Horns for Precision Micro-Grinding Applications *Rajeshkumar Madarkar, Buckinghamshire New University, UK (MNAET25177)*
16:15-16:30	**Oral 6**: On the use of Virtual Image Correlation methods to enhance accuracy in contour identification using X-ray computed tomography data *Filippo Mioli, University of Padova (MNAET25179)*

16:30-16:45	**Oral 7:** Robust Salvinia-inspired superhydrophobic surfaces on hydrophilic materials via two photon polymerization *Kai Liu, University of Padova, IT (MNAET25155)*
16:45 -17:05	**Discussion**

	Session 6: Poster session for poster pitch verbal presentations *1 minute / 1 slide*
17:05-17:30	1. *Molecular dynamics study of 4H-SiC indentation deformation mechanism* *Zhongwei Hu, Huaqiao University (MNAET25143)* 2. *The effect of grinding speed on the deformation mechanism of single crystal gallium nitride studied by nanoscratching* *Yueqin Wu, Huaqiao University (MNAET25144)* 3. *Unveiling the Anisotropic Deformation Mechanisms of β-phase Gallium Oxide* *Xipeng Xu, Huaqiao University (MNAET25149)* 4. *Theoretical Study on High-Precision Optical Manipulation Based on a Novel Optical Force Device* *Chunyang Gu, Chinese Academy of Sciences (MNAET25151)* 5. *Enhancement of Irradiation Performance in Fast Atom Beam Source with Internal Electrode* *Taichi Hino, Nagoya University (MNAET25154)* 6. *Multi-channel wide spectrum high resolution spectrometer for thin film thickness measurement* *Bosong Duan, Zhejiang University (MNAET25157)* 7. *Challenges in Manufacturing and Measuring Microstructures with Re-Entrant Features Using Two-Photon Polymerization and Micro-CT* *Tomasz Bartkowiak, Poznan University of Technology (MNAET25158)* 8. *Nano-cutting fluids based on graphene nanoparticles for deep hole drilling under MQL conditions* *Roberto Teti, Franhofer, University of Naples Federico II (MNAET25159)* 9. *Off-axis Wavefront Measurement for Defocus Lens Design* *Chenhua Zhang, University College Dublin (MNAET25161)*

	10. *Nanoscale Film Formation via Dilute Solution Spin Coating: Exploring the Thickness Limit and Uniformity* *Qiuyu Liu, Dalian University of Technology (MNAET25163)* 11. *Holographic mask fabrication by photoelectrochemical etching* *Pan Peng, Huazhong University of Science and Technology, China (MNAET25133)* 12. *Generation of robust algorithms for dense image matching in dimensional metrology, Ladji Fofana, LNE (MNAET25172)* 13. *A polishing process simulated using molecular dynamics to explain atomic-level origins in machine tool processing* *Baozhen Li, GENERTEC Machine Tool Engineering Research Institute CO., LTD. Beijing (MNAET25184)* 14. *Deep learning-assisted measurement system for the 3D profiles of inner surfaces of components* *Xiangyu Zhao, Huazhong University of Science and Technology (MNAET25124)* 15. *Selective Laser Melted Porous CuSn20-Bonded Diamond Grinding Tool: Functional Cellular Structures Design, Service Performance Evaluations and Properties Tailoring Database Establishment* *Yangli Xu, Huaqiao University (MNAET25136)* 16. *Enhanced Interferometric Measurement of Discontinuous Surfaces: Improved Morphology - based Phase Unwrapping Algorithm* *Shuai Wang, Zhejiang University (MNAET25137)* 17. *Synergistic modulation of corrosion and tribological performance of MoS2 coatings based on chemical annealing and Ti doping* *Congming Ke, Huaqiao University, China (MNAET25139)* 18. *Investigation of the Effects of LaB6 Microparticles on the Laser Powder Bed Fusion of Copper: Printability, microstructure and properties* *Yanlong Cao, Zhejiang University (MNAET25146)* 19. *A Concept for Making Molds for the Replication of Parts with Combined Micro- and Submicro-Structured Surface* *Holger Ruehl, (IFM), University of Stuttgart (MNAET25171)* 20. *Development and Application of Large-Scale and High-Precision Gratings,* *Wenhao Li, Changchun Institute of Optics (MNAET25191)*

	21. *In-process monitoring and servo control with cost-effective radio frequency (RF) signal in micro-EDM,* Zequan Yao, KU Leuven *(MNAET25193)* 22. *Dimensional nanometrology and sub-nanometre positioning using X-ray interferometry, Andrew Yacoot, NPL (MNAET25194)*
17:30-17:45	**Free time with Posters**
17:45-18:00	**Close Day 2 - Coaches depart for networking dinner** **Transport provided one way to restaurant**
19:00-22:00	**Dinner at Bouillon Racine**

Day 3: Friday 19th September 2025

Time (CET)	Programme
08:30-09:00	**Keynote 5**: Advanced fabrication technologies for scaling optical micro- and nano-structures to application relevant areas Professor Dr. U.D. Zeitner, Senior Director, Opto-Mechanical Systems, Fraunhofer
	Session 7: Micro-manufacturing
09:00-09:20	**Session Keynote:** Micro-Injection Molding of TPU for medical devices: Material influence on dimensional accuracy and surface quality. *Maria del Angel Guerrero, ITESM (MNAET25123)*
09:20-09:35	**Oral 1:** Modular Assembly System for Hollow Microneedle Array Device Fabrication *Xingyu Fu, MNMT (MNAET25195)*
09:35-09:50	**Oral 2**: Improvement of irradiation performance in fast atom beam source with bidirectional magnetic field for surface activated bonding *Yuki Miyoshi, Nagoya University (MNAET25138)*
09:50-10:05	**Oral 3:** Evaluating the Impact of Internal Structural Defects on Fatigue Performance in Polylactic Acid Components Manufactured via Fused Deposition Modeling *Liang Wang, Beijing Institute of Technology (MNAET25140)*
10:05-10:20	**Oral 4:** Two-Photon Polymerization for Advanced Calibration Artefacts in Optical Areal Metrology *Julian Hering-Stratemeier, University of Kaiserslautern-Landau (MNAET25141)*
10:20-10:45	**Discussion**

10:45-11:00	**Coffee and networking**
11:00-11:15	**Oral 5**: Enhanced Hot-Embossing of Submicrometric Structures in Polymers for Optofluidic Applications *Thomas Guenther, (IFM), University of Stuttgart (MNAET25168)*
11:15-11:30	**Oral 6**: Defect-free replication of polymeric micro structures using novel Ni-PTFE nanocomposite moulds *Tianyu Guan, University College Dublin (MNAET25169)*
11:30-11:45	**Oral 7**: High-resolution master fabrication for tool-based manufacturing using two photon lithography *Manuel Luitz, UpNano GmbH (MNAET25181)*
11:45-12:00	**Discussion**
12:00-12:15	**Oral 8**: Femtosecond-laser-fabricated interfacial microrobots for versatile non-contact applications *Bowen Chen, University of Science and Technology of China (MNAET25182)*
12:15-12:30	**Oral 9**: Investigation on Mechanism of Starch-based Ultra Stable Foam for Potential Application of Sprayable Mulch Film *Huifang Xie, Henan Academy of Sciences, Institute of Chemistry (MNAET25186)*
12:30-12:45	**Oral 10**: New challenges faced by high-precision laser manufacturing of 3D components with complex shape: up-scaling inspection methodologies for control dimensions, a real case study *Eva Rodriguez, Tekniker (MNAET25189)*
12:45-13:00	**Discussion**
13:00-14:00	**Lunch**
14:00-15:00	**Universite Paris-Saclay laboratory tour**
15:00:15:20	**Closing remarks** Prof Kornel Ehmann AET President, Northwestern University Announcement of next AET event: Prof. Kazuya Yamamura, Research Center for Precision Engineering, Graduate School of Engineering, The University of Osaka, Japan Dr. Oltmann Reimer (eu**spen**) and Prof. Nabil Anwar (local host)
15:30	**CONFERENCE ENDS**

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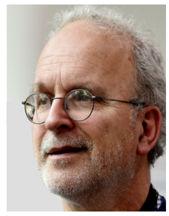
Current Status and Future Outlook in Atomic-Scale Processing



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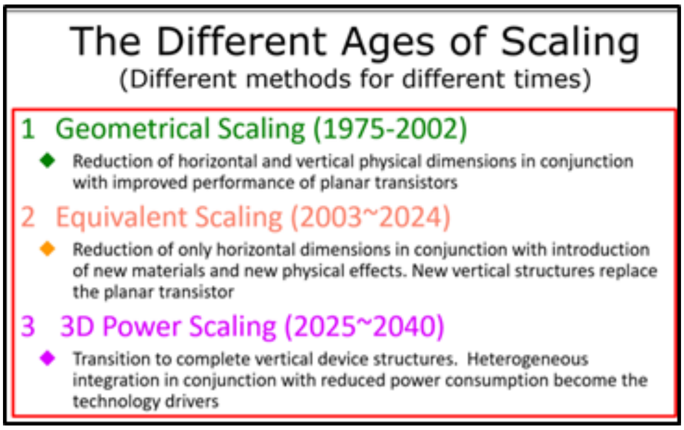
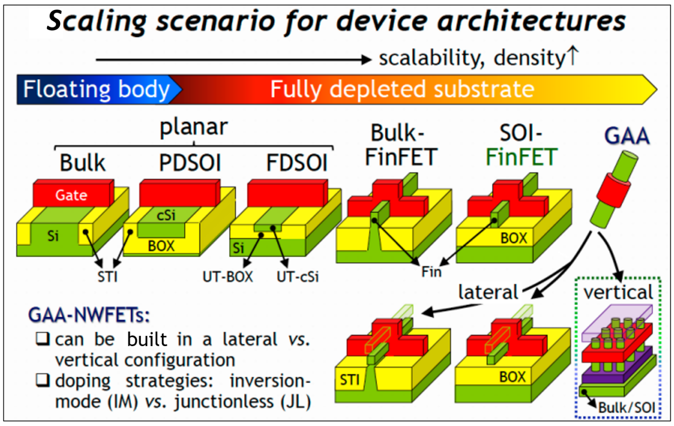
Abstract

The IRDS-2022 Roadmap [1] catches the three different scaling ages for the past and upcoming decades. Today, we witness the transition to the third age named '3D Power Scaling' in a sequence of eras that started with straightforward geometrical scaling by continuous shortening of the wavelengths (from regular UV to deep UV/immersion) used in lithographic patterning of planar transistor structure. In the second 'equivalent scaling' era, new superior material properties and critical dimensions nearing single-digit nanometer values could still be realized by cost-effective technology solutions.





Ever more complex device architectures requiring extreme edge placement accuracy, layer conformality and shape fidelity in all processing steps (deposition, etching, cleaning) can only be realized by Atomic Layer Deposition (ALD) and Atomic Layer Etching (ALE). Today, these techniques are indispensable in the manufacture of fully 3D-integrated devices using vertical intra- and inter-chip concepts, thus alleviating the need for capital-intensive EUV-tools, at ~40% total tool costs for modern fabs.

This keynote focuses on the fundamentals and latest trends in Atomic Layer Processing in sub-10 nm fabrication of 3D-architectures. ALD and ALE have manifested to cost-effectively bridge the >10-years incubation time needed to bring EUV-technology from prototype to commercial use. These techniques can be uniquely used to create 3D-devices in dedicated isotropic (thermal and radical-enhanced) and anisotropic (directional and ion-enhanced) processing modes. Here, energetic species (radicals and/or ions in a plasma) are used in one or two steps, with ions yielding anisotropic profiles (used in FinFET logic and 3D-NAND memory), and neutrals/radicals yielding isotropic profiles to create single-digit-nm features in devices containing horizontal nanowires, nanosheets and 'forksheets' in GAA-FETs, and complementary FETs [2].

1) International Roadmap for Devices and Systems (IRDS™) 2022 Edition - IEEE IRDS™, and references therein.
2) L. Van den Hove, 20-year semiconductor roadmap | imec (imec-int.com), IMEC International Technology Forum, July 2023.

Biography

Fred Roozeboom holds a doctorate in technical sciences from University of Twente (Netherlands) with specialization in inorganic chemistry and catalysis. After three years in catalysis at ExxonMobil R&D Labs in Baton Rouge (USA), he joined Philips Research (from 2007: NXP) in Eindhoven, Netherlands to work most of his life on thin-film technology and plasma processing (1983-2009). From 1997-2009 he led a team that focused here on applications in 3D passive and heterogeneous integration for System-in-Package devices for wireless communication and power management. In 2007 he became Research Fellow and also full professor at TU Eindhoven (2007-2021), working on atomic layer deposition and etching. In 2009 he left NXP to join TNO Holst Centre to work on spatial atomic layer process and reactor design.

In 2021 he left TU Eindhoven and TNO to join University of Twente as guest (emeritus) professor, where his research focuses on inorganic membranes for nanofiltration applications. Since 2021 he is or was also consultant for high-tech industry in applications of thin-film processing in EUV optics lifetime, 3D Li-ion batteries, etching and greenhouse gas emission reduction.

Fred holds over 50 US patents, granted or pending, and published 200+ papers in journals (h-index 44 Scopus). He is ECS Fellow and AVS Fellow, and the winner of the ECS 2023 Gordon E, Moore Medal Award.

Achieving atomically smooth diamond substrates by plasma-assisted polishing

Kazuya Yamamura

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Abstract

Diamond has the highest hardness and thermal conductivity among any substance, so it is used in tools for cutting and grinding, X-ray window materials, heat spreader materials, and so on. Recently, due to its excellent electronic properties, it has been expected to be used as a material for quantum devices and power devices. However, diamond is extremely difficult to polish due to its hardness and chemical inertness. In conventional diamond polishing, the scaife polishing using diamond abrasive causes cracks and subsurface damage to the substrate, and in the case of CMP, the material removal rate is very low.

By applying plasma-assisted polishing to the polishing of diamond substrates, we have succeeded in obtaining atomic order surface roughness with high efficiency and without introducing subsurface damage. In this presentation, the characteristics of plasma-assisted polishing for single crystal and polycrystalline diamond substrates will be introduced.

Biography

Dr. Yamamura is a Distinguished Professor at the University of Osaka and Director of the Center for Precision Engineering at the Graduate School of Engineering. And he is an associate member of CIRP and a fellow of the Japan society for Precision Engineering (JSPE). His research area is development of physicochemical ultraprecision nanomanufacturing method and its application. By using numerically controlled plasma vaporization machining, he succeeded in uniforming the thickness distribution of quartz wafers to less than 2 nm, and contributed to the development of a process for mass-production of the world's smallest quartz crystal units. Furthermore, he invented the plasma-assisted polishing technology, which has succeeded in finishing of difficult-to-polish materials such as GaN and diamond substrates with high efficiency and damage-free.

Adaptive laser writing for three-dimensional precision fabrication of functional devices

Martin Booth

Optical and Photonic Engineering, Department of Engineering Science, University of Oxford, United Kingdom

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Abstract

Adaptive optics allows for spatial control over the phase and intensity of a laser beam, making it a powerful tool to assist ultrashort pulse laser machining. Optical aberrations caused by refraction at interfaces distort the laser focus, compromising resolution and fabrication efficiency. We show how the aberrations can be dynamically compensated using adaptive optics, such as liquid crystal spatial light modulators, for improved manufacturing of functional devices. Examples include fabrication of waveguide circuits in a range of materials, fiber based Bragg sensors for harsh environments, diamond based electronics and compact tunable liquid crystal devices

Biography

Prof Martin Booth is chair in Optical and Photonic Engineering at the University of Oxford. His research involves the development and application of adaptive optical methods in microscopy, laser-based materials processing and biomedical imaging. In particular, his group have developed numerous implementations of adaptive optics for aberration correction in high resolution microscopes and precision laser fabrication systems. He has held Royal Academy of Engineering and EPSRC Research Fellowships and an Advanced Grant from the European Research Council. In 2014 he was awarded the International Commission for Optics Prize. He was appointed Professor of Engineering Science in 2014 and Chair in Optics and Photonics in 2023. He is a fellow of SPIE, Optica, and the Institute of Physics and serves on the board of Optica. He has over 180 publications in peer-reviewed journals, over thirty patents, and has co-founded two spin-off companies, Aurox Ltd and Opsydia Ltd.

Electrospinning of Intelligent and Sustainable Materials

Seeram Ramakrishna

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Abstract

Historical observations suggest that humans are increasingly living in a manufactured world. Expectations on the materials for future manufactured products include new functionalities, intelligence and sustainability in addition to the usual performance, availability, and cost criteria. Intelligent material interacts reversibly with its environment, or responds or adapts to changes in the environment. Two types of intelligent materials are envisaged: a) assisted intelligent materials rely on externalities and b) built-in intelligent materials are fully self-sufficient.Sustainable material fosters a healthy living ecology via the elimination or reduction of associated greenhouse gas (GHG) emissions, wastage, and resources depletion. They are purposely designed or selected with lower ecological footprint and human health effects, and higher circularity and regenerative potential. In recent years, electrospinning emerged as a nanotechnology method of manufacturing science and engineering. This seminar illustrates this technology with strategies for producing sustainable and intelligent materials/ products.

Biography

Academician Seeram Ramakrishna is a world-renowned professor at the National University of Singapore (NUS). He is a recipient of the China Government Friendship Award and Chang Jiang Scholar of Ministry of Education, China. He is among the top four scientists of Singapore (Top 10 Scientists in Singapore (2024) - Top 2% Scientists).

He is named among the World's Most Influential Minds (Thomson Reuters) and a Highly Ranked Scholar (Scholar GPS) with more than 500 Q1 journals papers with 217 H-Index and about 220,126 citations. His contributions also appeared in journals such *Nature, Nature Reviews Methods, Nature Communications,* Matter, so on. Highest professional distinctions include Fellow | Foreign Academician of Chinese Academy of Engineering; UK Royal Academy of Engineering (FREng); Singapore Academy of Engineering; Indian National Academy of Engineering; ASEAN Academy of Engineering & Technology; International Academy of Engineering and Technology; and International Academy of Bionic Science. He is also an elected Fellow of AAAS, ASM International, ASME, AIMBE, USA; IMechE and IoM3, UK; ISTE, India; and IUBSE (FBSE). Besides, he is also a Senior Chartered Engineer (Sustainability) of the Institution of Engineers Singapore in 2025. He received a PhD from the University of Cambridge, UK, and TGMP from Harvard University, USA.

He received advanced research experiences from MIT and Johns Hopkins University, USA and KIT, Japan. He is a Chair Professor of Tsinghua University and Xinghua Distinguished Chair Professor, China; Distinguished Professor of IIT Hyderabad, India; Everest Chair of MBUST, Nepal, and Vice-Chairman of World Artificial Consciousness Association (WACA). Out of three decades of working at the National University of Singapore (NUS), about 15 years of senior academic leadership includes NUS Vice-President (Research Strategy); Dean of NUS Faculty of Engineering; Director of NUS Enterprise; Director of NUS Industry and Technology Relations Office (INTRO); Director of NUS International Relations Office (IRO); Chairman of Solar Energy Institute of Singapore (SERIS); Director of NUS Bioengineering Initiative; and Director of NUS Nanoscience & Nanotechnology Initiative (NUSNNI).

Advanced fabrication technologies for scaling optical micro- and nano-structures to application relevant areas

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Abstract

In modern photonics the use of nano-structures offer the access to a wide range of novel functionalities not realizable with conventional optical components. Popular examples of such structures are the so called optical meta-materials which utilize sub-wavelength sized metallic or dielectric nano-structures for the flexible manipulation of amplitude and phase of an optical field. Such structures have their own challenging requirements on the nano-fabrication techniques. The patterns are often curvilinear, require a precise shape control, need to be placed with very high positioning accuracy over large distances spreading several tenths of centimeters, and need to be transferred into various materials with high aspect ratio.

The availability of high-resolution and high throughput lithographic fabrication technologies such as electron-beam lithography based on Variable Shaped Beam writing and Character Projection – in combination with complementary technologies such as e.g. Atomic-Layer-Deposition – opens the way for the flexible use of various optical nano-structures for some of the most demanding applications. The presentation will discuss the technical features, advantages, and limitations of lithographic pattering approaches and will show how they can favorably be combined to realize optical micro- and nano-structures for applications which are as diverse as gratings for ultra-short laser pulses or high resolution spectrometers, computer generated holograms for asphere testing, optical meta-lenses, or ultra-low loss photonic integrated circuits.

Biography

Uwe D. Zeitner received his PhD in physics in 1999 for a work on diffractive optics in laser resonators from the Friedrich-Schiller-University Jena. In 2008 he received the Habilitation from the same university for his work on spatio-temporal control of light using micro-structured optics. From November 2022 until May 2025 he held a research professorship for Technical Optics at the University of Applied Sciences in Munich. Since 1999 he is with the Fraunhofer IOF, Jena, currently being a member of the scientific board.

His field of research is the development of micro- and nano-lithographic solutions for optical applications enabled by fundamental research in various fields. He has a strong background in the development of high-performance optical components and gratings for applications like laser pulse compression or space-borne spectroscopy for several missions of the European Space Agency.

Preliminary introduction to atomic and close-to atomic scale manufacturing

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Abstract

The evolution of manufacturing technology and systems can be fundamentally classified into three paradigms based on scales of manufacturing precision, functional features, material manipulation (removal, migration, and addition), and underlying theory. The emergence of atomic and close-to-atomic scale manufacturing (ACSM) is an inevitable outcome shaped by the three fundamental paradigms of manufacturing advancement.

This talk introduces a research framework, including scientific issues and research of ACSM, which aims to realize cost-effective, deterministic, and scalable manufacturing of next-generation products with atomic-level precision by addressing quantum uncertainty in atomic-level material manipulation (removal, migration, and addition). ACSM is regarded as the fundamental technology for opening a new manufacturing paradigm. Underpinning fundamental knowledge and theory and potential industrially viable processing technologies for realising ACSM will also be presented in this talk, followed by scientific and technological challenges, and future research perspectives.

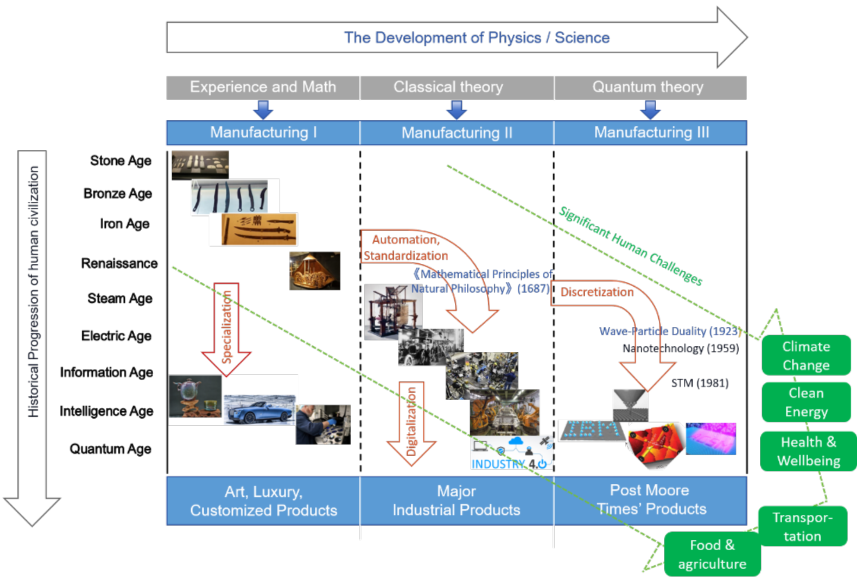

Figure 1: The three manufacturing paradigms of manufacturing advancement

Two-Photon Laser Oxidation as a Promising Technique for Area-Selective ALD on Graphene: A Review of Surface Modification Approaches

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Abstract

Silicon (Si) has long been regarded as the foundation of semiconductor technology, but its scaling limitations, low carrier mobility, and thermal inefficiencies present challenges for next-generation electronics and optoelectronics. Graphene, a two-dimensional (2D) material with exceptional electronic, thermal, and mechanical properties, offers a promising alternative. Integrating graphene into field-effect transistors (FETs), memory devices, sensors, quantum technologies, and optoelectronic applications requires high-k dielectrics as gate insulators, tunneling barriers, and protective coatings. Atomic Layer Deposition (ALD) is the preferred method for depositing ultra-thin, uniform high-k dielectrics due to its precise thickness control and large-area scalability. However, graphene's chemically inert sp^2-hybridized surface inhibits direct ALD precursor adsorption, necessitating surface functionalization.

The paper reviews current candidates for surface modification of graphene. Several functionalization strategies—such as plasma treatments (O_2, H_2, NH_3), chemical functionalization (O_3, Cl_2, XeF_2), organic and metallic seed layers, and self-assembled monolayers (SAMs)—have been employed to enhance ALD nucleation. While effective, these methods introduce significant drawbacks, including defect formation, contamination, increased roughness, uncontrolled oxidation, additional processing complexity, and time-consuming multi-step procedures. Plasma treatments damage graphene's lattice, reducing carrier mobility, while chemical methods leave residues that degrade device performance. Seed layers not only increase roughness but also impose limitations on the minimum achievable dielectric thickness, making them suboptimal for ultra-thin integration. Additionally, these methods lack precise control over functionalization and require additional post-processing.

To address these limitations, two-photon laser oxidation (2PLO) has emerged as a highly selective, mask-less, and contamination-free functionalization approach. By tuning laser fluence, pulse duration, and wavelength, 2PLO enables spatially controlled oxidation at the nanoscale with exceptional precision and reproducibility.

Unlike conventional techniques, it offers high-resolution patterning, direct area-selective functionalization, and precise oxidation levels without the need for masks or chemical processing. At fluences just below the ablation threshold, oxidation occurs through two-photon absorption, enabling controlled defect formation that enhances ALD nucleation without compromising graphene's structure.

Despite its advantages, research on 2PLO for ALD remains limited. A recent study demonstrated its feasibility for ZnO deposition but did not extend to other high-k dielectrics essential for graphene-based devices. In this paper, we explore 2PLO as a versatile and scalable technique for enabling area-selective ALD of high-k dielectrics, positioning it as a key technology for next-generation graphene electronics, optoelectronics, and quantum devices.

Deformation behaviour of monocrystalline silicon under AFM dynamic lithography

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Abstract

Atomic and close-to-atomic scale manufacturing (ACSM) represents the next frontier in manufacturing. Mechanical machining at this scale faces significant challenges, particularly regarding tool edge radius, applied force and underlying manufacturing mechanisms. While atomic-scale simulations have advanced valuable understanding, experimental validation remains limited. This study explores dynamic lithography using an atomic force microscope (AFM) tip, which enables cyclic penetration of the sample surface at low peak forces. However, the underlying deformation mechanisms remain unclear. To address this, diamond AFM tips with radii ranging from 8 nm to 20 nm were used for dynamic lithography on monocrystalline silicon. The machined features, including surface phase shifts, protuberances, grooves, and cavities, were examined using AFM and SEM. The material deformations were attributed to elastic deformation, plowing, and cutting. Despite the undesirable formation of protuberances and pile-ups due to plowing, this technique shows potential for atomic-scale material removal when combined with post-processing methods such as wet etching. These findings bridge the gap between theoretical simulations and experimental validation, thus providing crucial insights into future ACSM strategies.

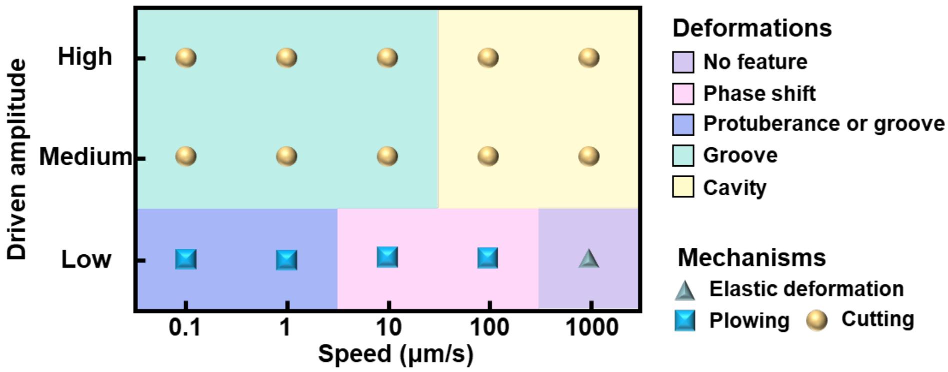

Figure 1: Deformation mechanisms of dynamic lithography on monocrystalline silicon

Atomic Features Characterisation using Conductive Atomic Force Microscopy under Ambient Condition at Atomic and Close-to-atomic Scale

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Abstract

Achieving atomic and close-to-atomic scale measurement, especially under ambient conditions, is one of the key goals of atomic and close-to-atomic scale manufacturing (ACSM). Such measurements require atomic-scale resolution in both the vertical and lateral directions. Atomic force microscopy (AFM) is a versatile technique that readily provides vertical atomic resolution; however, achieving lateral atomic resolution—particularly in ambient conditions—remains challenging due to the nanometer-scale radius of AFM tips. Conductive atomic force microscopy (C-AFM), an extension of AFM with sub-picoampere level current-sensing capabilities, brings additional measurement abilities to simultaneously characterize surface electronic properties and topography. In this study, we investigate the potential of C-AFM in resolving the atomic features in graphene—a prototypical two-dimensional material characterized by atomic-scale monolayer thickness and periodic hexagonal atomic patterns within each layer. These natural features make graphene an ideal benchmark material for validating both vertical and lateral directions at the atomic scale. The resolution performance of C-AFM is governed by both the complex interplay of both mechanical and electrical interaction at the tip-sample interface. Thus, we systematically investigate the influence of critical parameters, including contact force, bias voltage, tip radius, and contact resistance, to elucidate the underlying interaction mechanisms. The results would provide a deeper insight into the resolution-determining factors of C-AFM and offer practical guidelines for achieving high-resolution C-AFM measurements under ambient conditions.

Coherent Diffraction Lithography Based on Fourier Holography

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Abstract

In integrated circuit manufacturing, lithography is a crucial process. Conventional projection lithography relies on specially designed masks and projection systems to transfer circuit patterns onto a wafer. However, as lithography nodes advance, the cost and complexity of these systems have escalated. Moreover, defects on the mask directly affect image quality, leading to high maintenance costs. In contrast, coherent diffraction lithography (CDL) offers a promising alternative by exploiting light's interference and diffraction properties. Using Gabor holography, CDL computes and generates masks that modulate incident light. This modulated light then passes through a single converging lens to form an image, significantly simplifying the system compared to traditional projection lithography. Additionally, because the CDL mask encodes frequency domain information rather than direct spatial features, it is highly tolerant to defects, which further reduces fabrication and maintenance expenses.

In our work, we designed and optimized holographic masks using stochastic gradient and local integration methods. We also built a visible light prototype of a coherent diffraction lithography system and carried out photoresist exposure experiments. The experimental results demonstrated wavelength-level resolution. These findings suggest that coherent diffraction lithography could emerge as a simpler, more cost-effective technology for high-resolution lithographic processes in the integrated circuit industry.

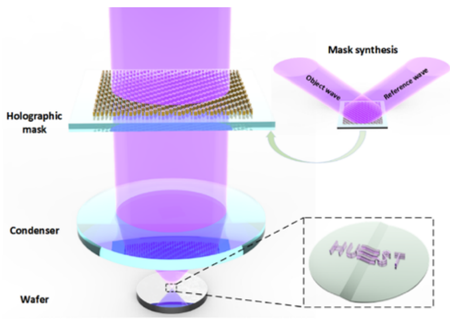

Figure 1: Schematic Diagram of the Principle of Coherent Diffraction Lithography

Atomic Layer Etching: A Review

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Abstract

The increasing miniaturisation of features on IC's which is depicted by Moore's law is now leading us to an age which will require Post Moore Era (PME) Chips such as photonic, quantum, and DNA chips that will have features at the atomic or close-to-atomic scale. It is also driving the development of atomic and close-to-atomic scale manufacturing techniques to overcome the quantised nature of matter at sub-10nm [1]. Atomic Layer Etching (ALE) is a self-limiting manufacturing technique that is an essential process required to achieve atomically precise layer-by-layer etching for the fabrication of features in future devices such as 3D and future transistor architectures – FinFETs, Gate-All-Around, nanosheet, Forksheet, and Complimentary FET (CFET) transistors – as well as 3D NAND and 3D DRAM [2-4]. Plasma-enhanced ALE has been researched for over 35 years but lacked in publications compared to its ALD counterpart until the last decade and the advent of thermal ALE in 2017 for etching oxides, nitrides, and metals [2, 5-6]. ALE still needs to address multiple research challenges related to process control, higher selectivity, materials, sustainability, and the complexity of structures that is required. Some of these challenges arise from the nature of the process and the use of a plasma-based process. The high energy ion bombardment causes damage to the top layer of silicon substrates and causes challenges in 3D structure fabrication as well. There is scope for these challenges to be addressed by the use of photons/laser as a potential superior energy source which will be introduced in this work in comparison to the plasma and thermal based process.

This work reviews the current state-of-the-art technology in ALE and its limitations. An overview of ALE, its applications, the solutions it provides, and challenges it addresses are presented before the current approaches to study ALE and the understanding they provide are detailed. The different types of ALE – primarily plasma-enhanced, thermal, and photon/laser-assisted ALE – are then reviewed after which the current challenges facing ALE are discussed, concluding with an outlook and future direction for ALE to meet the current and future research challenges and demands of the semiconductor industry as we step into the Post Moore Era.

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Manufacturing of silicon dioxide nanodots using rolling nanoelectrode Lithography

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Abstract

The fabrication of discrete SiO_2 nanodots is critically important for a wide range of emerging technologies, such as photonic crystals, quantum-dot memory and high-sensitivity sensors, but remains highly challenging due to competing demands for nanoscale precision, uniformity and throughput. Here, we demonstrate a novel Rolling Nanoelectrode Lithography (RNEL) approach that overcomes these barriers to produce highly uniform oxide nanodot arrays on Si(100) substrates.

Our bespoke RNEL platform integrates three orthogonal linear translation axes and a fourth rotating axis, supporting a roller wrapped with GeoMatec g.moth™ film bearing random nanoscale protrusions. To render the film conductive for local anodic oxidation, it is first sputter-coated with a thin Au layer. A polydimethylsiloxane (PDMS) backing layer ensures conformal adhesion of the sticky film to the roller core, while a flexure hinge-based tilting stage actively controls roller alignment. Real-time force-toposition feedback converts contact-force deviations into vertical stage adjustments, maintaining a constant pressure profile across the wafer. At a given DC bias voltage and rotation speed, localised anodic oxidation proceeds continuously, yielding SiO_2 nanodots with diameters below 50 nm and high spatial uniformity.

This work addresses the principal challenges of RNEL, namely achieving reproducible oxide morphology under dynamic rolling conditions, precise stamp–wafer contact control and scalable pattern transfer, through integrated mechanical design and closed-loop control strategies.

By combining nanoscale resolution with high throughput, our RNEL implementation paves the way for integrating SiO_2 nanodots into photonic devices, next-generation memory architectures and advanced biosensing platforms. Ongoing efforts will focus on optimising process controllability, exploring engineered stamp patterns, and extending RNEL to other semiconductor materials, thus broadening its impact in industrial and academic nanofabrication.

Effect of near-surface gas flow on surface roughness in atmospheric plasma chemical vaporization machining

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Abstract

To realize the damage-free, highly efficient, and ultra-precision figuring of difficult-to-machine materials, atmospheric pressure plasma chemical vaporization machining (AP-PCVM) was proposed and achieved great performance on low spatial frequency roughness (LSFR) features. However, being a chemical etching technique driven by reactive plasma jet, surface roughness deterioration after AP-PCVM is observed. This issue takes extra expense and efforts to improve the surface roughness by further polishing and might cause the figuring precision loss. In this study, the spatial features of surface roughness deterioration with both the formation location and microscopic topography were discussed. A transient large-eddy simulation (LES) model with the multi-component fluid mixing model was developed and validated by the experiment. With this model, the detailed fluid behaviours around the near-surface region were captured. It elucidated the relationship between near-surface vortex formation and surface roughness deterioration through normalized Q criterion distribution, which visualized the local vortex distribution in the near-surface region.

Keywords: chemical vaporization machining; surface roughness; local vortex formation

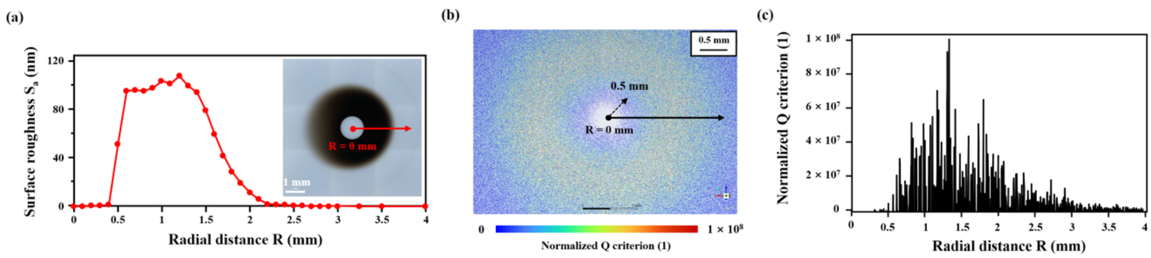

Figure 1: Mechanism elucidation of surface roughness deterioration after plasma chemical vaporization machining (PCVM). (a) surface roughness radial distribution and laser microscopy image of the processing spot, (b) Normalized Q criterion distribution on the plane 5 μm away from the surface (where vortex fully developed), and (c) Normalized Q criterion distribution along the radial direction on the plane 5 μm away from the surface.

Investigation of Ultrasonic Vibration-assisted Polishing of Reaction-Sintered Silicon Carbide

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Abstract

Reaction-sintered silicon carbide (RS-SiC) is widely used as optical mirrors due to its superior mechanical properties. However, conventional polishing methods face significant challenges in polishing RS-SiC mirrors because of its extreme hardness, brittleness, and multiphase composition. To address these limitations, a hybrid polishing technique integrating plasma oxidation and ultrasonic vibration assistance is proposed. The oxidation behaviour of the RS-SiC surface under plasma treatment is analysed using COMSOL multiphysics with the plasma module, investigating the effects of plasma power, gas flow rate, oxidation duration, and nozzle-to-workpiece distance. Experimental validation is conducted to assess the effectiveness of plasma oxidation in modifying the material surface and enhancing the surface finish. The synergistic effect of plasma oxidation and ultrasonic vibration is explored, demonstrating its potential to improve both material removal efficiency and surface integrity. This study provides theoretical and experimental insights for the advancement of ultrasonic-assisted polishing technique with an integration of plasma oxidation.

Reactive Ion Beam Figuring of optical materials

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Abstract

Beam-based technologies such as atmospheric pressure reactive plasma jet machining (PJM) or ion beam figuring (IBF) have been shown to be feasible for generating freeform geometries or correcting residual topography errors. While PJM has become an established technique for the efficient fabrication of such optical elements in fused silica, silicon or SiC, its underlying chemical material removal mechanism based on silicon-fluorine reactions limits its broader application to a wider range of substrate materials, e.g. Zerodur or optical glasses such as N-BK7. As such materials contain constituents that are non-etchable through the chemical etching regime, masking layers are formed that degrade etch performance in terms of etch rate and surface roughness. Even for easy-to-etch materials, the sensitivity of pure chemical etching mechanisms to contaminants or sub-surface damage (SSD) results in significant roughening, requiring post-polishing steps. On the other hand, IBF has been shown to be largely insensitive to such obstacles, producing smooth surfaces. However, the comparatively low etch rates of IBF make it inefficient for free-form generation, where significant amounts of material must be removed. Reactive ion beam figuring (RIBF) offers a promising alternative, combining chemical and physical etching mechanisms for both freeform generation and correction. This dual mechanism approach effectively mitigates the above challenges. Physical sputtering reduces the impact of surface impurities, SSD, or non-silicate constituents. Chemical mechanisms help to significantly increase the etch rate. The paper presents a comparative study of freeform generation for fused silica, Zerodur and N-BK7 using PJM and RIBF. Aspects such as processing effort and convergence as well as surface roughness evolution and chemical surface modifications are discussed.

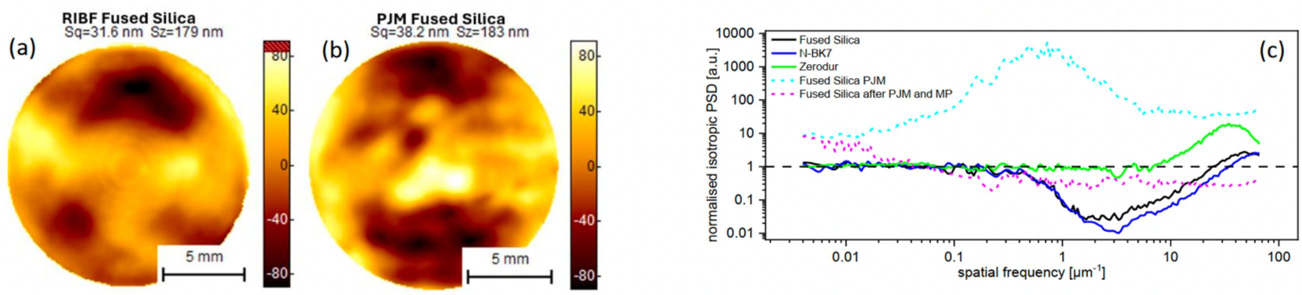

Figure 1: (a,b) Residual figure error of freeform with PV 5 µm, (c) PSD function representing the alteration of roughness structures on treated surface (PSD < 1: smoothing, PSD > 1: roughening)

Atomic-Level Stress-Free Precision Machining of Fused Silica via Electrochemically Induced Chemical Etching

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Abstract

Surface figure accuracy, as a critical determinant of optical system performance, presents significant challenges for precision manufacturing technologies due to the stringent requirements for nanoscale control. This study bases on the non-contact machining method of electrochemically induced chemical etching (ECICE), overcoming the limitations of conventional mechanical and chemical polishing techniques, such as subsurface damage and surface topography degradation, realizes stress-free and high-precision fabrication of fused silica. By changing the etching gap and implementing a rotating electrode compensation strategy, the peak-to-valley (PV) surface error was reduced to 111 nm over a 9 mm-diameter processing area, with further reduce the area achieving 56 nm PV within a 6 mm-diameter zone. Experimental validation demonstrates the feasibility of this approach for high-precision, stress-free micro-nanofabrication applications, including metalens array and diffraction gratings. The proposed ECICE technique offers a Innovative solution for atomic-scale manufacturing demands in advanced optical metasurfaces, quantum photonic devices, and other nanotechnology-enabled systems.

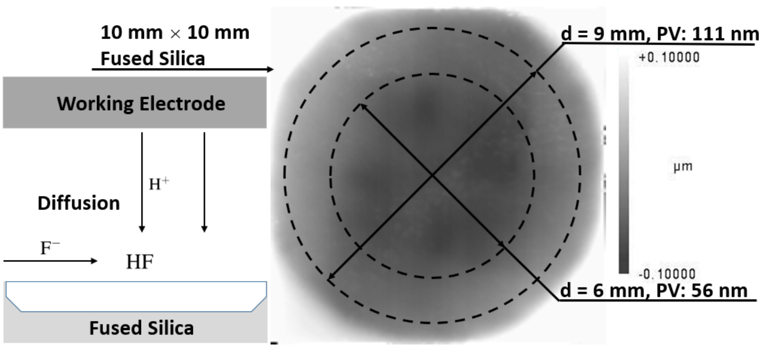

Figure 1. Mechanism and etching result surface topography of ECICE process

Advancements in Scanning Probe Microscopy for Characterizing Solar Cell Materials

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Abstract

In-depth microscopic characterization of materials and devices is crucial for enhancing photovoltaic conversion efficiency and ensuring long-term reliability. In this presentation, I will highlight our recent advancements in the development and application of scanning probe microscopy (SPM) techniques to state-of-the-art perovskite solar cells. I will begin by discussing our contributions to the development of champion silicon-perovskite tandem cells. Using Kelvin probe force microscopy, we gained valuable insights into the effects of carrier transport layer treatments and the internal electric field distribution within the tandem structure. Next, I will present the development of novel electrical probe techniques, showcasing preliminary results from ongoing efforts in our group. Specifically, we successfully applied scanning capacitance microscopy to perovskite materials by incorporating a high-quality alumina thin film. This modification enabled precise mapping of carrier distribution and allowed us to investigate variations in carrier concentration and type. Additionally, I will introduce a 3D tomography current mapping method, which we used to assess how surface and bulk passivation treatments impact the carrier transport properties of perovskite thin films. Finally, I will address key failure mechanisms in perovskite solar cells and modules. By integrating macroscale electrical characteristics with nanometer-scale SPM techniques, we revealed critical mechanisms behind potential-induced degradation, Ultraviolet-induced degradation, and phase segregation in perovskite materials. These findings provide crucial insights into the challenges and opportunities for improving the long-term stability and performance of perovskite-based technologies.

High-speed lateral-scanning white-light interferometry with vertical off-axis compensation

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Abstract

The growing demand for high-throughput metrology of large-scale micro-nano structures has given rise to lateral-scanning white-light interferometry (LSWLI), which avoids frequent stepping and stitching. However, maintaining accuracy comparable to conventional white light interferometry (WLI) remains challenging due to straightness errors in the translation stage and environmental vibration. We present a high-speed LSWLI employing Linnik configuration with vertical off-axis compensation to address this limitation. Phase step errors induced by off-axis motion are extracted through Lissajous ellipse fitting (LEF), and a least-squares sine fitting (LSF) based WLPSI algorithm is proposed to demodulate the interference signal with random phase steps, enabling robust surface topography reconstruction. Experimental results demonstrated a similar height measurement accuracy compared with WLI, even under a scanning speed of 1 mm/s and an off-axis motion range of 600 nm.

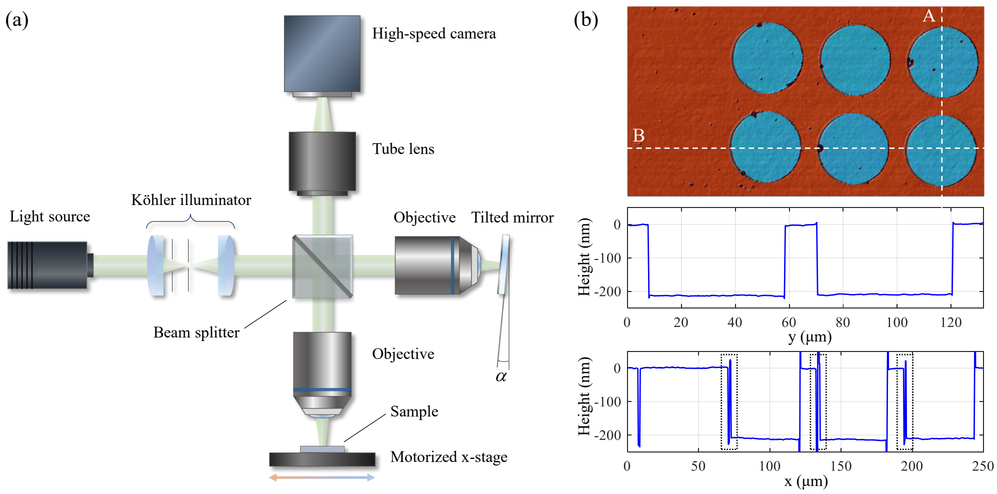

Figure 1: (a) The schematic of the LSWLI system, (b) Reconstruction results of etched structures.

The Molecular Dynamics Simulation of the Damage Mechanism of Ni/Graphene Composite Dynamic Sealing Layer

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Abstract

This study addresses the interface failure problem in hypersonic vehicle and wind tunnel Machnumber-variable nozzle dynamic sealing systems under wide temperature range (300-1200 K) and high-pressure differential (>5 MPa) coupling shock. Molecular dynamics (MD) methods are employed to investigate the damage mechanism of nickel/graphene composites. The aim is to reveal the competitive mechanisms of interface dislocation nucleation, graphene bonding evolution, and vacancy defect response, and to establish a model linking extreme working conditions with sealing performance, providing theoretical support for atomic-level sealing structure design.

This study systematically investigates the damage evolution mechanism of the nickel/graphene composite dynamic sealing layer using molecular dynamics simulations. LAMMPS software is used to construct the nickel/graphene composite model, with atomic interactions described by multipotential functions such as Tersoff, Morse, and Lennard-Jones. Nanoindentation and scratch simulations are performed to analyze the material's dynamic response. The evolution of the dislocation nucleation energy barrier in the nickel matrix under high-temperature conditions is further explored, and the critical stability threshold of graphene's sp^2 bonding network under thermal loading is clarified. Additionally, the dynamic behavior of interface vacancy defects and its relationship with sealing performance degradation is revealed.

At shallow indentation, graphene maintains elastic adhesion, while deep indentation causes mismatched plastic deformation in the nickel matrix, leading to graphene rupture. Structural analysis shows that the dislocation density in the nickel layer increases with indentation depth, while a sharp drop in dislocation density occurs after graphene rupture, reflecting brittle failure characteristics. Residual stress field analysis reveals that uneven stress induced by deep indentation exacerbates interface detachment. In future work, this study will conduct molecular dynamics simulations under high-temperature and high-pressure conditions and develop a "temperature-stress" multi-parameter control model to elucidate the transfer paths of

interface damage under extreme conditions, providing optimization guidelines for atomic-level high-reliability dynamic sealing structure design.

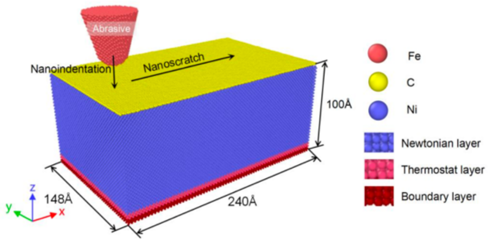

Figure 1: Molecular dynamics simulation model of Ni/graphene composite dynamic sealing layer

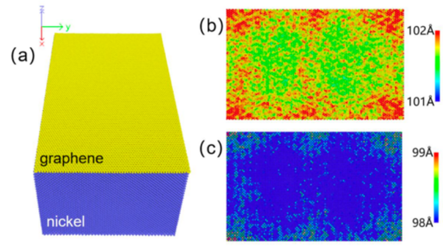

Figure 2: (a) Graphene adsorbed on the nickel surface, (b) morphology of graphene adsorbed on the nickel surface, (c) morphology of the nickel matrix surface.

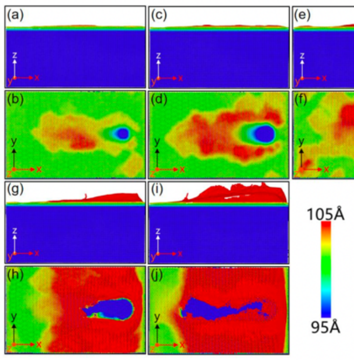

Figure 3: Surface morphology of seal layer atoms under nanoindentation depths of 0.5 nm (a), (b), 1.0 nm (c), (d), 1.5 nm (e), (f), 2.0 nm (g), (h), and 2.5 nm (i), (j).

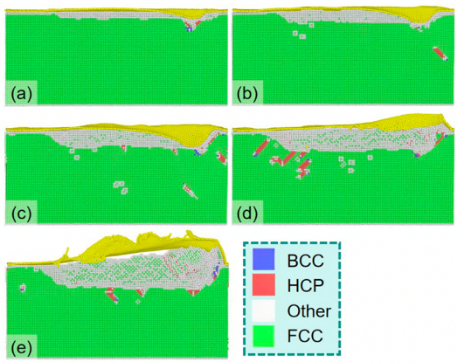

Figure 4: CNA analysis of nickel under nanoindentation depths of 0.5 nm (a), 1.0 nm (b), 1.5 nm (c), 2.0 nm (d), and 2.5 nm (e).

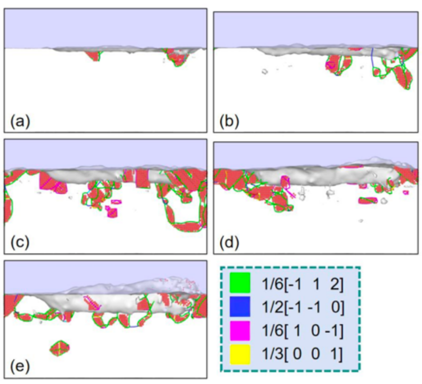

Figure 5: DXA analysis of nickel under nanoindentation depths of 0.5 nm (a), 1.0 nm (b), 1.5 nm (c), 2.0 nm (d), and 2.5 nm (e).

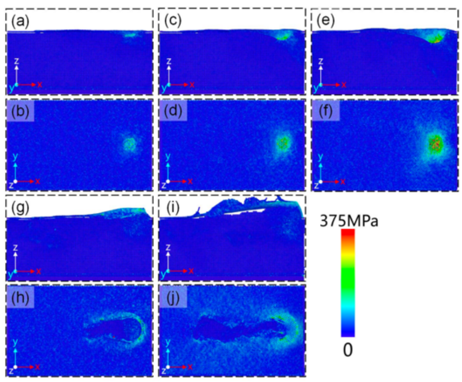

Figure 6: Stress analysis of seal layer atoms under nanoindentation depths of 0.5 nm (a), (b), 1.0 nm (c), (d), 1.5 nm (e), (f), 2.0 nm (g), (h), and 2.5 nm (i), (j).

Design of Triaxial Robust Repetitive Control for Fast Atomic Force Mircroscopy Imaging

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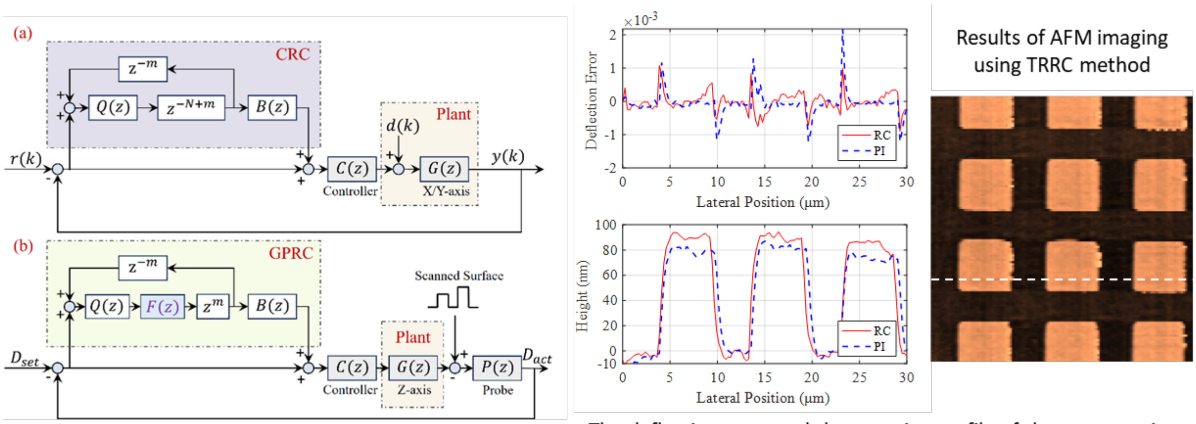
Abstract

Recently, atomic force microscopy (AFM) has become a popular choice for the imaging and characterization of samples at the nanometer level. However, the achievable imaging performance with the fast scanning speed of AFM is severely limited by the deteriorated tracking accuracy of nanopositioner and the increase of interaction forces between the sample and the probe's tip. To meet these challenges, the triaxial robust repetitive control (TRRC) strategy is proposed in this article due to its efficiency in performing repetitive tasks. Noting the fact that the lateral movements of the nanopositioner in the imaging process are repetitive motion, the conventional repetitve control (CRC) method is implemented in the fast and the slow axes to alleviate the periodic tracking errors and the cross-coupling effects introduced by the fast scanning speed. For the z-axis of the nanopositioner, the general parametric repetitive control (GPRC) method based on the IIR filter is selected for its superiority and robustness to remedy the undesired inherent sensitivity to the shifted frequency of the CRC method. The stability condition and controller design scheme of TRRC are analyzed in detail systematically. To validate the superiority of the proposed TRRC method, simulations and comparative experiments are conducted in a triaxial nanopostioner for AFM imaging. The simulation results show better tracking performance of the proposed method compared to the PI control scheme. Furthermore, the imaging experimental results reveal the reduction of deflection errors in the cross section of the proposed method and thus present a higher imaging quality. Typically, the normalized root-mean-square force error is reduced by 21% utilizing the proposed TRRC method. In conclusion, in contrast with the traditional PI control scheme, the proposed TRRC method exhibits better tracking accuracy and system robustness.



The proposed TRRC scheme: (a) the x/y-axis (b) the z-axis

The deflection error and the scanning profile of the cross-section, sizing 30×30 μm², with 125×125 pixels resolution and 10 Hz scanning-line-rate

Figure 1: The graphical abstract of the proposed TRRC method

A Point Cloud Analysis-Based Surface Characteristic Method for Directed Energy Deposition (DED) Additive Manufacturing

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Abstract

Directed Energy Deposition (DED) additive manufacturing offers significant advantages in efficiently producing complicated metallic parts, but lacks standardized surface characterization methods, posing challenges for consistent quality assurance. Building upon previous work, this research introduces a refined, multi-scale surface characterization framework using advanced point cloud analysis, specifically tailored for Six-beam Wire Laser Additive Manufacturing (WLAM).

Utilizing high-resolution Faro Quantum arm laser scanning, detailed 3D point clouds of single-bead specimens printed with varied process parameters (travel speed and wire feed rate) are acquired. This enhanced approach integrates automated dimensional assessment through cross-sectional profile fitting and detailed geometric consistency evaluation via improved Iterative Closest Point (ICP) registration against nominal bead models. Utilizing this approach, a further investigation on the effects of travel speed and wire feed speed on the final deposition quality is conducted. Additionally, in-situ melt pool monitoring is employed to elucidate the parametric effects from the process perspective. Experimental results indicate that lower travel speeds generally yield wider and taller beads with increased surface roughness due to prolonged melt pool exposure, whereas higher speeds resulted in narrower, smoother beads but introduced localized geometric inconsistencies primarily resulted from intensified thermal gradients. Comparatively, variations in wire feed speed have a more significant impact on bead dimensions and deposition stability, demonstrating its criticality in balancing dimensional accuracy and surface finish.

On the other hand, identification and quantification of localized surface irregularities are implemented through segmented surface texture characterization base on statistical metrics (Sa, Sq, Ssk, Sku) and unsupervised learning-based defect detection, i.e., density-based spatial clustering of applications with noise (DBSCAN). This advanced machine learning model allows for automated localization of surface defects and dimensional deviations based on the extensive dataset generated from point cloud measurement. The

detected defect information enables in-situ adaptive monitoring and optimized process parameter selection, significantly improving the reliability and precision of DED manufacturing processes.

Mating Surface Contact Behavior Analysis and Assembly Accuracy Prediction for Precision Mechanical Products

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Abstract

Assembly accuracy analysis is a critical step to ensure the quality and performance of mechanical products. This is particularly important for precision opto-electromechanical products in aviation, aerospace, and related fields, as their growing demands for enhanced precision, reliability, and functionality have created significant challenges for assembly accuracy analysis methods. Traditional assembly accuracy analysis methods are based on the variation of degrees of freedom in geometric features. These methods facilitate the uniform representation and cumulative calculation of different deviation types, and have been well applied in relevant computer-aided design and tolerancing systems. However, it is not sufficient to accurately predict and effectively control the assembly accuracy of precision mechanical products due to neglecting the effects of the real topography of mating surfaces and the mechanical contact behavior during assembly. In this context, this paper conducts research on mating surface contact behavior analysis and assembly accuracy prediction for precision mechanical products. Through the systematic exploration on multiscale construction of the Skin Model Shapes tolerance model, elastic-plastic contact behavior solving of rough mating surfaces, and assembly accuracy prediction and optimization methods, the theoretical foundation and key technical support have been laid for the analysis of assembly accuracy in high-precision scenarios.

Keywords: Precision Mechanical Products; Skin Model Shapes; Tolerance Analysis; Deviation Propagation; Assembly Accuracy Prediction

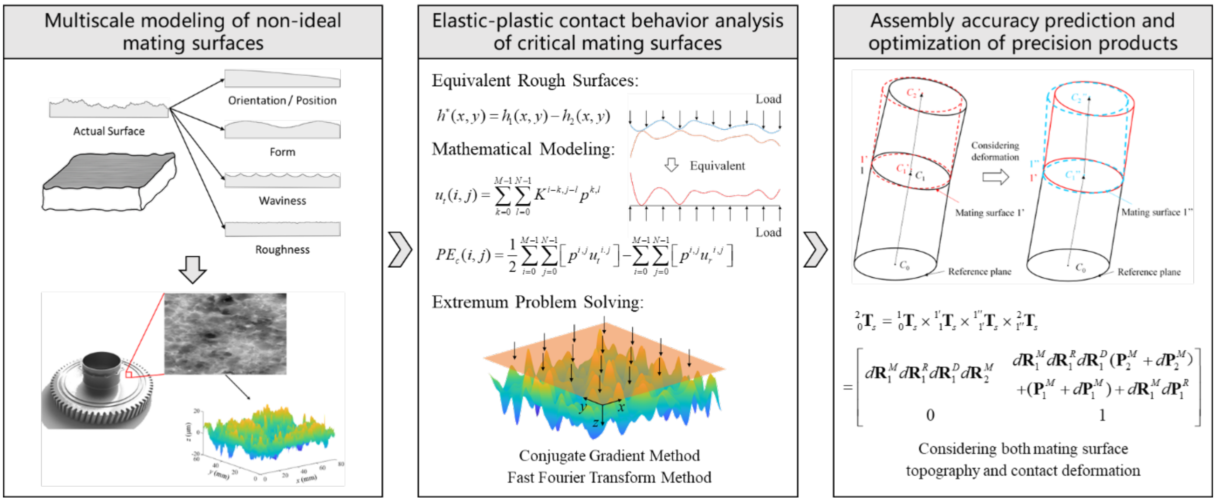

Figure 1: Overall structure of the paper

Design of an Abbe Error Free Three-Dimensional Coordinate Measuring Machine

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Abstract

Coordinate Measuring Machines (CMMs) are essential for ensuring precision and quality in manufacturing. This paper presents a novel CMM design that utilizes a single displacement sensor to deliver high-precision 3D measurements while considerably reducing system complexity and cost. In this design, a laser displacement sensor is aimed directly at the tip of a touch-trigger probe to eliminate the effect of Abbe errors, establishing the sensor's functional line at a 45° angle to the x-y, x-z, and y-z planes while maintaining a fixed distance from the probe, see Figure 1. Accurate probe tracking is achieved through a comprehensive kinematic model. Additionally, a metrology frame with independent translations along the x and y axes forms a volumetric workspace of 40 × 40 × 40 mm, ensuring consistent measurement alignment. Experimental validation using calibrated gauge blocks demonstrates that the system offers a cost-effective and simplified alternative to conventional CMMs by reducing the number of sensors without compromising measurement accuracy.

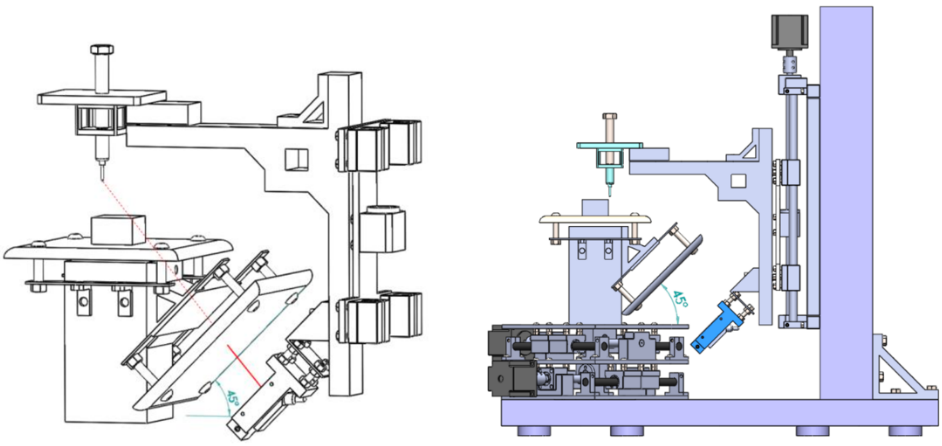

Figure 1: 3D model of the single sensor CMM

On the use of B-spline reconstruction for roughness evaluation of complex profiles

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Abstract

Surface metrology aims to capture inherent qualitative information about surface topology and to describe it as quantities expressed as roughness parameters. The results of roughness measurements are then used to assess the surface quality. This work focuses on extending profile roughness analysis to complex profiles that are not analysable with standard methodologies. Indeed, the set of operations to be performed according to the standards (ISO 21920-2 [1]) is based on the hypothesis that the analysed profile could be expressed as an explicit function (i.e. each x coordinate maps one and only one z value). These profiles are described as height maps; in this work, they will be referred to as “pseudo-flat”. This work proposes an innovative workflow for profile roughness measurement that uses B-splines to extend roughness measurement to complex profiles (i.e., not representable by explicit functions). The flowchart of operation reported in [1] suggests extracting surface information via (i) the acquisition of points, (ii) suppression of noise components via the use of a high-pass filter (S-Filter), (iii) removal of form error, and finally, (iv) suppression of waviness components using a low-pass filter (Lfilter). The output of this set of operations is the roughness profile, i.e. the components of the initial profile whose wavelengths lie between the cut-off lengths of the two filters, L and S.

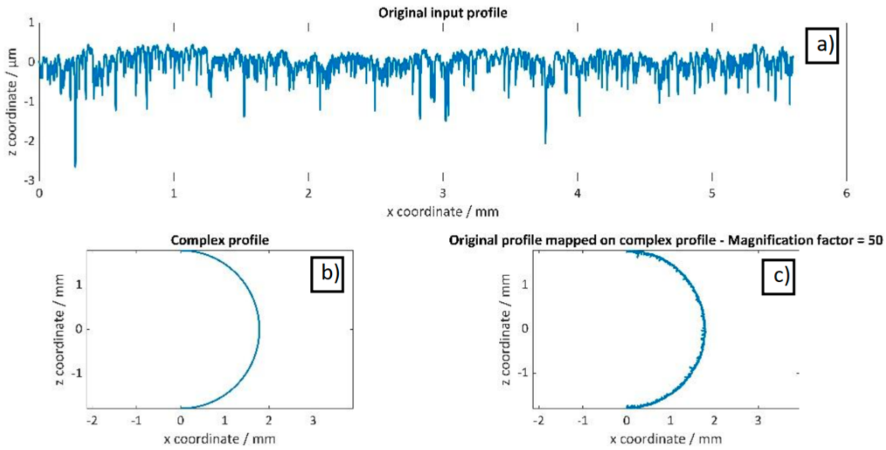

Figure 1: Analysed profiles: (a) original profile, (b) complex shape profile, (c) original profile mapped on the complex shape.

Roughness parameters are then computed with a set of mathematical operations using the vertical and horizontal distances of the roughness profile points. B-splines are parametric curves and surfaces highly employed for continuous representation. Previous works suggest their application also for filtration (Mioli et al. [2]), while Janecki et al. [3] developed a B-spline-based filter for “pseudo-flat” surfaces. The proposed method intends to extend those works to extract roughness parameters from complex profiles that would be otherwise not analysable. The foundational idea is to describe the profile as $r(t)$ = $rwav(t)$ + $rres(t)$, where $rwav$ is the B-spline waviness parametric profile and $rres$ represents the residual profile. A definition similar to that of the AST parameters presented for surfaces in [4] is used for profiles to compute the roughness parameters. These parameters are approximated using the input profile's normal distances (instead of the vertical height residual). The proposed flowchart incorporates the form removal (iii) and L-filtration (ix) operations in one reconstruction operation performed with the B-spline. To ensure the reliability of surface roughness measurement, a “pseudoflat” profile is analysed by applying a Gaussian filter (0.8mm). Secondly, the same profile is analysed using the proposed method to validate it against the standardised reference. Lastly, the profile is mapped on a complex profile where $rwav$ is a semi-circle and $rres$ is the “pseudo-flat” profile. This makes it unsuitable for direct analysis with standard methodologies. Fig.1 shows the analysed profiles. The roughness parameters Ra, Rvt, and Rpt obtained are compared in Tab.1. These preliminary results showed good agreement (deviations of less than 6%) between the parameters evaluated with the standardised and proposed methodologies on the “pseudo flat” profile. Furthermore, the proposed method showed excellent comparability of results regardless of the shape of the profile. Future works will focus on tuning the methodology to improve the agreement with the standard methods and later extending this case study to more parameters and areal measurements.

Roughness parameter	*Original profile + standard method*	*Original profile + proposed method*	*Complex profile + proposed method*
Ra (Arithmetic mean height) [µm]	*0.1887*	*0.1913 [+1.38%]*	*0.1914 [+1.43%]*
Rpt (Maximum peak height) [µm]	*0.5457*	*0.5774 [+5.81%]*	*0.5778 [+5.88%]*
Rvt (Maximum pit depth) [µm]	*2.5199*	*2.4694 [-2.00%]*	*2.4699 [-1.98%]*

Table 1: Comparison of Ra, Rpt and Rvt parameters. Values in brackets [ ] represent the percentage deviation from the equivalent value obtained on the original profile using standard methodology (Gaussian filter)

Acknowledgments

This work has been carried out within the project 23IND08 DI-VISION, which has received funding from the European Partnership on Metrology, co-financed from the European Union's Horizon Europe Research and Innovation Programme and by the Participating States.

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Pattern transfer by atmospheric pressure plasma jet etching for manufacturing hybrid optical elements

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Abstract

To make optical systems more compact, advanced optical elements with dual functions are needed. For example, lenses with binary structures can both focus and diffract. Conventional methods are limited when it comes to structuring curved surfaces, so this study pursues an approach in which laser radiation is used to structure a polymer film on the substrate, and this structure is then transferred to the substrate using atmospheric pressure plasma jet (APPJ) etching. This process chain also has the advantage of being carried out under atmospheric conditions throughout, allowing for more cost effective and sustainable production. Initially, the etch rates of potential masking materials, and the optical substrate (fused silica) are investigated as a function of the APPJ etch parameters, in particular the gas composition (O2/CF4) and the dwell time. While the etching rates of the quartz glass are between 25 and 80 nm·s-1, the etchings on the polymers deepen at a rate of 140 to 370 nm·s-1. The surface morphology of the masking materials is subject to alterations during the etching process, acquiring additional nanoscale roughness and waviness. Nevertheless, a roughness of 2-5 nm rms at an etch depth of 3000 nm can be realized for the polymers, and 1.5 nm rms at 600 nm for fused silica. Finally, the transfer of a binary structure with a depth of 200 nm to a spherical lens is demonstrated.

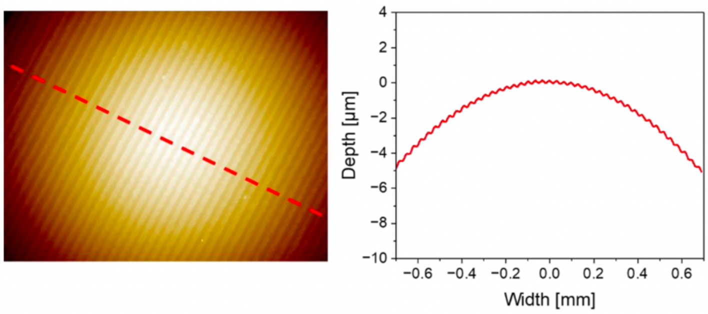

Figure 1: White light interferometry image of a structured lens surface with the corresponding crosssection

Exploring nano/atomic scale removal mechanism of semiconductor materials in energy field assisted ultra-precision machining

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Abstract

For the substrate material of key electronic components, semiconductor materials are widely used in aerospace, national defense, and new energy industries. In traditional ultra-precision processing, the performances of semiconductor materials are easy damage and low efficiency. It is a key technical difficulty in manufacturing high-performance and high-efficiency electronic components. In response to the above problems, various energy field assisted ultra-precision machining, including plasma-assisted and laser-assisted machining, provide effective ways for high efficient removal and no damage processing in nanoscale/atomic scale. However, the nano/atomic scale material structure evolution, extremely small scale deformation and removal mechanism of semiconductor materials in energy field assisted ultra-precision machining have not been deeply explored. This report reviews the removal mechanism of semiconductor materials in energy field assisted ultra-precision machining from the nano/atomic scale, which would provide theoretical support for high efficient and no damage ultra-precision machining of semiconductor materials.

Optimal Model-Free Iterative Learning Control of Fast Tool Servo for Real-Time Turning Toolpath Tracking of Freeform Surfaces

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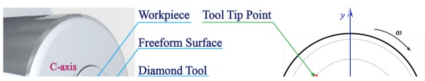
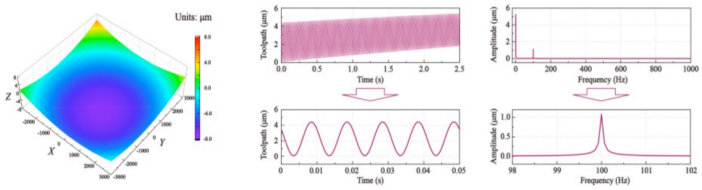
Abstract

Benefiting from the rapid yet low-cost machining capability, the fast tool servo (FTS) diamond turning technology has been widely used to fabricate modern complicated optical freeform surfaces. However, the submicron scale accuracy requirement of freeform surfaces imposes enormous control challenges for the FTS system since the FTS system commonly suffers from the hysteretic nonlinearity and resonant vibration. To address these issues and thus achieve the real-time, high-speed and ultra-precise tracking of FTS toolpath trajectories of freeform surfaces, an optimal model-free iterative learning control (OMFILC) is proposed in this article by synthesizing the PI feedback controller, PD-type learning filter and FIR low-pass filter. The stability and convergence of this real-time control scheme are systematically discussed and analyzed. Based on the basic framework and the convergence conditions of the OMFILC scheme, a comprehensive parameter optimization algorithm is developed to acquire an optimal tracking performance for the specific FTS toolpath trajectory by using the measured input-output data without the system modeling process. Comparative experiments are performed to validate the effectiveness and advancement of the OMFILC scheme for tracking periodic and quasi-periodic FTS toolpath trajectories. The experimental results reveal that the OMFILC scheme presents much better tracking performance than the standard ILC and benchmark PD-type ILC schemes, especially for tracking the quasi-periodic FTS toolpath trajectories due to its real-time iteration behaviour. Typically, the root-mean-square tracking error of the proposed OMFILC scheme is reduced from 80.1 nm of the standard ILC and 46.9 nm of the benchmark PD-type ILC both with a batch-to-batch pattern to 20.7 nm for tracking the quasi-periodic FTS toolpath trajectories of the conventional freeform surface under

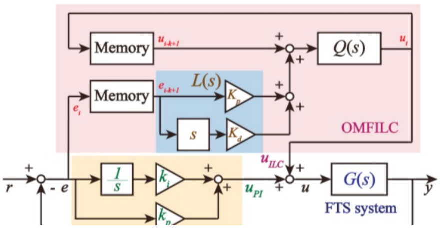
the fundamental frequency of 200 Hz. In general, the online iteration mechanism of the OMFILC scheme endows it a significant advantage over conventional offline ILC schemes in terms of the tracking accuracy and time consumption.



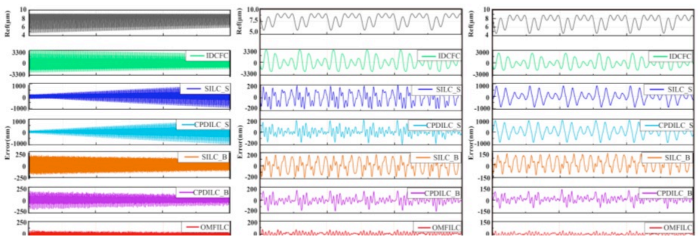
The FTS diamond turning system



The FTS toolpath trajectory analysis of the conventional freeform surface



The proposed OMFILC scheme



The time-domain FTS toolpath trajectory tracking results of the conventional freeform surface

Figure 1: The graphical abstract of the proposed OMFILC scheme

Temperature-Dependent Machinability of Optical Polymers in Diamond Turning

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Abstract

Intraocular lenses (IOLs) are essential optical implants used to restore vision in cataract patients by replacing the natural crystalline lens. The surface quality of IOLs is critical for their optical performance, necessitating ultra-precision manufacturing methods. Diamond turning of optical polymers offers a high-precision, single-piece fabrication approach, ideal for customized and small-batch production. However, the thermal effects during machining, especially in polymers with low glass transition temperatures (Tg), remain insufficiently understood.

This study investigates the influence of ambient temperature on the machinability of optical polymers during ultra-precision diamond turning under controlled environmental conditions. A thermal regulation system was developed to maintain consistent ambient temperatures, enabling the isolation and analysis of temperature-induced material behaviour. Experiments were conducted using polymethyl methacrylate (PMMA) and a novel hydrophobic polymer with a low Tg, employing monocrystalline diamond tools. Key performance metrics include surface roughness and cutting forces. Preliminary findings indicate a significant impact of environmental temperature on surface integrity and material removal mechanisms, contributing to a deeper understanding of thermal effects in precision polymer machining.

Insights into the atomic-scale removal mechanism of SiC in plasma-assisted polishing

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Abstract

Plasma-assisted polishing (PAP) technology enables efficient and damage-free material processing through the synergistic effects of plasma-induced surface modification and soft polishing pads. However, analyzing the material removal mechanism during silicon carbide (SiC) machining remains challenging due to limitations in experimental techniques for real-time observation of the processing zone. Molecular dynamics (MD) simulation, as an atomic-scale numerical method, provides a powerful tool to observe material evolution and elucidate removal mechanisms. This study innovatively incorporates Reax FF Molecular Dynamics (Reax FF MD) simulation to investigate the PAP process of SiC, unveiling for the first time the atomic-scale material removal mechanism and the synergy between mechanical interactions and chemical reactions. Reax FF MD simulation results reveal that oxygen-containing plasma effectively oxidizes and weakens the SiC surface, forming gaseous C-O compounds and low-binding-energy Si-O bonded structures, thereby significantly facilitating material removal during subsequent soft-pad polishing. Furthermore, comparative studies of oxygen plasma-assisted and non-oxygen plasma-assisted polishing processes demonstrate that the oxidative modification induced by oxygen-containing plasma effectively promotes material removal. This work provides novel insights into the material removal mechanism in SiC plasma-assisted polishing, and offers critical guidance for advancing next-generation ultra-precision machining technologies.

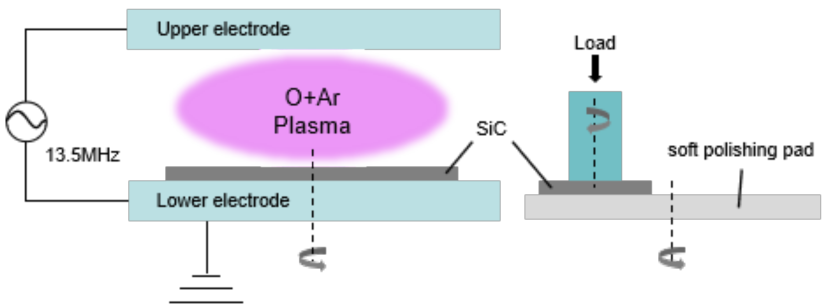

Figure 1: Schematic view of PAP

High-Efficiency Force Rheological Polishing of Hemispherical Resonator Inner Stem

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Abstract

The hemispherical resonator gyro, as a core component of high-precision inertial navigation systems, has its performance directly determined by the machining surface quality and geometric accuracy of hemispherical resonators. Traditional machining methods struggle to achieve efficient ultra-precision machining for complex-shaped components with small curvature radius due to insufficient profiling capability and limited process adaptability. This paper addresses the high-precision polishing challenge of hemispherical resonator inner stems by proposing a shear-thickening polishing method based on non-Newtonian fluid to achieve uniform material removal. Based on force rheological polishing principles, we designed and developed a specialized polishing device for hemispherical resonators, employing specially shaped polishing heads combined with open flow field control technology to realize dynamic adjustment of shear rate on workpiece surfaces. The polishing fluid utilizes polyhydroxy polymer-based shear-thickening fluid whose viscosity changes nonlinearly with shear rate, forming " solid-like fixed abrasive tool" on workpiece surfaces to adapt to surface topography. Through finite element simulation and hydrodynamic analysis, we revealed the influence patterns of polishing speed and shear stress on material removal rate, establishing a material removal model. Single-factor experiments investigated the effects of polishing head rotation speed, machining gap, and polishing fluid composition on processing performance, determining the ranges of key process parameters. Orthogonal experiments optimized parameter combinations, achieving high-efficiency and high-quality polishing of hemispherical resonator inner stems while improving their roundness. This research provides a novel approach for high-precision manufacturing of hemispherical resonator gyros, demonstrating significant application value in aerospace and precision instrumentation fields.

Research on high-efficiency ultra-precision polishing technology of resonant oscillator lip edge

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Abstract

The rotating thin-walled resonator is a key component of the core device in the inertial navigation system (such as the hemispherical resonant gyroscope), and the surface quality and machining accuracy of its lip edge directly influence the vibration characteristics and system reliability of the device. However, traditional polishing techniques (such as magnetorheological polishing, ion beam polishing, etc.) face issues such as low processing efficiency, susceptibility of thin walls to deformation, and interference from support rods, making it difficult to meet the manufacturing requirements for high-precision resonators. Therefore, this study proposes a high-efficiency precision machining method for the lip edges of rotating thin-walled resonators based on Stress Rheological Polishing (SRP), aiming to achieve a synergistic enhancement of surface quality and processing efficiency.

The shear thickening effect of non-Newtonian fluids was studied, and a special force-rheological polishing slurry formulation and experimental platform were designed. Combined with ANSYS statics and hydrodynamics simulation, the structure and process parameters of the polishing tool (polishing pressure, flow rate, spacing, etc.) were optimized to solve the problem of thin-wall deformation and material removal uniformity control.

Experiments show that this method can significantly improve the surface morphology of the lip, and the material removal rate is nearly twice that of traditional magnetorheological polishing, which meets the strict requirements of high-precision inertial devices for ultra-smooth surfaces. This work provides a new idea for the efficient precision machining of complex thin-walled structures.

Achieving ultra-smooth and damage-free surface on deep structure through understanding the material removal mechanism of the modification layer

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Abstract

HSFR (High-spatial Frequency Roughness) induces large angle scattering, resulting in the loss of light energy during transmission or reflection. To meet the needs of etching periodic pattern on optical components to achieve the filtering effect and reduce the light energy loss, higher requirements are put forward to optimize the high-spatial frequency error for both top and bottom of etched groove.

The presentation illustrates the state-to-the-art HSFR precision of a variety of dry etching methods & substrate materials. By optimizing the etching process, we propose a high uniformity super polished surface etching technology based on the ultra-smoothing polishing. After etching 3 microns, the expected roughness is maintained 0.1 nm RMS and the uniformity is better 1%. Finally, an attempt will be made to explain the mechanism of the influence of the selection of process parameters on etching.

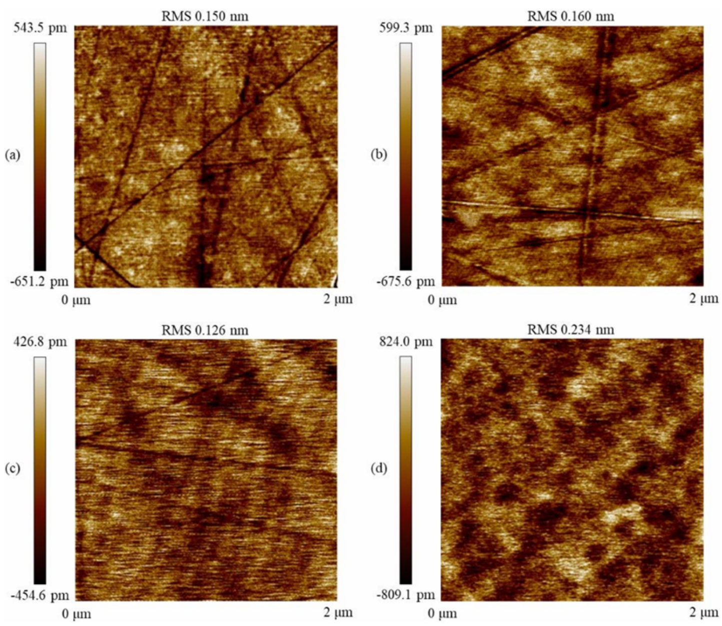

Figure 1: Evolution of surface High-frequency roughness

Compact piezo-driven inchworm rotary mechanism for LISA Space mission

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Abstract

LISA is an ongoing joint-European effort to develop a system capable of detecting low-frequency gravitational waves in space with high precision. This interferometry-based measurement system suffers from tilt-to-length coupling noise leading to misalignment of laser beam with the telescopic interface. An optical beam alignment mechanism actuated with a rotary mechanism is being developed and integrated with the optical bench of the measurement system. This paper talks about the design and development of compact piezo-driven inchworm rotary mechanism adhering to LISA requirements. The mechanism allows shaft rotation in clockwise and anticlockwise directions with high precision. It mimics the rotation of a cylindrical object with two finger twist. A pair of high precision angular contact ball bearings are used to reduce the parasitic movement of the rotor, which is essential to maintain the beam stability. A single actuation cycle consists of four steps as mentioned in Figure-1. The device can turn the rotor by 40 mDeg in a single actuation cycle while maintaining the parasitic translational and angular displacements within ± 1 µm and 6 mDeg, respectively.

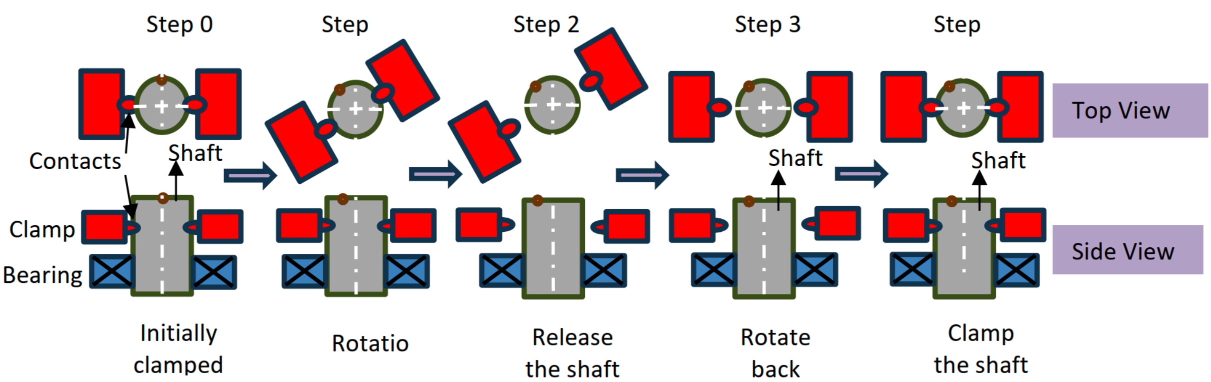

Figure 1 Single actuation cycle steps: Step-0: The shaft is held in place mechanically with two-line contacts, Step-1: Rotation piezo is actuated to rotate the shaft, Step-2: Clamp piezo is actuated to release the shaft. The bearings hold the rotated shaft. Step-3: Rotation piezo is de-energized to come back to original position. Step-4: Clamp piezo is de-energized to clamp the shaft. This becomes the initial state for the next rotation cycle.

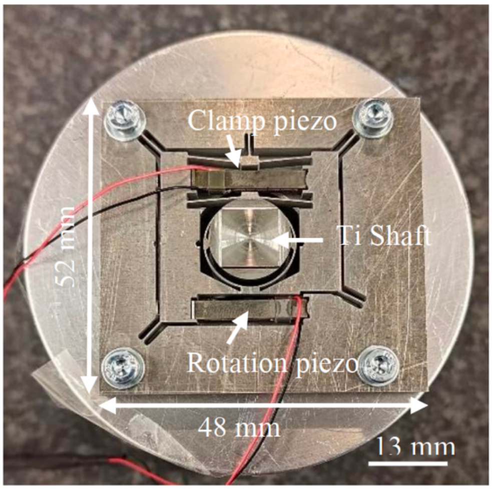

Figure 2 Image of the developed piezo driven rotary mechanism.

Ultra-precision Fly Cutting and Nano-imprinting of Sub-Micron Gratings for AR/VR Applications

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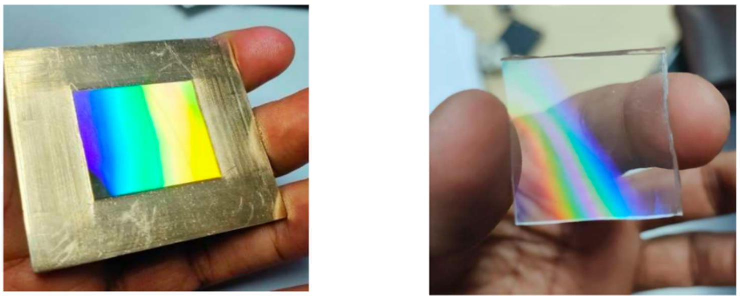
Abstract

The fabrication of sub-micron optical structures is crucial for applications like AR/VR, spectroscopy, and compact imaging. Traditional methods are often complex, expensive, and limited in material and shape compatibility. This work introduces a cost-effective and flexible approach using ultra-precision machining with a customized fly-cutting attachment on a diamond turning platform. This technique enables the creation of high-resolution grating patterns on brass substrates with precise control over depth and pitch, achieving a grating periodicity less than 1 µm and a groove depth of 300 nm over a 25 mm² area.

The resulting brass master is then used in soft lithography to replicate the grating structures onto PDMS, producing transparent soft master with negative structures ready for further replication on actual substrate. Characterization confirms the dimensional accuracy and uniformity of the replicated structures. This method provides a scalable and economical alternative to expensive fast-tool servo systems and cleanroom-based lithography, making it suitable for prototyping and small-scale production of diffractive optical elements, particularly for cost-sensitive AR/VR systems and compact spectrometers.



(a) (b)

Figure 1: (a) Brass grating master (b) Replicated pattern on PDMS

Thermal stability analysis and optimization of field-assisted diamond turning

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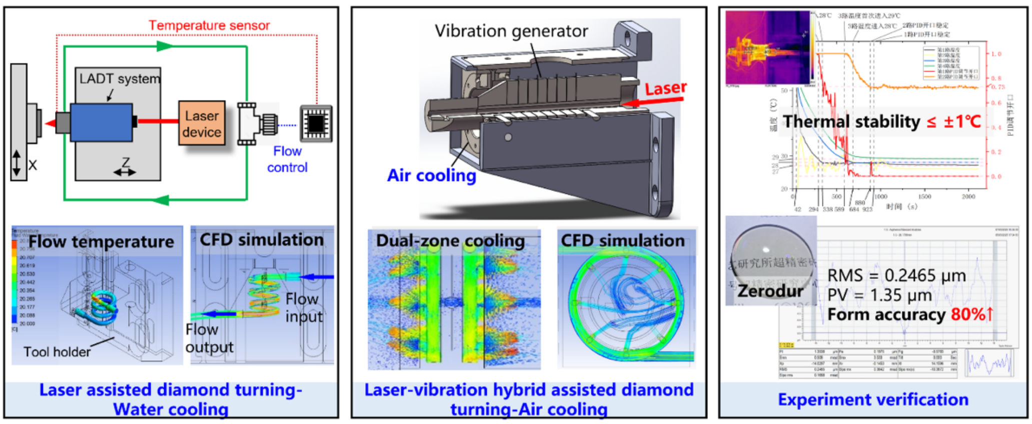
Abstract

Field-assisted diamond turning method, such as laser and vibration-assisted diamond turning, has got wide application in the field of hard-to-machine materials finish. But these methods will introduce external energy fields that significantly impact the system thermal stability. In laser-assisted diamond turning, laser energy partially reflects off the cutting tool, causing the thermal deformation of the tool holder, which affects the overall machining process. These thermal effects severely limit machining precision and workpiece form accuracy. To address these challenges, this study proposes innovative solutions: a water-cooled temperature-controlled tool holder for the laser-assisted turning system, and a closed-loop air-cooled tool holder for the laser-vibration hybrid assisted turning system. These methods effectively mitigate thermal stress within the tool holder, improving thermal stability. Finite element analysis shows that the maximum equivalent stress and strain in the temperature-controlled tool holder are reduced by a factor of 20 compared to conventional tool holders. Additionally, temperature control precision is maintained within ±1°C. To further address residual thermal deformation, a tool path pre-compensation technique is applied based on thermal analysis. Experimental results indicate that the RMS surface form accuracy improved from 1.1409 μm (without temperature control) to 0.2465 μm when the temperature-controlled tool holder and tool path compensation were applied. This demonstrates a significant improvement in form accuracy, validating the feasibility and effectiveness of the proposed methods.



Fabrication of Micro-Structured Ceramic Artificial Hip Joints via Digital Twin-Enhanced Ultra-Precision Grinding

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Abstract

Total joint replacement surgery is an effective method to restore human motion when the joints encounter serious diseases. However, the current lifespan of commercial artificial hip joints (AHJ) is insufficient, and the failure of AHJ entails that there are patients have to undergo revision surgery, which imposes severe physical risks and financial burdens for them. To prolong the longevity of AHJ, the fabrication of micro-structures on ceramic AHJ surfaces using ultra-precision grinding methods was investigated in this study. The tribological performance and fluid behaviour of micro-structured AHJ were analysed through fluid-structure interaction using finite element simulations. For AHJ with curved features, the grinding process for machining micro-structure arrays on the surfaces was planned and optimised using a digital twin method. Subsequently, the micro-structure arrays on the curved surfaces of ceramic AHJ were produced on a multi-axis ultra-precision machining platform. Finally, the surface morphology of obtained micro-structured AHJ was characterized and evaluated. The proposed method provides insights for the efficient and high-precision fabrication of micro-structured arrays on AHJ surfaces, contributing to the advancement of biomedical implant applications and the improvement of patients' quality of life.

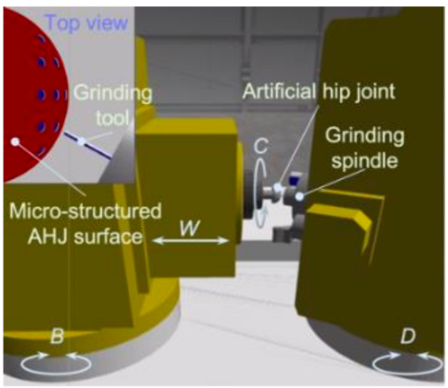

Figure 1: Digital twin model for ultra-precision grinding of micro-structured surface on AHJ.

Characterization and experimental study of electromechanical coupling of ball screw servo feeding system

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Abstract

To study the effect of deformation, vibration and uneven mass distribution of the mechanical structure of the feeding system on the electromechanical coupling characteristics of the ball screw drive system, in this paper we obtained the stiffness matrix of the complex structure of the bearing group, the screw nut pairs and so on through theoretical analysis. We built a finite element model of the mechanical structure of the servo feeding system of the ball screw and verifies the finite element model of the mechanical structure through the comparison of the theory of the transmission relationship and the simulation results. On the basis of the above research, we have used the MATRIX27 unit integrated with a PID control unit to establish an electromechanically coupled finite element model of the ball screw servo feeding system. We used the model to analyze the electromechanical coupling characteristics of the servo feed, and obtained the modal characteristics of the system as well as the effects of the moving mass change and mass distribution on the performance of the servo system. We carried out electromechanical coupling characterization experiments based on the servo feeding system of a small precision five-axis CNC machine tool, obtained the dynamic characteristics of the system as well as the influence law of the table mass and distribution on the performance of the servo system, and verified the correctness of the electromechanical coupling finite element simulation results.

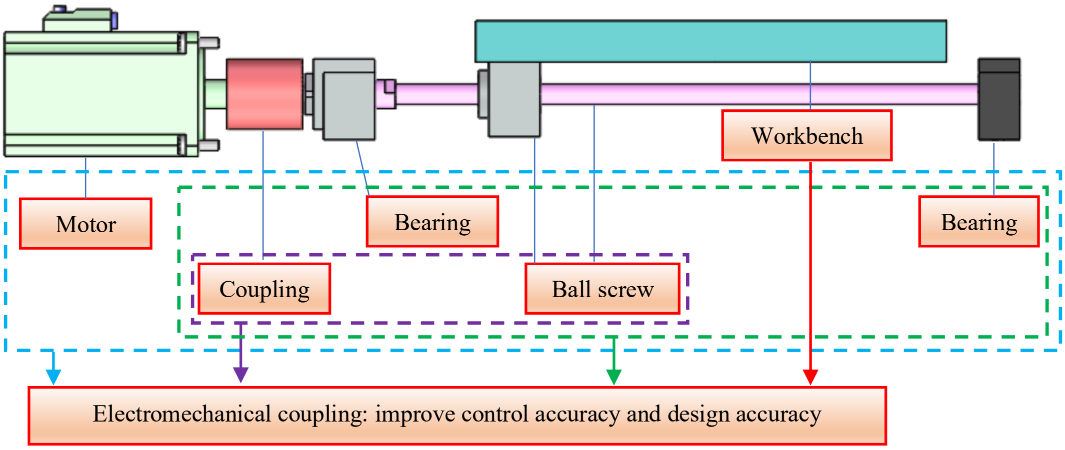

Figure 1: Composition and coupling relationship of ball screw servo feed system

Electrode shape wear prediction in micro-edm with machine learning

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Abstract

Micro electrical discharge machining (micro-edm) is a cost-effective way to fabricate micro-scale features on conductive materials. This non-contact process uses electric sparks to achieve material removal and shows the advantages of high precision and dimensional accuracy, as compared to traditional micro-milling/micro-drilling processes. However, electrode wear electrode wear is a key issue, with limits the precision of the fabricated features. This is especially important for micro-edm, as the minor change in the electrode can copy these errors into micron-scale features. In micro-edm, two different types of electrode wear occur simultaneously. Type one is the axial length wear. The electrode gets shorter in the axial direction with the progression of machining process. Type two is electrode shape wear, where the shape of the electrode changes with the progression of micro-edm process. In the literature, the type one wear has been intensively investigated. However, the study on the evolution of type two shape wear is rather limited.

This study conducted a series of electrode shape wear experiment with micro-edm slot milling as a case study, considering the influence of milling layer depth, electrode diameter and cutting distance. A comprehensive database capturing electrode shape wear characteristics—specifically wear depth and wear width—was established. A Broad Learning System (BLS) machine learning model, well-suited for small-sample-size prediction, was developed and trained using this dataset. The model accurately predicts the evolution of electrode shape wear during the micro-EDM process and can be effectively applied to guide electrode change or dressing in micro-edm process, to improve its precision.

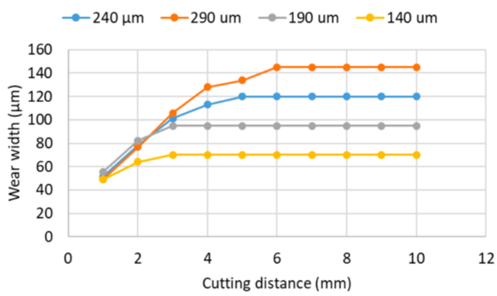

Figure 1: Influence of electrode diameter on the shape wear width evolution in micro-edm

Comparing state-of-the-art 2PP to competing processes – a take on precision, accuracy and throughput

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Abstract

In photopolymer-based micro-additive manufacturing, the application areas of projection micro-stereolithography (PµSL) and two-photon polymerization (2PP) overlap in terms of the overall achievable part sizes, which range from a few hundred micrometers to several millimeters. While µSL offers potential throughput advantages through layer-wise parallelization, the actual precision of printed parts typically falls significantly short of the advertised nominal resolution, due to limitations inherent to the single-photon process. In contrast, 2PP enables manufacturing with sub-micrometer precision. Technological advances in 2PP, including *Adaptive Resolution*, which dynamically adjusts the voxel size during printing, enable a significant increase in throughput towards batch production.[1] Moreover, in vat-based 2PP the voxel is kept at a constant height above the bottom of the vat, creating a consistent liquid interface below the part.[2] In contrast to PµSL, there is no need to delaminate from the bottom of the vat after each layer, which can damage delicate parts and adds a time delay of typically 4–5 s per layer.[3]

In both cases, the question of how to optimize the printing process for maximum absolute dimensional accuracy in practical parts is often overlooked. The fundamentally different printing mechanisms make direct comparisons of basic machine parameters difficult and underline the need for robust statistical evaluation of representative prints to accurately assess process capabilities and avoid misleading conclusions about performance trade-offs.

Here, we show how the 2PP process can be augmented via dynamic control of lateral voxel size for efficient multi-scale printing, matching the throughput of PµSL while exhibiting an order of magnitude better precision. Based on a reliable automated analysis of part dimensions, we can take a detailed look at both part repeatability (intrinsic printer precision) as well as a multitude of effects (often much larger than the bounds on precision) that affect dimensional accuracy. The latter include mechanical influences such as beam steering and thermal drifts, chemical effects such as global shrinkage, boundary erosion and material batch

variations, anisotropic exposure, or the optimization of slicer algorithms, among others. We predictively model these effects to optimize process capability without requiring part-specific iterative finetuning.

In conclusion, we demonstrate that the versatility of the 2PP process can uniquely provide polymer printing with true sub-micrometer precision and accuracy, at competitive throughput, even up to the macroscopic domain.

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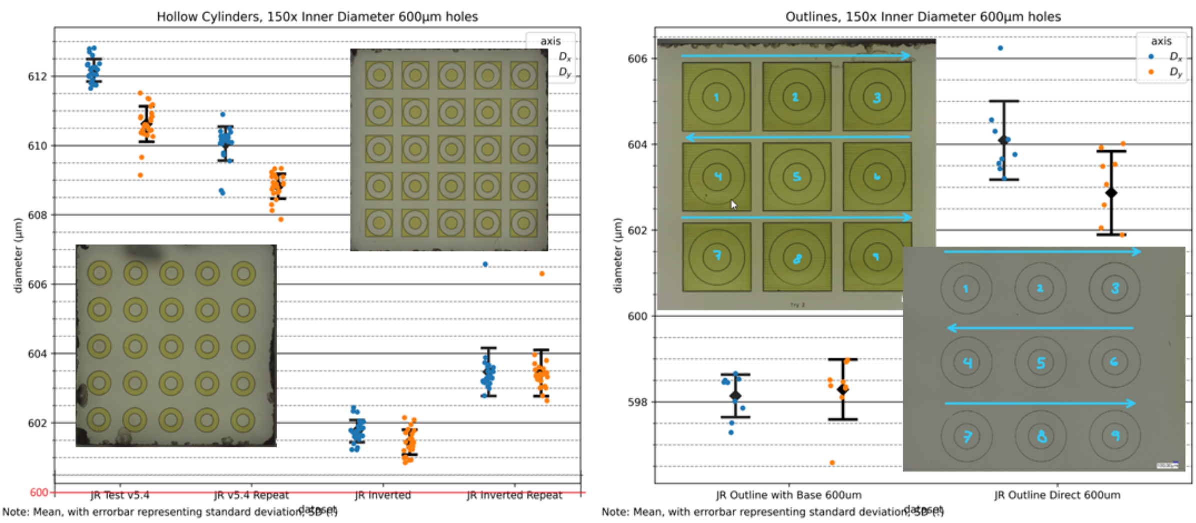

Figure 1: Statistical analysis of various test structures to single out various different effects influencing print precision and accuracy in 2PP with a low magnifying 5x objective in coarse mode: *Left to right* - hole ellipticity, long-term drift between repeated prints of batches, mismatch between nominally equal inner and outer diameter, shrinkage of bulk material, scanner miscalibration manifesting as diameter mismatch of outlines printed directly on substrate.

Simulation-Driven Design of Ultrasonic Horns for Precision Micro-Grinding Applications

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Abstract

High-precision micro-machining and grinding processes are increasingly vital for the fabrication of nextgeneration components in aerospace, biomedical, and semiconductor industries. As the demand for tighter tolerances, superior surface finish, and material integrity increases, conventional machining techniques face limitations in tool wear, heat generation, and material removal efficiency. Ultrasonic Vibration-Assisted Grinding (UVAG) and Ultrasonic Minimum Quantity Lubrication (UMQL) have emerged as promising solutions, enabling improved performance through high-frequency vibrations superimposed on conventional grinding operations.

This research focuses on the simulation-based design and optimization of ultrasonic horns, critical components in delivering high-frequency energy, to enhance micro-grinding effectiveness. Traditional horn designs often rely on heuristic and trial-and-error methods, which are time-consuming and prone to detuning, especially in precision applications. To address this, we propose a comprehensive design framework integrating analytical modeling, finite element simulations, and experimental validation. Initial design begins with resonance length estimation using elastic wave propagation theory, followed by the development of parametric CAD models. Modal and harmonic analyses in ANSYS Workbench ensure tuning accuracy to the target frequency (20 kHz), maximize amplitude gain, and minimize stress concentrations. A coupled horn-workpiece model is simulated to replicate realistic operational conditions. Post-simulation, horns are fabricated using ultra-precision machining, and their vibrational characteristics are validated with frequency analysers and displacement measurement systems. Deviations from the simulated behavior are corrected via iterative refinement, ensuring system compatibility and robust performance.

This study presents a robust and adaptable methodology for the design of ultrasonic horns specifically tailored to micro-machining and precision grinding applications. The approach significantly advances ultrasonic tool development by offering improved dimensional accuracy, streamlined design processes, and increased operational efficiency. Moreover, the methodology is well-aligned with Industry 4.0principles, enabling seamless integration into digitally connected, data-driven manufacturing ecosystems.

On the use of Virtual Image Correlation methods to enhance accuracy in contour identification using X-ray computed tomography data

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Abstract

ISO 17450-1 [1] introduces a set of feature operations to specify and verify geometrical and dimensional tolerances (GD&T). Among these, partition, extraction, association, and reconstruction are important feature operations. The latter is employed to create a continuous feature from discrete data. Unlike the association operation [1], reconstruction aims to preserve the topology of the input feature[2]. Looking forward to modern challenges in surface metrology, reconstruction seems to have a pivotal role in the analysis of complex surfaces. Jiang et al. [3] used an approximated NURBS (Non-Uniform Rational B-spline) as the reference surface to perform roughness analysis on freeform surfaces. The use of B-splines also shows prospects in the filtration of complex geometries [4, 5].

In this work, a method to reconstruct surfaces with the use of B-splines directly from the raw data extracted via X-ray computed tomography (XCT) is introduced. A Virtual Image Correlation (VIC) method is used to reconstruct image contours using B-splines. B-spline VIC methods were used in different applications (Z. Jiang et al. [6], J. Réthoré et al. [7]), showing promise in achieving sub-pixel accuracy [7, 8]. This work aims to extend those findings to complex industrial cases, e.g., surfaces of additively manufactured parts. As in all optimisation problems, the approximation is guided by the minimisation of a score function. While for most methods the score function is computed from the difference between the data to be fitted and the reconstructed feature, in VIC methods it is computed from the differences between a real and a virtual image. The real image is obtained after the XCT scan of the actual part. The virtual image is created using a mathematical contour that defines the parts' boundaries. Therefore, the minimisation of the score function guides the deformation of the mathematical contour until the virtual image best represents the real one.

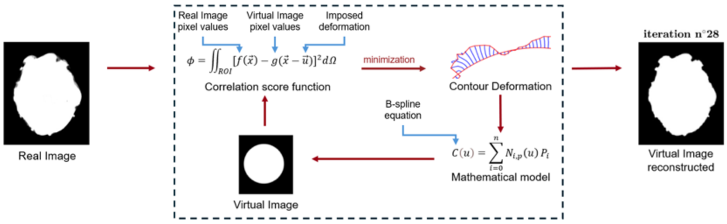

Figure 1: schematic representation of the B-spline virtual image correlation method.

In the present work, the mathematical contour consists of a closed B-spline, and the reconstructed images are XCT cross-sections of cylindrical samples produced via additive manufacturing, particularly using laser powder bed fusion of metals (PBF-LB/M). Fig.1 shows a schematic representation of the proposed methodology applied to a cross-section of one of the fabricated samples. Fig.2 compares the reconstructed contour using the B-spline VIC method with the contour reconstructed from the discrete data obtained with the ISO-50% segmentation method. While the two contours show overall good agreement (Fig. 2b), the detailed images in Fig. 2c and 2d show minor discrepancies in the description of details at the microscale.

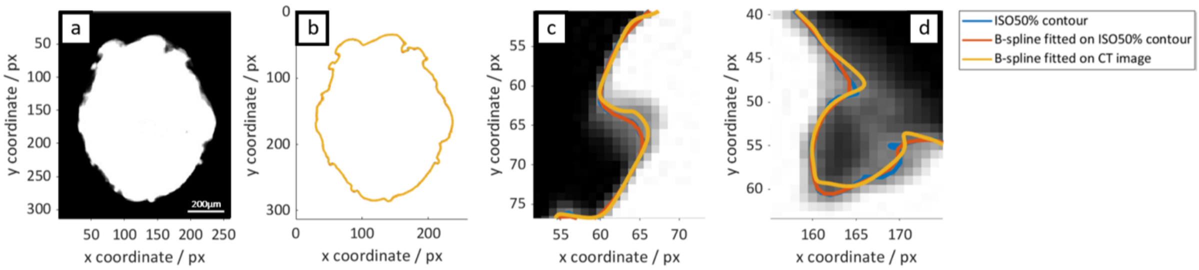

Figure 2: XCT cross-section of a cylindrical sample produced via PBF-LB/M, with pixel size equal to 3 µm (a); comparison of the contours reconstructed by using the B-spline VIC method and by fitting on the ISO50% contour(b); same comparison on detailed regions of the image (c, d).

These local differences, whose magnitude is around 1-3 pixels, could span from one to tens of micrometres, depending on the pixel size. This observation highlights the importance of investigating alternative contour reconstruction methods and assessing their accuracy and precision. Virtual image correlation methods, by working directly on the raw XCT images and incorporating the extraction and reconstruction operations, have the potential to enhance the contour reconstruction of XCT cross-sections. Future works will focus on validating this method against calibrated artefacts and extending it to surfaces.

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Robust Salvinia-inspired superhydrophobic surfaces on hydrophilic materials via two photon polymerization

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Abstract

Salvinia-inspired superhydrophobic surfaces are characterized by their exceptional air-retention capability and have demonstrated significant potential across a wide range of engineering applications, including drag reduction, water harvesting, evaporation control, liquid repellence, oil–water separation, and thermal insulation. Furthermore, these bio-inspired structures provide an effective strategy for imparting superhydrophobicity to intrinsically hydrophilic surfaces, thereby expanding the functional versatility of such materials. However, these surfaces typically possess small contact areas, leading to high localized stresses, and are prone to physical damage. This makes it especially important to investigate their mechanical stability and develop more robust and durable superhydrophobic structures. The Salvinia structures exhibit superhydrophobic properties over a wider range of heights and widths, making them effective across multiple length scales. Combining features at different heights and scales has proven to be an effective strategy for achieving robust wettability - even after partial wear or abrasion, the surface can still maintain its wettability characteristics. This study employs the sophisticated prototyping technique of two photon polymerization (TPP), offering a hundred-nanometer-scale resolution and three-dimensional fabrication capability. This enables the flexible and precise construction of diverse and intricately designed micro- and hundred-nanoscale structures. The critical thresholds of superhydrophobicity are investigated through the design of surface structures with varying heights and characteristic scales. These insights guide the development of structural integration strategies with varying geometries to maintain superhydrophobic performance under mechanical wear. Surface wettability is assessed after controlled material removal at different depths, providing experimental validation of structural robustness, with fabrication carried out via TPP.

Keywords: Superhydrophobic, Robust, Salvinia structure, Two photon polymerization.

Molecular dynamics study of 4H-SiC indentation deformation mechanism

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Abstract

4H-SiC is widely used in the fabrication of semiconductor devices which has a strategically important position in aerospace, medicine, electronics and electric power, etc. However, the high hardness and brittleness of 4H-SiC make it prone to have surface and subsurface damage during abrasive machining. Owing to the complex anisotropy and atomic arrangement of 4H-SiC crystals, the deformation behavior of the material during processing is highly complicated. Therefore, it is of great practical significance to elucidate the deformation mechanism of 4H-SiC in the abrasive processing. In this study, molecular dynamics simulations were employed to investigate the material deformation mechanisms of 4H-SiC during the nanoindentation process. The deformation mechanisms were analyzed in terms of mechanical response, laminar deformations and slips, with indentation experiments conducted for verification. The results reveal that the mechanical response during indentation process has phase fluctuation, which is mainly related to the generation of dislocations. The slips lead to the laminar deformations of 4H-SiC, which are primarily attributed to the unique atomic arrangement of 4H-SiC as well as the stress effect. Notably, the prismatic slip is closely associated with the transverse slip, with prismatic slip easily generated at the end of a transverse slip as indentation depth increases. The reliability of the MD simulation results was verified by indentation experiments. The findings provide valuable insights into the deformation mechanisms of 4H-SiC and offer significant reference value for the practical processing of 4H-SiC.

The effect of grinding speed on the deformation mechanism of single crystal gallium nitride studied by nanoscratching

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Abstract

Grinding of single-crystal gallium nitride (GaN) is a complex process involving interactions between numerous diamond grits and the workpiece. Consequently, its material removal and deformation mechanisms are significantly influenced by grinding parameters, with grinding wheel speed being one of the most critical factors. Therefore, investigating the effect of strain rate variations induced by grinding speed on the material's deformation mechanism is of great importance. In this study, a Berkovich indenter was employed to perform nanoscratch experiments on the (0001) (C-plane) of GaN across a velocity range from 0.1 μm/s to 100 μm/s, mimicking the grit-workpiece interaction in the grinding process at varying grinding wheel speed. The results reveal that at various scratch velocities, the damage induced by the Berkovich indenter encompasses both brittle deformation, characterized by surface and subsurface microcracks, as well as plastic deformation, primarily attributed to dislocation slip. Moreover, as the scratch velocity increases, the critical normal load required for the transition from plastic to brittle deformation in GaN also rises. Furthermore, reductions in both the width of scratch grooves and the thickness of the subsurface damage layer suggest that higher scratch velocities promote low-damage removal of GaN within the plastic regime. Transmission electron microscopic characterization of the subsurface damage provides deeper insights into GaN deformation mechanisms of GaN. These findings have significant implications for advancing ultra-precision grinding techniques for GaN substrate.

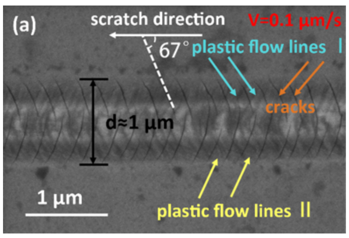

Figure 1: Scanning electron microscopy image of surface morphology of the scratched surface of GaN substrate with various deformation features labelled.

Unveiling the Anisotropic Deformation Mechanisms of β-phase Gallium Oxide

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Abstract

β-phase Single-crystal gallium oxide (β-Ga_2O_3), as a next-generation wide-bandgap semiconductor material, holds great potential for applications in high-voltage and high-power devices. However, its high brittleness, pronounced anisotropy, and cleavage-prone characteristics pose challenges for efficient and precise substrate processing. In this study, stacking fault energy calculations, molecular dynamics simulations of nanoindentation, and nanoindentation experiments were performed to investigate the deformation mechanisms on four commonly used crystallographic planes of β-Ga_2O_3 substrates. The results reveal that the presence of a local minimum energy site at 1/2[001] on the (400) plane contributes to the propensity for stacking fault formation on this plane. Indentation-induced deformation of β-Ga_2O_3 exhibits significant anisotropy. Specifically, the (100) plane displays a higher critical load for the elastic-to-plastic transition, with uniform plastic deformation confined to the surface. At increased indentation depths, cracks form on multiple crystallographic planes. On the (010) plane, dislocation loops with a Burgers vector of [010] are generated under indentation and extend deeper into the material, resulting in more extensive plastic deformation. Stacking fault energy calculations indicate that the low stacking fault energy and small Burgers vector along the [010] direction on prismatic planes are key factors underlying the anisotropic deformation of the substrate. Additionally, slip on pyramidal planes facilitates uniform plastic deformation, effectively accommodating the anisotropic deformation behavior of β-Ga_2O_3 under indentation. The slip system model proposed in this study provides a robust framework for understanding the anisotropic deformation mechanisms observed in β-Ga_2O_3 during nanoindentation.

Theoretical Study on High-Precision Optical Manipulation Based on a Novel Optical Force Device

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Abstract

Optical force is a highly precise, non-destructive and non-contact force capable of manipulating macroscopic devices at the atomic and close-to-atomic scale. It holds promise as a critical breakthrough for next-generation ultra-precision optical sensing, metrology, and manufacturing technologies. A novel optical force device was recently proposed that enables rapid response to applied optical forces and linear conversion into device displacement under standard gravitational conditions. This study focuses on achieving high-precision macroscopic manipulation based on this optical force device. According to the device's geometric structural model, the steady-state and dynamic displacement models driven by optical force are established using the micro-scale cantilever beams theory. In the steady-state model, the Euler-Bernoulli equation is utilized to describe the elastic deformation process of the device under optical force, from which the equivalent elastic coefficient of the device is derived. Subsequently, based on the mass-spring equation, a dynamic model of the device is formulated by incorporating the derived elastic coefficient. Through analytical calculations of these models, the transient displacement responses of the device under various time-varying optical force conditions are systematically analyzed, thereby obtaining the required modulation parameters and control equations for achieving high-precision optical force manipulation. The theoretical result demonstrates that the displacement uncertainty due to the oscillation induced by the dynamic optical force in the manipulation canbe controlled within 0.7Å when the device is subjected to an optical force of 132.60 nN. This study provides a theoretical foundation and methodological framework for implementing optical force manipulation of macroscopic-scale objects with high accuracy.

Enhancement of Irradiation Performance in Fast Atom Beam Source with Internal Electrode

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Abstract

Surface activated bonding (SAB) is a room-temperature bonding technique that enables the direct joining of materials such as semiconductors. In this process, a fast atom beam (FAB) is irradiated onto the wafer surface in a vacuum environment to remove native oxide layers and surface contaminants, thereby activating the surface. When two activated surfaces are brought into contact, covalent bonds form, allowing for direct bonding without the need for thermal processing (Figure 1). Owing to this advantage, SAB facilitates room-temperature bonding of dissimilar materials and has been widely employed in the fabrication of electronic components such as surface acoustic wave (SAW) filters and in three-dimensional integration technologies for semiconductor devices.

The FAB source, which generates the fast atom beam, operates by converting argon gas into plasma, accelerating the argon ions, and subsequently neutralizing them to produce a fast neutral argon beam. As wafer diameters continue to increase, the demand for enhanced beam uniformity and improved irradiation performance across the wafer surface has grown. In this study, we propose a novel FAB source design and investigate the impact of adding an internal electrode on its irradiation characteristics (Figure 2).

Irradiation performance was evaluated through oxide film removal tests. The results demonstrated superior oxide removal capability and a significantly larger irradiation area compared to a conventional FAB source (Figure 3). These enhancements are attributed to a reduction in the gas flow required to sustain the plasma, which increases the mean free path of the neutral atoms and thereby maintains higher beam energy. The findings suggest that the proposed FAB source design offers substantial advantages for large-diameter wafer processing over conventional configurations.

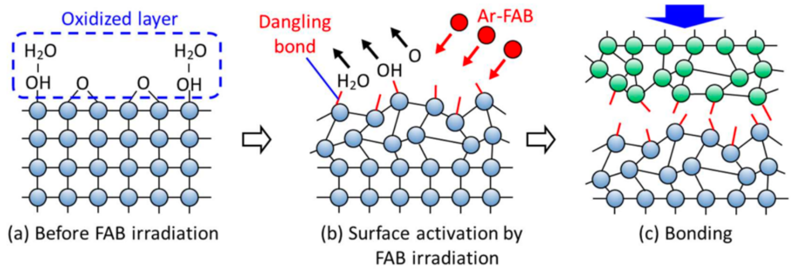


Figure 1: Surface activation bonding

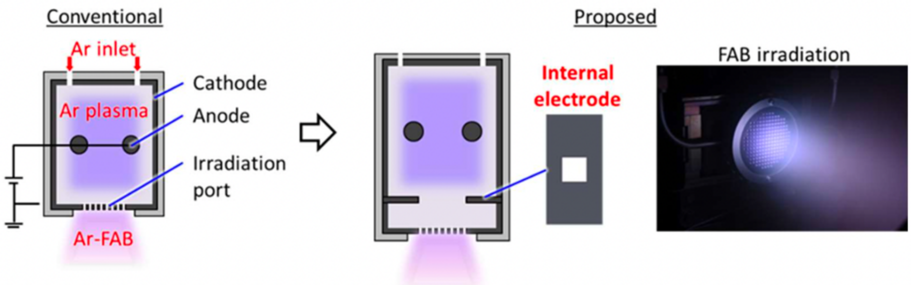


Figure 2: Comparison of FAB source structures between the conventional and the proposed designs

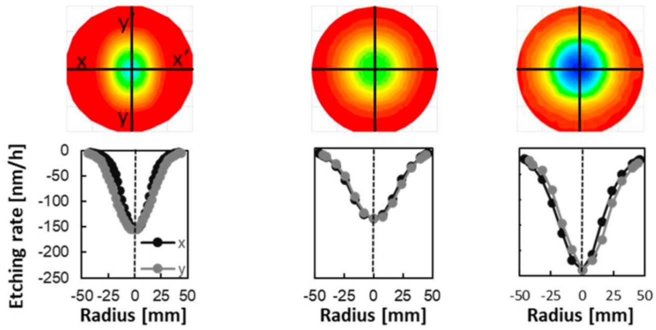
Type	Conventional (64-Φ2.3)	Proposed (192-Φ2.3)	
A	-	542.9 mm²	77.4 mm²
Voltage	1.0 kV	1.0 kV	1.0 kV
Current	100 mA	100 mA	100 mA
Ar flow	50 sccm	72 sccm	8.2 sccm
Etching rate	154.4 nm/h	135.8 nm/h	238.2 nm/h
Removal image			
Section profile and etching rate [nm/h]			
FWHM(x)	29.39	44.70	41.53
FWHM(y)	39.30	45.25	42.09

Figure 3: Comparison of oxide layer removal test

Multi-channel wide spectrum high resolution spectrometer for thin film thickness measurement

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Abstract

With the increasingly extensive application of thin films in industrial and scientific research fields, precise measurement of thin-film thickness has become of utmost importance. Traditional spectroscopic interference-based thin-film thickness measurement techniques face limitations when dealing with new thin-film materials and complex structures. This study presents a multi-channel wide-spectrum high-resolution analysis technology. By implementing a multi-channel spectral sampling strategy, integrating precise spectroscopic elements and independent optical focusing and imaging systems, this technology optimizes the utilization of photosensitive element resources. Optical system correction techniques, including coma aberration optimization, astigmatism correction, and high-order aberration correction, are employed to enhance the imaging quality and spectral resolution. Moreover, multi-channel calibration and compensation techniques, such as least-squares-based multi-channel calibration and non-linear correction, are utilized to improve the accuracy and reliability of measurement data. Notably, this technology enables high-precision measurements spanning from the nanometer to the millimeter scale, and its wide-spectrum characteristic provides a significantly larger measurement range ratio compared to conventional spectrometers. Simulation results verify the effectiveness of this technology. It outperforms existing technologies in terms of comprehensive information acquisition, analysis accuracy, and detection efficiency, offering a novel approach for thin-film thickness measurement. This technology holds broad application prospects in fields like semiconductor chip manufacturing and optical coating. Future research will focus on further expanding the spectral range, improving the resolution, and enhancing the real-time measurement ability.

Challenges in Manufacturing and Measuring Microstructures with Re-Entrant Features Using Two-Photon Polymerization and Micro-CT

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Abstract

Two-Photon Polymerization (2PP) is a cutting-edge additive manufacturing technology that enables the fabrication of intricate three-dimensional microstructures with complex geometric features in the sub-micrometer range. One of the unique capabilities of 2PP is its ability to produce re-entrant features—geometries that curve or fold back into themselves, such as undercuts, overhangs, and internal cavities. The presence of re-entrant features can give 2PP-fabricated components superior functional and structural properties, critical in fields such as biomedical scaffolds, tribology and micro-optics.

From a metrological standpoint, however, re-entrant features introduce significant challenges for dimensional verification. Conventional tactile probes are inherently limited by their physical size and geometry of the tips—which prevent them from accessing internal or recessed areas of a part. Likewise, optical measurement techniques rely on line-of-sight principles and are unable to capture occluded surfaces or undercuts accurately. These limitations make it impossible to fully characterize the geometry of re-entrant structures using standard surface metrology tools at micrometer level.

In contrast, metrological X-ray computed tomography (microCT) provides a non-destructive and volumetric imaging approach, capable of reconstructing the internal and external geometry of complex microstructures. MicroCT can measure fine-scale features across a range of material types and densities, and crucially, it can

capture hidden or inaccessible surfaces, including those within re-entrant geometries. However, its volumetric resolution is limited and cannot compete with vertical resolution of optical or tactile systems.

In this study, we conducted a case analysis of re-entrant features with varying thicknesses, radii, and height values. Multiple structures were fabricated onto a single sample (Fig. 1) and measured using micro-CT to delineate the limitations of both the manufacturing and measurement machines (Fig. 2). This leads to new insights into the characterization of re-entrant features using the micro-CT technology and helped to indicate the limits of that measurement technique in quality surface inspection of micro-additively manufactured parts.

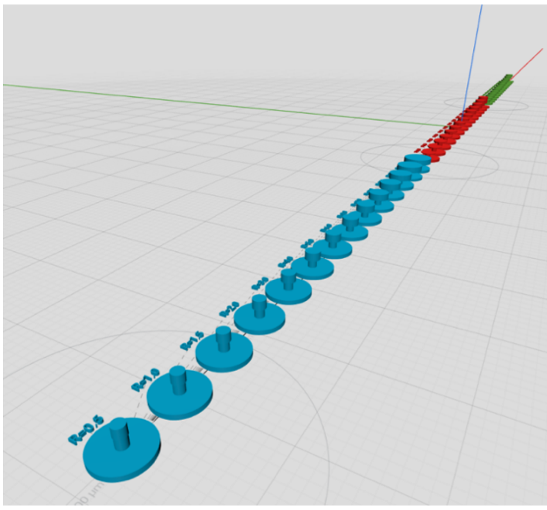

Figure 1: Sample design for the parameter study using different design geometries for 2PP

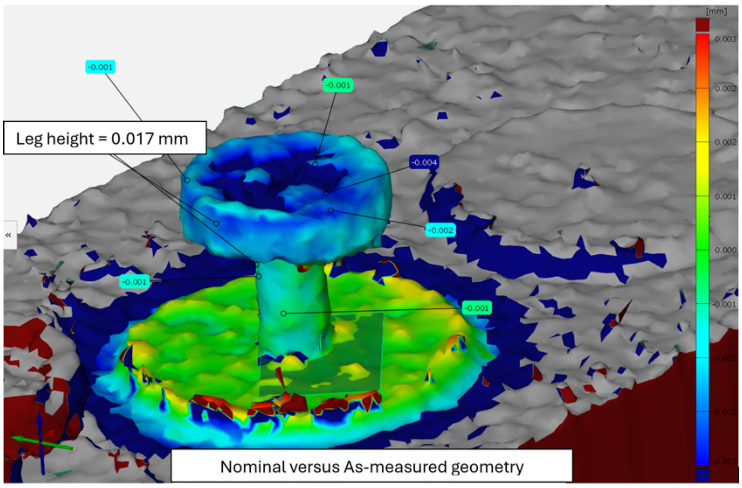

Figure 2. Exemplary comparison of nominal and as-measured geometry with microCT scanning

Nano-cutting fluids based on graphene nanoparticles for deep hole drilling under MQL conditions

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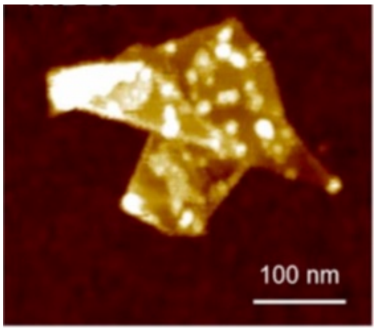
Abstract

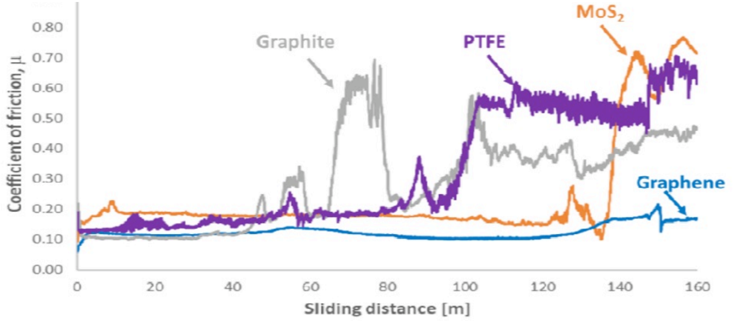
Minimum quantity lubrication (MQL) is increasingly taking on a fundamental role into the field of machining technologies as a cost effective and highly sustainable replacement for conventional flood lubrication since it requires only few milliliters of lubricant per hour for machining operations.

Nano-cutting fluids (NCF) are emerging as very promising alternatives to conventional cutting fluids (CCF) for MQL applications in machining to solve the problems due to CCF drawbacks and provide enhanced operation performance. NCF are mixtures of CCF and nanoparticles: as a matter of fact, the addition of suitable nanoparticles to CCF can improve wettability, lubrication properties, and cooling properties of the obtained NCF, providing for reduced temperature in the cutting zone, decreased cutting forces, improved machined surface quality and extended tool life

In this work, a comparative study of tool wear, surface roughness, hole cilindricity and coaxiality during deep drilling with CCF and NFC under internal MQL conditions is undertaken. The NCF was prepared by adding graphene nanoparticles to the corresponding CCF considering that, as graphene has a high thermal conductivity (5000 $W/m^{-1}*K^{-1}$) and low friction coefficient (Fig. 1b), graphene nanoparticles (Fig. 1a) can endow an increased thermal conductivity and improved friction behaviour to the cutting fluid and thus represent an ideal additive to a CCF in order to realise an effective NCF.

The results of this study show that hole quality parameters are enhanced when performing deep drilling operations under MQL with NCF in comparison to CCF.





(a) (b)

Fig. 1: (a) Graphene nanoparticles (thickness: 20 nm). (b) Graphene coefficient of friction vs. sliding distance

Off-axis Wavefront Measurement for Defocus Lens Design

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Abstract

Myopia, referred to as shortsightedness, is a common cause of visual disability throughout the world. Study shows that the development of myopia is significantly affected by the off-axis aberrations. One of the myopia control approaches is wearing defocus lenses targeting at the correction of the off-axis wavefront aberration. However, due of the lack of effective approaches to measure the off-axis wavefront, currently defocus lenses are designed and manufactured without the capability to fully eliminate the off-axis aberration. Based on Hartmann-Shark wavefront sensing technology, a novel measurement approach for efficient characterization of off-axis wavefronts was developed. This method allows the measurement of a large visual field angle up to ± 50° and takes all meridian scanning into account, which means it can be used for global scan of wide range of human retina and provide detailed wavefront data for the development of more effective defocus lenses.

An elliptical scanning mechanism was developed to achieve off-axis measurements. Consisting of galvanometer scanners and a robust displacement stage moving along an elliptical trajectory, this mechanism can pivot the light paths to direct the laser into the pupil at an off-axis angle and transfer the reflected light back to the sensor.

One of the significant challenges in the measurement process is to align the laser with the pupil to maintain accuracy. The research overcomes this by developing precision calibration methods. A separate stand holds the calibration mark, thereby simulating the stationary state of a human pupil and preventing interference from the rotating parts in the system. Additionally, a dual-aperture structure is employed to accurately indicate the rotation axis of the system. The introduction of an iterative adjustment method—alternating between rotational and translational movements, with finetuning guided by photometric feedback—ensures that the laser is continuously adjusted toward the ideal central line, as shown in Fig. 1. Mathematical analysis confirms that repeated iterations minimize both deviation angle and distance.

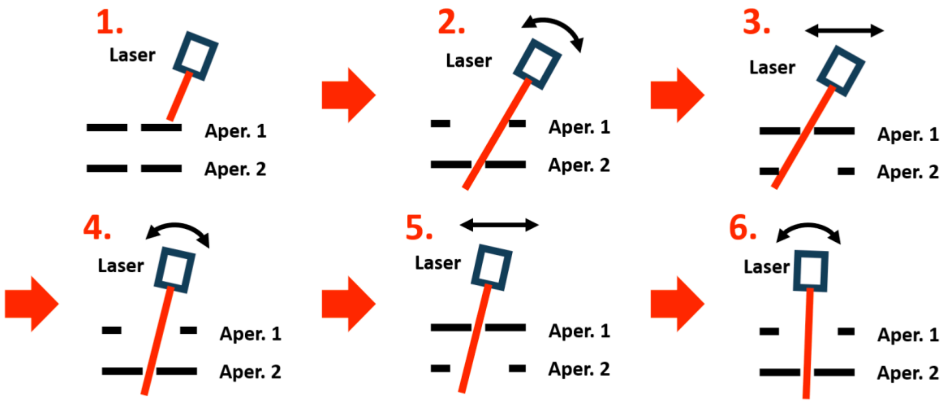

Figure 1: Iterative adjustment method

A control system is also developed based on a distributed architecture integrating hardware and software seamlessly. The host computer executes user commands and coordinates various subsystems—such as stepper motors, scanners, infrared cameras, and wavefront sensors—using multiple communication protocols. A dedicated microcontroller is also integrated within the spinning chamber to manage local device control, which simplifies the overall design and enhances real-time responsiveness. This is further supported by a custom adaptor featuring a power converter and a fourline data driver.

Nanoscale Film Formation via Dilute Solution Spin Coating: Exploring the Thickness Limit and Uniformity

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Abstract

As nanoscale devices advance toward sub-10 nm fabrication, achieving ultrathin and uniform photoresist films has become increasingly critical for applications such as EUV lithography, quantum computing, and nanophotonics. This study investigates the limiting nanoscale film thickness attainable through dilute solution spin coating and its influence on film uniformity. By systematically varying spin speed and solution viscosity, ultrathin photoresist films approaching the process limit were fabricated. A wet etching technique was employed to create step profiles on the film surface above the substrate, and an optical profilometer was used to precisely measure film thickness, enabling efficient, non-destructive evaluation of thickness and uniformity across the entire surface. Experimental results reveal that film thickness decreases with increasing spin speed following a power-law relationship, with improved agreement to theoretical predictions under higher dilution. However, as the film approaches its limiting thickness, significant non-uniformity arises. A spin-coating process window is defined based on the proposed concept of a uniformity-constrained limiting thickness, providing practical guidance for producing reliable nanoscale coatings. These findings offer essential insights into the controlled formation of ultrathin photoresist films for high-performance next-generation nanomanufacturing.

Holographic mask fabrication by photoelectrochemical etching

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Abstract

Holography has been researched and widely applied in diverse fields, including advanced optical imaging, non-destructive testing in engineering, biomedical imaging, virtual reality, and the digital arts and design. Holographic lithography, due to its high tolerance to defects, simplicity of optical systems, low cost, and capability for three-dimensional lithography, has become an excellent technology for micro-nano fabrication. In this context, we propose a low-cost and rapid fabrication method of holographic lithography masks without using a photomask. Our approach is based on photoelectrochemical etching, in which an optical system generates a structured light field on the sample's surface that approximates a holographic mask pattern. We fabricated several masks with different pixel counts and compared each mask's corresponding holographic imaging results. We believe this technique has the potential to pave a new way for the low-cost and rapid fabrication of holographic masks.

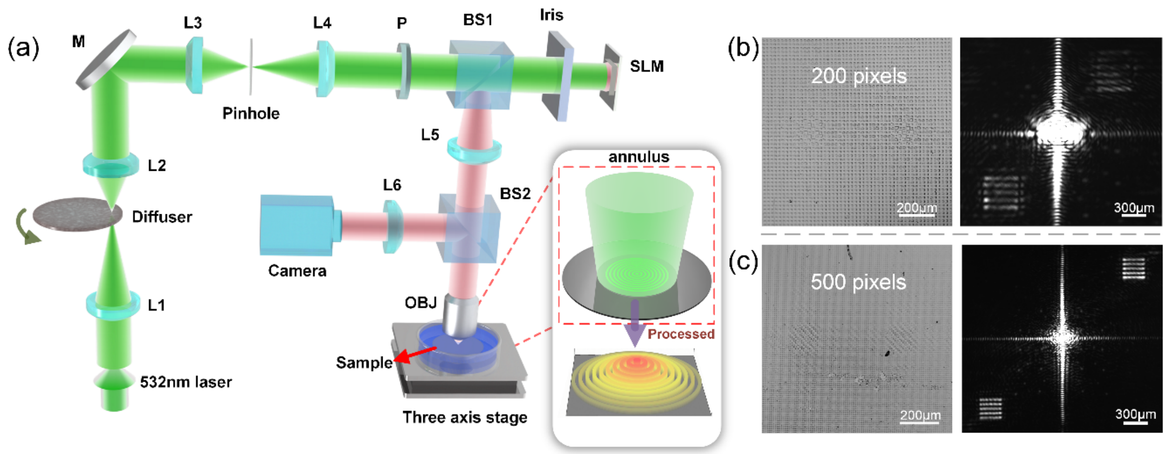

Figure 1: A method for the simple, low-cost, and rapid fabrication of holographic masks. (a) Schematic diagram of the PEC etching system. (b) and (c) are Processing and holographic imaging results of 200-pixel and 500-pixel holographic masks, respectively.

Constant pressure polishing deterministic surface form correction and parameter optimization

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Abstract

As a common optical surface manufacturing technology, polishing often has problems such as low convergence efficiency and obvious edge effect. Therefore, a deterministic constant pressure polishing (CPP) method based on a single point polishing model is proposed in this study. The method dynamically adjusts the polishing pressure distribution to improve the surface accuracy. Firstly, the polishing trajectory is planned, the dwell time is calculated, and the continuous material removal model is established. Then, the initial surface form is measured and the theoretically formed surface is simulated. Finally, the theoretical machining deviation is extracted to guide the deterministic surface form correction. In addition, quantitative evaluation criteria were introduced to verify the improvement of the material removal uniformity achieved by CPP. The response surface method (RSM) and machine learning were used to optimize the key process parameters, and the prediction error was about 5%. The results show that the proposed CPP strategy significantly improves the surface accuracy and polishing efficiency, and provides a reliable solution for high-precision optical manufacturing.

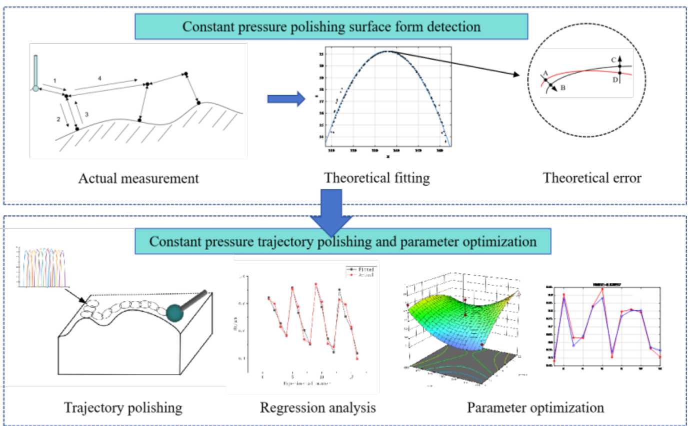

Figure 1: The process of deterministic surface correction

Generation of robust algorithms for dense image matching in dimensional metrology

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Abstract

Optical 3D stereovision systems are pivotal in modern metrology, providing dense images for inspecting geometrical properties of complex parts. Therefore, achieving micron-level accuracy in industrial applications remains challenging due to noise, lighting variations and surface inconsistencies. The proposed research aims to develop robust algorithms for dense image fusion, integrating geometric constraints, machine learning and uncertainty quantification to address these challenges. The validation of the implemented algorithms will be carried out on a number of references soft gauges generated with regard to the F2 software measurement standard according to ISO 5436-2 (2012). The validated dense image fusion method will be applied for real-time tolerance assessment and in-line metrology systems aligned with Industry 4.0.

Keywords: Dimensonal Metrology, Optical 3D Stereovision, Dense Image Fusion, Uncertainty Quantification, Machine Learning, Industry 4.0.

Aknowledgements

This research is part of the 23IND08 DI-Vision Project, dedicated to advancing traceable machine vision systems for digital industrial applications. We acknowledge the support and collaboration of the European Partnership on Metrology and its associated institutions, which played a pivotal role in enabling the development and validation of methodologies essential to this work.

A polishing process simulated using molecular dynamics to explain atomic-level origins in machine tool processing

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Abstract

Optical surfaces with extremely low roughness and high surface accuracy are the key to securing the performance and life of critical devices. The processing of ultra-smooth mirrors is realized by polishing in ultra-precision polishing machines. However, adjusting the polishing process to a reasonable level takes considerable time, and the quality of the surface processing is affected by the lack of clarity of the polishing mechanism. Benefiting from the molecular dynamic's simulation of the polishing process, the deformation or removal of rough surfaces by abrasive particle populations in polishing is analyzed. By analyzing the process of rough surface smoothing, the variation of low, medium and high spatial frequencies during the polishing process was obtained. Statistics on different process parameters such as polishing pressure, spindle speed, polishing disc speed, polishing fluid concentration, material removal rate of optical element materials and surface quality are optimized to obtain the best process parameters. It is possible to obtain e.g. an elaboration of the surface integrity, material removal process in essence, which guides the realization of an efficient and high quality polishing process on machine tools.

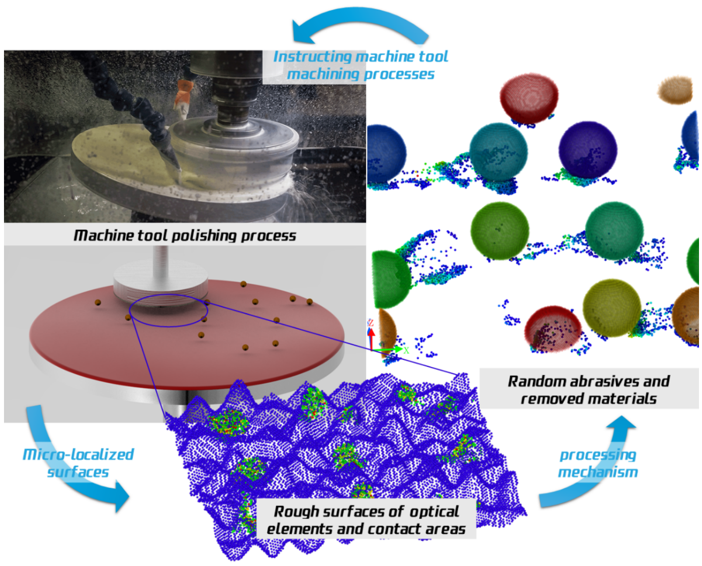

Figure 1: Ultra-precision polishing technology from macroscopic to close-to-atomic scales.

Deep learning-assisted measurement system for the 3D profiles of inner surfaces of components

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Abstract

Components with inner surface, such as valves, bearings, molds, pipelines, printed circuit boards, and surgical instruments are widely used in the fields of aerospace, precision manufacturing and measurement, machining process research, energy transportation, photoelectronic industry, and medical equipment. The 3D profiles of a component's inner surface can affect the quality of assembly, which may lead to undesirable effects such as incomplete sealing, increased friction and vibration, and accelerated wear. It is critical to accurately measure the 3D profiles and surface roughness on the inner surface of precision components.

We developed a deep learning-assisted measurement system, which integrates white light interferometry system with an inserted microprism, to precisely reconstruct the 3D profile and surface roughness on the inner surface of precision components. The system uses a residual learning method to construct the mapping between the captured low-resolution interferometric images and the theoretical high-resolution interferometric images. We demonstrated that the deep learning-assisted measurement system could improve the measurement accuracy of 3D profiles by more than 30%. We envision this work may find its applications in diverse fields such as precision manufacturing and measurement, machining process research, energy transportation, and medical equipment.

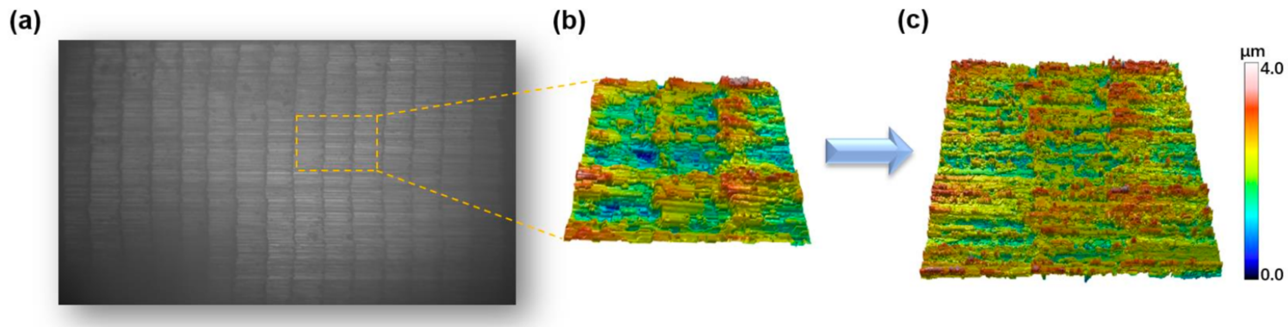

Figure 1: Measurement results of 3D profile of inner surfaces of precision components. (a) Optical microscopy image of the sidewall of the component. (b) 3D profile image of the sidewall. (c) 3D profile image after residual network enhancement.

Selective Laser Melted Porous CuSn20-Bonded Diamond Grinding Tool: Functional Cellular Structures Design, Service Performance Evaluations and Properties Tailoring Database Establishment

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Abstract

In this research, a novel design strategy for grinding tools is proposed to optimize performance. The grinding tool is divided into three functional regions: the regions in contact with the tool holder is designed for high mechanical strength to withstand applied forces. The regions in contact with the workpiece focuses on maximizing grinding efficiency and the remaining regions prioritize high permeability to ensure sufficient chip removal capacity and coolant flow. This design approach aims to achieve a balanced combination of mechanical, permeability, and grinding properties is required for the grinding tools to achieve the requisite performance in specific regions. Cellular structures based on triply periodic minimal surfaces (TPMS), topology optimization, and biomimetic designs were developed to meet high permeability, mechanical performance, and long service life. All the designed cellular structures were fabricated by selective laser melting (SLM), and their manufacturing fidelity, compressive strength, permeability, and grinding performance were analyzed. Finally, a properties tailoring database was established, integrating performance data (e.g., compressive, permeability, and grinding properties) with structural characteristics, leveraging predictive models such as the Gibson-Ashby model and the Kozeny-Carman equation.

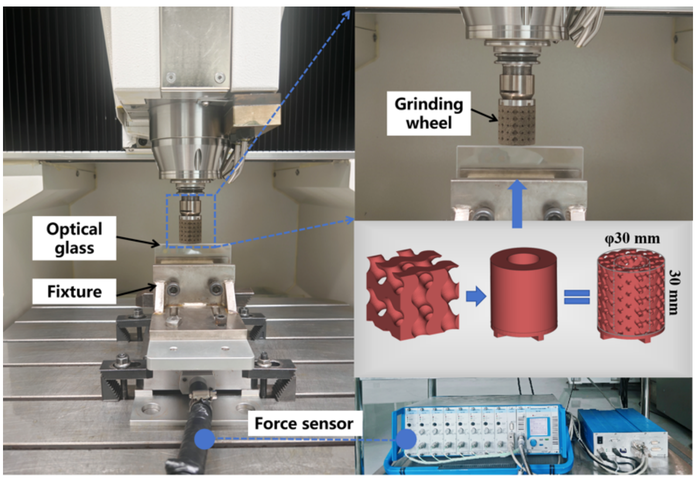

Figure 1. Grinding performance of additive manufacturing diamond tools

Enhanced Interferometric Measurement of Discontinuous Surfaces: Improved Morphology - based Phase Unwrapping Algorithm

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Abstract

In our previous work, aiming at the flatness measurement of a large number of discontinuous surfaces using a laser interferometer, we developed a morphology-based phase unwrapping algorithm (MBPU) tailored for flatness measurement of discontinuous surfaces. This paper presents improvements to the existing morphology - based phase unwrapping algorithm for interferometric measurement of discontinuous surfaces. The original algorithm effectively conducts phase unwrapping through morphological operations such as dilation, connection, and connected - component selection. However, in this study, we further optimize the algorithm. Specifically, the valid data filtering method is upgraded from the extrema- based filtering to the interference amplitude - based filtering. This new method can identify valid data points more accurately, reducing the interference of invalid data on the measurement results. In addition, the dilation unit is extended from a sphere to other cubes like a cuboid. This extension enables the algorithm to expand its phase - unwrapping capabilities without causing phase aliasing between two layers due to excessive dilation in the Z - axis direction. It significantly improves the algorithm's performance in phase - unwrapping for discontinuous surfaces with large inter- surface distances. Through theoretical analysis and experimental verification, the improved algorithm shows better adaptability in the interferometric measurement of discontinuous surfaces, which broadens the application scope of the morphology - based phase unwrapping method.

Synergistic modulation of corrosion and tribological performance of MoS_2 coatings based on chemical annealing and Ti doping

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Abstract

The utilisation of thin-film protection has emerged as a pivotal strategy for safeguarding critical components, particularly in the domains of aerospace and marine equipment. In this research, a synergistic modulation strategy of corrosion and tribological performance of MoS_2 coatings based on chemical annealing and Ti doping is proposed. The effects of magnetron sputtering process, Ti content and annealing process on the microstructure, mechanical, tribological and anticorrosion properties of the MoS_2 coating are systematically investigated. Appropriate content of Ti doping have been shown to improve the morphology, phase structure, composition of MoS_2 and enhance the coating properties. The annealing of Ti-doped MoS_2 coating in a sulphur atmosphere, which can significantly reduce the oxygen content in the Ti-doped MoS_2 and improve the corrosion and tribological performance of Ti-doped MoS_2 coatings for corrosion protection. The above results show that high performance Ti-doped MoS_2 coatings have a broad potential for protecting key components in corrosive environments.

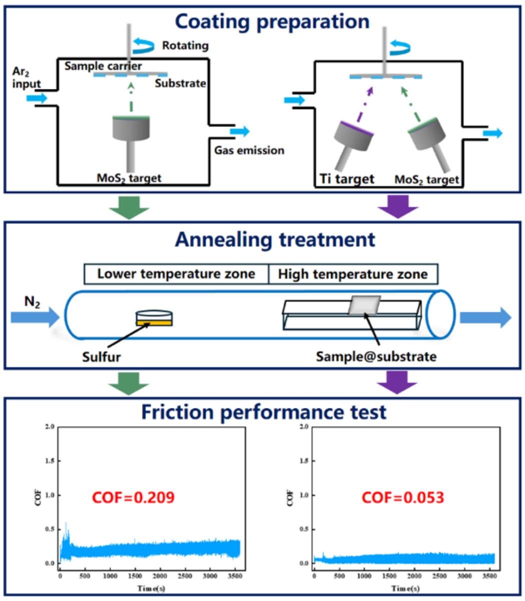

Figure 1. Preparation process and tribological performance of Ti-doped MoS_2 coatings.

Investigation of the Effects of LaB6 Microparticles on the Laser Powder Bed Fusion of Copper: Printability, microstructure and properties

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Abstract

Copper material is indispensable in critical field components, benefiting from its exceptional electrical and thermal conductivity, such as high-power electronic devices and efficient thermal management systems. With the rapid development of advanced manufacturing and electronic information industries, the demand for high-performance copper components with complex geometries is continuously increasing. Laser Powder Bed Fusion (LPBF), one of the typical Additive Manufacturing (AM) technologies, overcomes the geometric limitations of traditional manufacturing, opening new avenues for the direct fabrication of high-precision, high-density metal components with intricate structures. However, the high laser reflectivity of copper (especially to the conventional infrared lasers) and its high thermal conductivity pose significant challenges to the direct fabrication of pure copper components via LPBF.

Here, we present a material dispersion-strengthening method with LaB6 microparticles to enhance the printability of copper in LPBF, thereby improving the relative density and performance of printed copper components. This study investigates the effects of LaB6 microparticles on the densification behavior, microstructural evolution, mechanical properties, and electrical and thermal conductivity of LPBF-processed copper. The incorporation of LaB6 microparticles increases the laser absorption rate by approximately 40% compared to the pure copper powder. With optimized process parameters such as laser power and scanning speed, near-full-density parts can be achieved. Specifically, the process window for copper with a small addition of LaB6 microparticles is 1.5 times wider than that of pure copper powder. It has been found these LaB6 microparticles exist in two forms within the pure copper matrix: larger unmelted LaB6 microparticles and smaller nanoscale particles that melt and subsequently precipitate. The uniform dispersion of the two types of particles in the matrix makes the electrical and thermal conductivity close to the pure copper while largely improving the strength. This work provides a theoretical foundation and key technical support for the efficient and cost-effective fabrication of high-performance copper components via LPBF.

A Concept for Making Molds for the Replication of Parts with Combined Micro- and Submicro-Structured Surface

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Abstract

To enhance the functionality of parts, the integration of features with dimensions in the micro-metric and submicro-metric length-scale on part surfaces is more and more addressed by academia. For the integration of such micro- and submicro-scale features into materials like plastics, molding techniques are commonly exploited, for which micro-structured molds or inserts are indispensable.

In this work, a concept for making molds for the replication of parts with a combined micro- and submicro-structured surface is introduced. The novelty of the concept is that precision machining of the mold, an alteration of the mold cavity surface by the deposition of a hard coating and a final processing of the applied hard coating exploiting micro- and nano-manufacturing techniques is conducted successively. Nonetheless, each applied process along the process chain has to be well mastered and to be carried out in order to achieve a certain surface integrity which ensures the functionality of the mold with respect to a sufficient mold lifetime but also the functionality of the molded part.

The focus of this work lies on the communication of results obtained in different studies, in which several precisions-, micro- and nano-manufacturing processes have been investigated. The capabilities of the processes loose-abrasive polishing, ultra-precision machining of steel with CBN and PCD micro milling tools or focused ion beam milling of PVD hard coatings are presented in the overarching context of mold manufacturing. Furthermore, the micro-geometrical and physico-chemical properties of PVD hard coatings obtained in different studies are presented.

Due to these coating properties and due to the determined capabilities of the precision-, micro- and nano-manufacturing techniques, the implementation of the concept for making molds, which are applicable for the replication of plastic parts with a hierarchical micro-structured surface, is discussed.

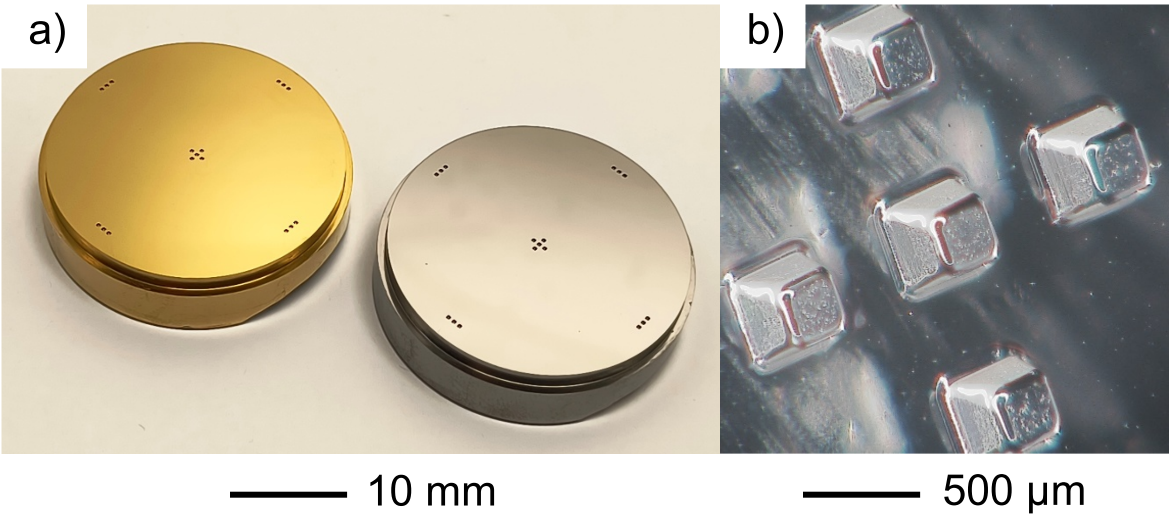

Figure 1: Hard coated mold and its use for the replication of parts with micro- and submicro-structures

Development and Application of Large-Scale and High-Precision Gratings

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Abstract

High-precision gratings are widely used in spectroscopy analysis, lasers, displacement measurement, optical communication, etc., and are indispensable core components in national major scientific projects such as inertial confinement nuclear fusion devices, large-scale astronomical observation equipment, and synchrotron radiation sources. The position of the microscopic scale groove lines and the accuracy of the groove shape determine the macroscopic characteristics of the grating, including the diffraction efficiency and the diffraction wavefront. Starting from the application requirements of high-precision gratings, this report analyzes the influence laws of the microscopic scale groove line position and groove shape parameters on the diffraction efficiency and wavefront of the grating, introduces the key technologies that the team has overcome in the fabrication of nanometer-scale precision gratings with millimeter-sized dimensions, and presents the world's largest-area ruled grating of 400mm×500mm and the largest single-unit seamless holographic grating of 650mm×1700mm, which has been successfully developed.

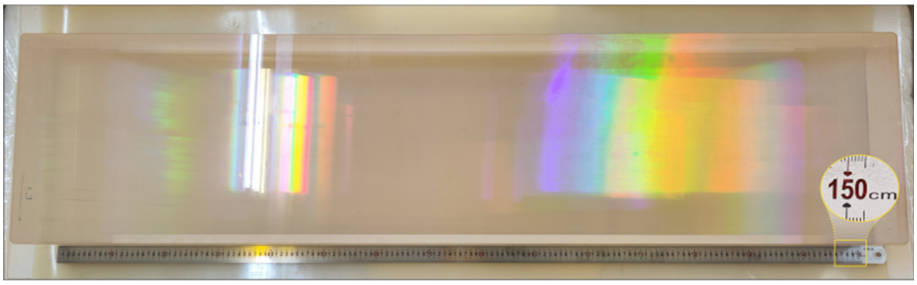

Figure 1: The largest single-unit seamless holographic grating in China of 650mm×1700mm

In-process monitoring and servo control with cost-effective radio frequency (RF) signal in micro-EDM

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Abstract

Micro-electrical discharge machining (micro-EDM) has inherently stochastic and dynamic discharge behavior due to its extremely complex gap condition. Process monitoring, especially when combined with control strategies, can improve stability and efficiency by detecting discharge patterns and anomalies. Traditional monitoring relies on electrical sensors to analyse pulses via statistical metrics but suffers from high cost, interference, and poor capture of transient, high-frequency dynamics. To overcome these limitations, this study presents an RF-driven in-process monitoring and control scheme for micro-EDM. First, by analyzing successive discharge waveforms, three machining states are defined using the integral value of voltage signals within a time window, simplifying state labelling. Due to the high-dimensional yet information-sparse nature of RF signals, a low-dimensional feature dataset is constructed for machining state identification. A hybrid hierarchical architecture is proposed, and various module combinations are evaluated. Experiments show the GRU-GAP model achieves over 90% accuracy for all states under varying conditions, with average and weighted accuracies exceeding 94% and 96%, confirming its robustness. Based on RF monitoring and state identification outcomes, an adaptive servo control strategy is implemented in deep-hole drilling, significantly extending effective machining time and enhancing feed rate stability compared to constant-parameter testing. This approach integrates deep learning and in-process control to develop a cost-effective and scalable system, paving the way for intelligent micro-EDM. Future work targets CNC integration, edge computing, and microchip deployment for industrial-scale intelligent manufacturing.

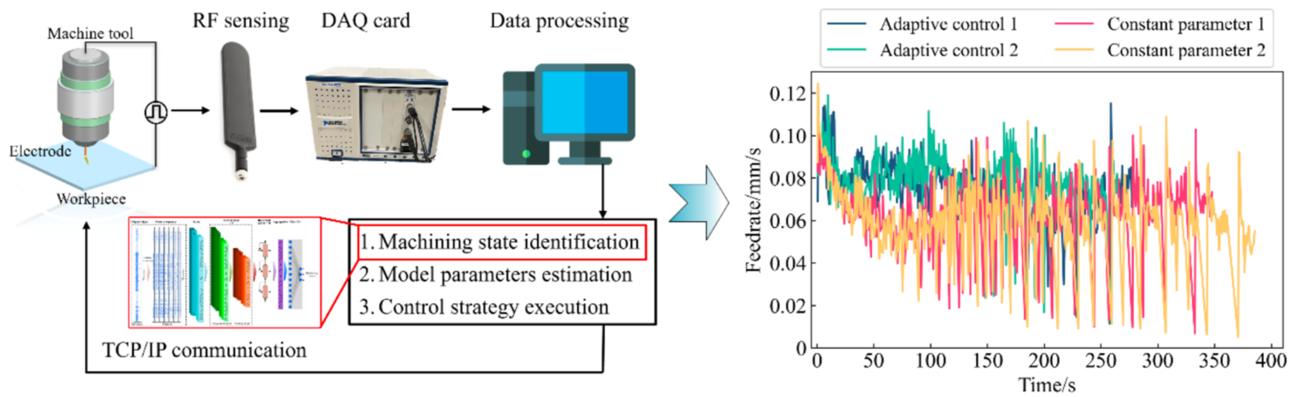

Figure 1: Schematic diagram of in-process monitoring and control system in micro-EDM.

Dimensional nanometrology and sub-nanometre positioning using X-ray interferometry

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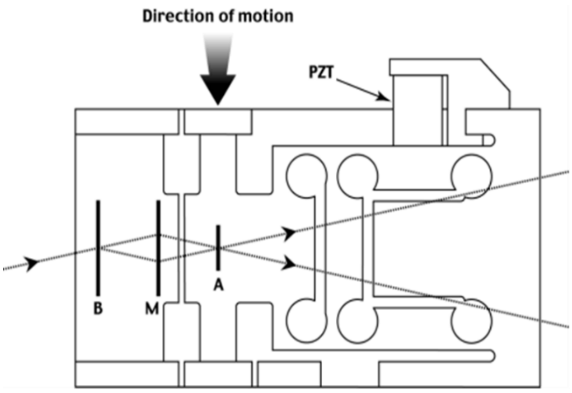
Abstract

The 2019 revision of The International System of Units (SI) adopted the lattice parameter of silicon as a secondary realisation of the metre to support dimensional nanometrology [1]. The d_{220} lattice spacing is quoted in CODATA as 192.0155714 pm, with a relative uncertainty, $\frac{\Delta d}{d} = 1.67 \times 10^{-8}$ [2].



X-ray interferometry [3] provides a route to traceability through the lattice spacing for sub nanometre positioning and evaluation of displacement measuring sensors such as optical interferometers. The X-ray interferometer (XRI) can be regarded effectively as a ruler, or translation stage with an integrated ruler whose graduations are the atoms in a silicon crystal.

Figure 1 shows a plan view of an X-ray interferometer (X-rays are diffracted from the first lamella (B) on the XRI. At the second lamella (M) the two diffracted beams are diffracted again and two of these beams recombine at the third lamella (A). This lamella sits on the XRI's translation stage that is integral to the XRI. As the stage is translated using a piezo actuator (PZT) there is a sinusoidal variation in the intensity of the diffracted beams from the third lamella giving x-ray fringes with a traceable periodicity of 192 pm. On the side of the XRI there are three mirrors, the central one being part of the translation stage. These mirrors provide a reference for an optical interferometer.

A servo control system can be used to move the X-ray interferometer in quantised steps corresponding to an X-ray fringe [5]. By introducing a 90° phase difference between components of the beams emerging from the X-ray interferometer, it is possible to obtain phase quadrature signals which enables continuous bidirectional displacement measurement with picometre accuracy as well as quantised sub- nanometre positioning [6].

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Design and Manufacturing of Bio-Hybrid Machines in the Framework of Biological Transformation in Manufacturing

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Abstract

The Biological Transformation, or Biologicalisation, in Manufacturing has been defined by the EU as a ground-breaking frontier that industry can harness to improve circularity and sustainability while increasing production efficiency and competitiveness through technological advances arising from the integration of bio-intelligent principles, functions, structures, materials and technologies in manufacturing engineering by applying knowledge derived from biology. To achieve such accomplishments, a convergence of biology and biotechnology, manufacturing processes and systems, information technology and ICT systems is essential for a breakthrough innovation change.

The first EU call topic on Biologicalisation "Development of technologies and devices for bio-intelligent manufacturing" was published in 2021 within the Horizon Europe Programme. In response to this call, the project "A Modular Framework for Designing and Producing Bio-Hybrid Machines (BHM) – BioMeld" was successfully submitted and approved with duration 2022-2025.

The 'BioMeld' project achievements are illustrated in this paper with regards to the integration of biological and artificial materials to achieve greater autonomy, flexibility and energy efficiency in the realisation of a BHM consisting of a bio-hybrid vascular catheter as innovative medical device for improved drug delivery in hard-to-reach areas of the human body. The 'BioMeld' project leverages bio-inspired artificial intelligence and machine learning to optimize product design and improve BHM manufacturing processes, aiming to reduce faults in manufacturing operations.

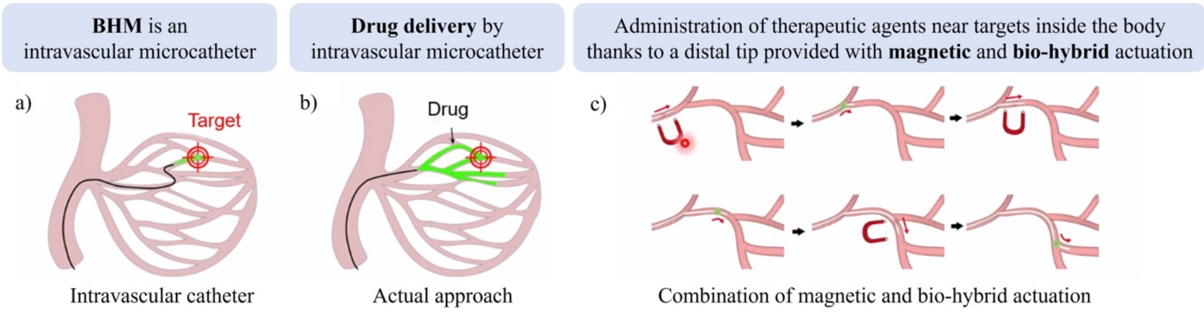

Fig. 1: The BHM consisting of a bio-hybrid steerable catheter which is flexible to produce a bending deformation depending on the force generated by living muscle cells in a bio-hybrid actuator

Micro-Injection Molding of TPU for medical devices: Material influence on dimensional accuracy and surface quality.

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Abstract

The use of Micro-injection moulding (µIM) is a well-known technique dedicated to the production of plastic devices within the micrometre range dimensions and tolerances, and parts typically weighing less than 1 gram [1]. This manufacturing process was chosen for this project given the dimensions of the medical insert with micro features (Ø200 µm, 200 µm deep), as well as the benefits that µIM provides, such as ease of use, high repeatability, extensive material processing catalogue availability, simplicity for precise dimensional control, among others. Another important aspect is the selection of the polymer to inject; in this study, thermoplastic polyurethane (TPU), Texin Rx70A, and Polyethylene (PE), PE Purell 1840, are the materials under test. TPU was selected because it contains both soft and hard linear segments within its molecular structure [1,2]. This structural characteristic enables TPU to be injected since it allows the material to melt and be processed in the injection moulding machine [3]. The hard segments of the TPU are accountable for the elastic properties and the hard segments are responsible for hardness and tearing strength. Both segments melt at different temperatures, but the fusion stage can be achieved for both at the same time [3]. The segments are incompatible with one another, therefore a microphase separation is observed where the soft segment is the matrix and the hard segment the fillers and cooling rate will determine the formation of new structures [3]; while PE is widely used in injection moulding process for its low processing temperature, which require less energy consumption to produce the same amount of injected parts, consequently lowers production cost. Both materials were processed in Arburg (370A 600–70) equipped with a micro unit. The replicability of the moulding process was measured with dimensional accuracy and surface quality by a microscope analysis to see any potential defects such as voids, sink marks, short shots or cross flows depending on the material's composition. This study helps to understand the impact of the use of TPU for µIM and corresponding process optimization in terms of injection parameters depending on the desire outcome of the application of the moulded part.

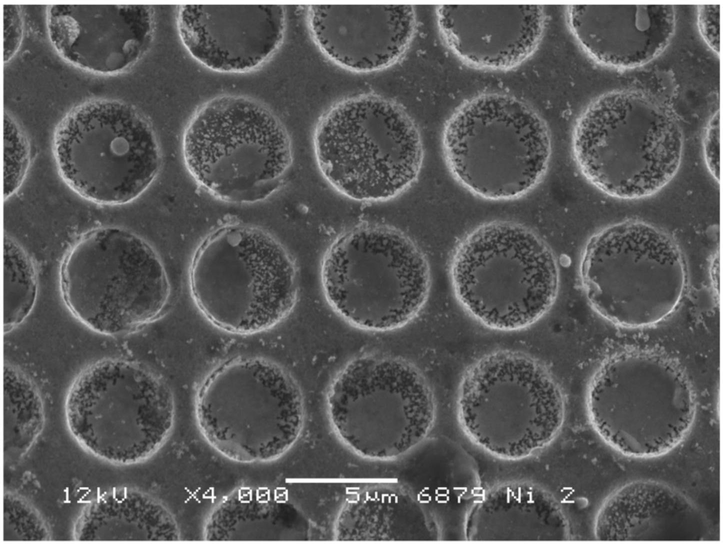

Figure 1: Scanning electron microscope (SEM) image of the microstructure area of the mold insert.

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Modular Assembly and Mechanical Validation of Hollow Polymeric 3D Microneedle Array Devices (3DMA) for Scalable Transdermal Drug Delivery

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Abstract

Hollow polymeric microneedle devices represent a promising platform for minimally invasive transdermal drug delivery. However, scalable manufacturing and robust assembly remain significant engineering challenges for current microneedle devices. This work presents a novel automated modular assembly approach for a 3D Microneedle Array (3DMA) device, designed for compatibility with both syringe-based and on-body drug delivery systems. Additionally, the mechanical behaviour and functional performance of the assembled devices are systematically evaluated.

The 3DMA modular assembly system comprises injection moulded microneedles and a separate base, assembled via a two-stage process. A custom automated platform was developed, incorporating a 3-axis precision stage for microneedle placement using a vacuum gripper, coupled with automated UV adhesive dispensing and curing. Each microneedle is positioned in under 15 s, enabling full array assembly within four minutes. A secondary sealing step applies an additional UV adhesive layer to reinforce mechanical integrity and prevent leakage. Further development of this step for a full microneedle array is expected to further enhance production throughput significantly, simplifying the manufacturing process and reducing cost.

Mechanical testing then validated the robustness of the assembled system. Fluid leakage pressure testing confirmed structural integrity at pressures exceeding 350 kPa, surpassing ISO 80369-7 standards for Luer lock connectors, thereby confirming the reliability of the adhesive seal. Functional validation was demonstrated via visual confirmation of jet flow from each microneedle outlet.

In accordance with ISO 10993-17 and 10993-5 standards, mechanical compression tests confirmed microneedle resilience under axial loads, with puncture and fracture resistance validated up to 1 N. This work establishes a scalable, industrially viable route for the production and quality assurance of hollow polymer microneedle systems suitable for both clinical and at-home use.

Improvement of irradiation performance in fast atom beam source with bidirectional magnetic field for surface activated bonding

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Abstract

Surface activated bonding (SAB) is an essential room-temperature bonding technology for nextgeneration communication devices, particularly in the bonding of substrates for surface acoustic wave filters, with potential applications in three-dimensional semiconductor integration. This method involves activating wafer surfaces under vacuum conditions by irradiating them with an argon fast atom beam (FAB), enabling direct wafer bonding.

FAB sources are widely used in practical SAB applications. However, they face a significant challenge: after several hundred uses, internal wear caused by argon ion sputtering leads to the emission of particles from the irradiation port. These particles can adhere to the wafer surface, creating voids at the bonding interface and resulting in bonding defects. Consequently, frequent electrode replacement is required to prevent bonding defects, negatively impacting productivity.

In this study, as a first step toward achieving higher performance, we investigated the effects of varying the intensity of bidirectional magnetic fields and modifying the anode structure. Our aim was to elucidate the relationship between these changes and irradiation performance. Therefore, we modified the method of applying the bidirectional magnetic field as shown in Figure 1 and fabricated new FAB source shown in Figure 2. By utilizing this newly developed FAB source, we successfully enhanced the performance beyond that achieved in Conventional FAB sources (Figure 3) and gained insights into the optimal conditions for magnetic field strength and anode structure that maximize the effects of applying bidirectional magnetic fields. This study provides significant contributions not only for maximizing the effectiveness of bidirectional magnetic fields in improving FAB source irradiation performance but also for extending the electrode lifetime of FAB sources. In other words, this research has significant contribution to improving the productivity of SAB.

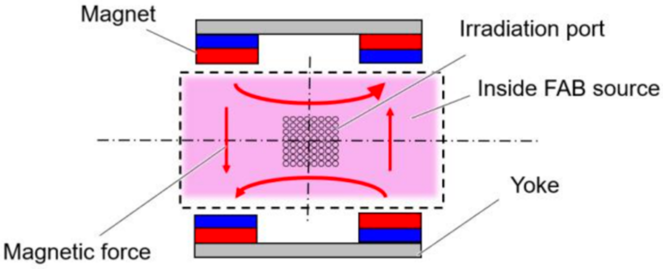


Figure 1: Structure of bidirectional magnetic field applied FAB source

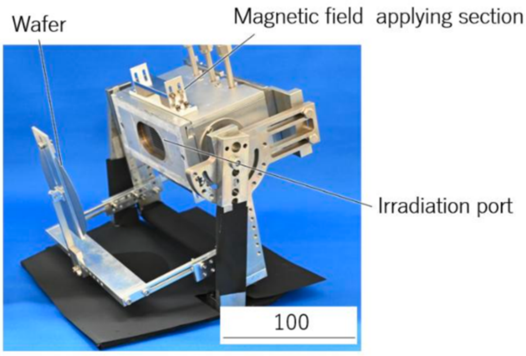


Figure 2: Appearance of bidirectional magnetic field applied FAB source and jig for irradiation test

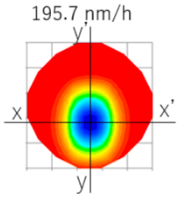
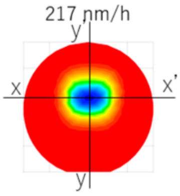
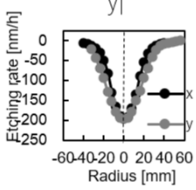
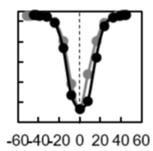
	Conventional	The present study
Voltage	1.0 kV	0.75 kV
Current	100 mA	100 mA
Ar flow	55 sccm	15 sccm
Etching rate	195.7 nm/h	217 nm/h
Removal image		
Section profile		

Figure 3: Comparison of the irradiation test results

Evaluating the Impact of Internal Structural Defects on Fatigue Performance in Polylactic Acid Components Manufactured via Fused Deposition Modeling

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Abstract

Microstructural defects significantly influence the service performance of structural components manufactured through additive manufacturing processes. This research aims to quantitatively characterize microstructural defects and develop fatigue performance predictions for polylactic acid (PLA) components fabricated via Fused Deposition Modeling (FDM). Initially, high-resolution computed tomography (CT) technology is utilized to identify the location, dimensions, and morphology of internal defects within FDM-processed PLA specimens. Subsequently, monotonic tensile and fatigue tests are conducted to examine how these internal defects affect the fatigue performance of PLA. Additionally, fatigue limit predictions are generated using extreme value statistics and the Murakami model, while a fatigue life prediction model is established by incorporating defect size and structural characteristics. Results demonstrate that the Gumbel distribution effectively characterizes the size distribution of internal defects, with maximum defect sizes reaching 4.09 μm. The fatigue limit prediction error is 6.77% when comparing extreme value statistics and Murakami model calculations with experimental results. Furthermore, the X-parameter-based life assessment model demonstrates superior reliability in predicting fatigue life for FDM-processed PLA.

Two-Photon Polymerization for Advanced Calibration Artefacts in Optical Areal Metrology

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Abstract

Two-Photon Polymerization (TPP), also known as Direct Laser Writing (DLW), has emerged as a pivotal additive micro/nano fabrication technique, enabling the creation of intricate three-dimensional microstructures with sub-micrometer resolution. Its applications in metrology are particularly noteworthy, offering innovative solutions for the calibration and characterization of optical measuring instruments.

In this contribution, we present the development of advanced material measures tailored for the calibration of optical areal measuring instruments. Utilizing TPP, we have fabricated complex microstructures that serve as material measures, facilitating comprehensive calibration and assessment of instrument performance. These structures are designed to evaluate critical metrological characteristics, including lateral resolution, linearity, and instrument transfer functions. Notably, our approach allows for the integration of multiple calibration features within a single artefact, streamlining the calibration process and enhancing efficiency.

Furthermore, we explore the robustness of the TPP process by systematically varying fabrication parameters and assessing the resultant microstructures under external stress factors such as temperature and humidity. Our findings indicate that the TPP-fabricated structures exhibit remarkable stability and resilience, underscoring the reliability of this technique for producing durable material measures.

Additionally, we introduce a novel chirped topography designed for holistic analysis of optical areal measuring instruments. This topography encompasses a broad range of spatial frequencies, enabling a thorough evaluation of an instrument's response across different scales. The fabrication of such complex structures is made feasible through the precision and versatility of the TPP technology.

Our work demonstrates the significant potential of Two-Photon Polymerization in advancing metrological applications. By leveraging TPP, we can produce sophisticated, reliable, and customizable calibration artifacts that enhance the accuracy and traceability of optical measurement systems. This synergy between micro-nano fabrication and metrology paves the way for improved quality control and standardization in precision additive manufacturing.

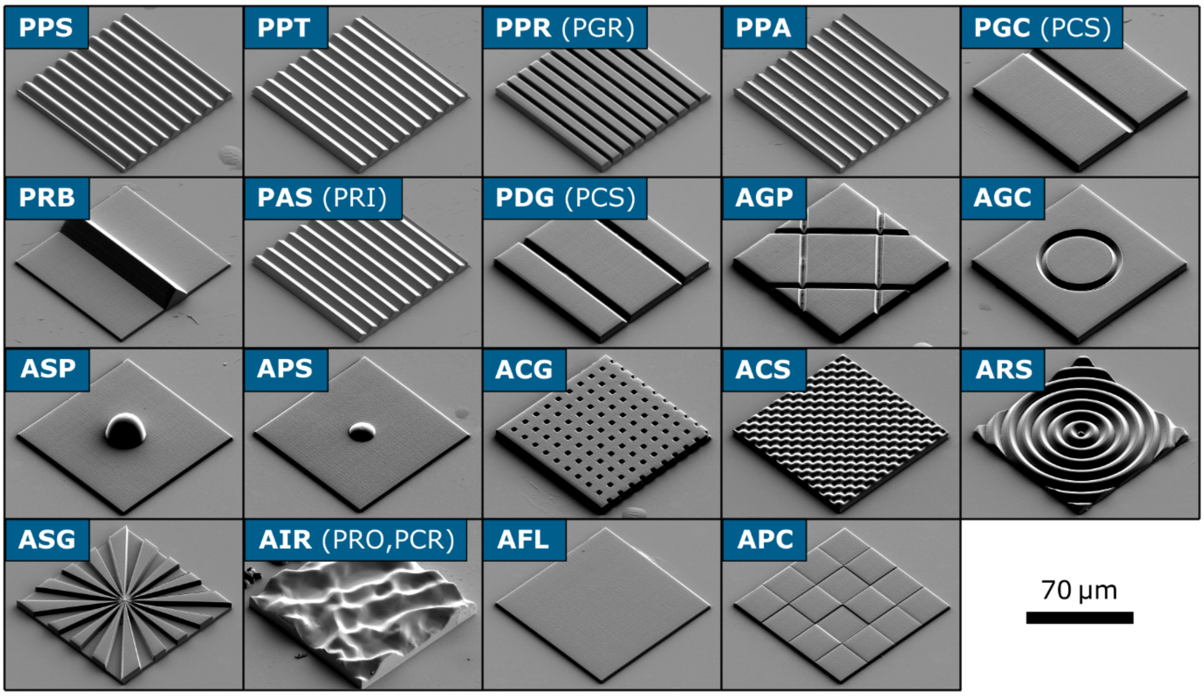

Figure 1: SEM images of TPP fabricated material measures (abbreviations according to ISO 25178 series).

Enhanced Hot-Embossing of Submicrometric Structures in Polymers for Optofluidic Applications

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Abstract

Modification of polymer surfaces allows for efficient integration of functional structures into technical components without the need of adding hybrid components. In particular, optical applications employing polymers can profit enormously from surface optimizations since refractive limitations apply due to the inherent material properties. Functional micro- and submicrometric structures can overcome those problems by adding diffractive as well as phase-shift optics. Polymer replication technologies on nanoscale have emerged throughout the last decade, providing advanced techniques such as roll-2-roll embossing, injection-compression moulding, nano imprint lithography, and many more. However, a multitude of challenges remain: Most prominent are development costs for new experimental structures based on state-of-the-art findings in photonics, realization of structures with high aspect ratios, and filling as well as demoulding polymers from deep cavity structures.

This study presents results from hot embossing micrometric and submicrometric structures into polymers in combination with ultrasound-assisted hot embossing, inductively heated stampers and vacuum enhanced imprinting. While focussing on potential scalable technologies, the methods are aimed to speed up prototyping to develop new structures, in particular for the use as photonic elements in optofluidic devices for biomolecular diagnostic tools.

Direct micro structuring of tungsten carbide tips by focussed ion-beam milling in combination with ultrasound assisted hot embossing allows to replicated microstructures into selected surface areas of fluidic chips, without the need to either modify the main tool, nor to integrate hard-to-engineer stampers. Furthermore, in order to improve accurate reproduction of surface details, heating methods for high-speed vario-thermal process control by inductive heating of microstampers has been tested. Since material displacement presents

a major challenge, protruding structures are easier to replicate, but more difficult to provide master structures. Vacuum enhanced micro hot embossing has been tested to test structural integrity of hard to fill recessed cavities, which are aimed to resemble meta surfaces for phase-shift optics.

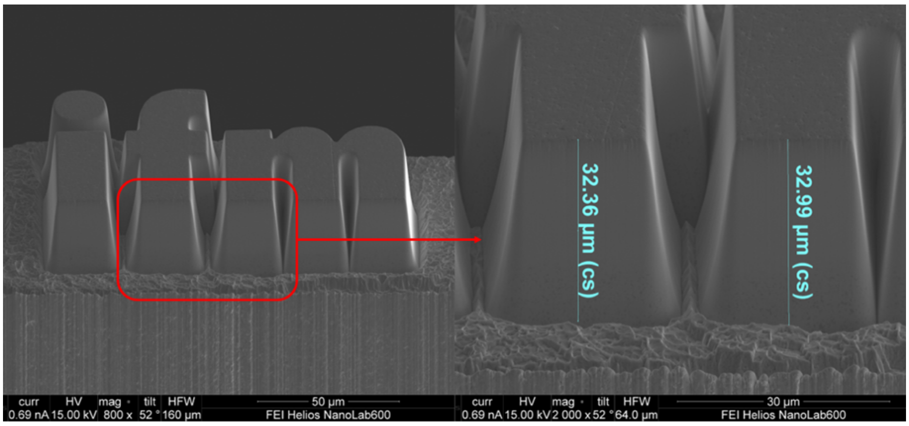

Figure 1: Protruding micro structures for ultrasound assisted hot embossing in tungsten carbide

Defect-free replication of polymeric micro structures using novel Ni-PTFE nanocomposite moulds

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Abstract

Demoulding defects like pile up plastic deformation and damage has constrained the quality of mass production of plastic micro products, such as microfluidic chips and optical gratings. A high-performance Ni-PTFE nanocomposite mould was fabricated for defects-free demoulding along with quantitative measurement of demoudling force. The Ni-PTFE nanocomposite mould performance was compared with pure Ni mould in terms of demoulding feature integrity, demoulding force, friction, wear and surface adhesion. Results consistently show that Ni-PTFE nanocomposite mould give profound surface integrity of microstructures with significant reduction of demoulding forces under various experiment conditions; the composite mould also displays 38% reduction in friction coefficient, while 5 times extended tool life, much less tool wear and adhesion compared to pure Ni mould. These micro injection moulding processes validated the self-lubrication properties of the Ni-PTFE nanocomposite mould for defect-free production of polymeric micro surface structures.

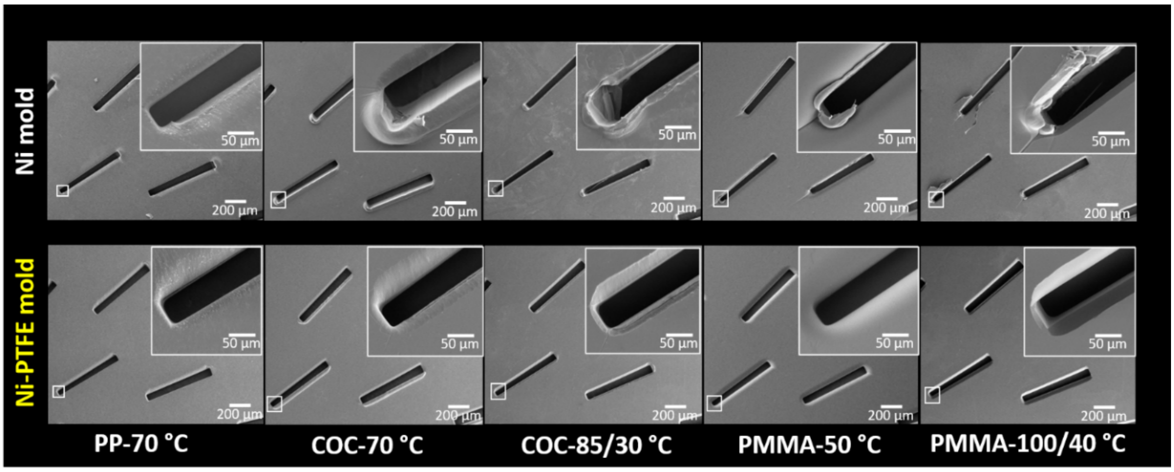

Figure 1: Surface morphology of injection molded PP, COC and PMMA from Ni mold and Ni-PTFE mold under different mold temperatures.

High-resolution master fabrication for tool-based manufacturing using two photon lithography

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Abstract

High-quality surfaces with micrometer and submicrometer features are highly sought after in various fields, such as diffractive optical elements (DOE). The primary replicative manufacturing processes for such structures in polymers are tool-based techniques.[1] Manufacturing the necessary metal tools typically involves electroplating lithographically fabricated templates using nickel, which requires expensive and inadaptable photomasks and electroplating is a slow process with growth rates in the micrometer per hour range. For small- to medium-scale manufacturing, the tool fabrication costs often exceed economic feasibility.

A novel process has been demonstrated based on metal casting of fused silica glass templates.[2,3] Initially, the positive master is 3D printed using two-photon polymerization (2PP) and subsequently transferred to PDMS. The PDMS master is then replicated using the photocurable silica nanocomposite material Glassomer µL24, which is transformed into fused silica glass via thermal debinding and sintering. Due to the high thermal shock resistance of fused silica, the glass master is directly used for metal casting or hot embossing to produce a negative metal tool for replication processes.

2PP is a 3D printing method driven by selective radical photopolymerization induced by two-photon absorption (2PA). 2PA is a nonlinear process where the excitation of the photoinitiator depends on the square of the light intensity, enabling resolution below the diffraction limit and allowing for the manufacturing of submicrometer features.[4] Hence, 2PP 3D printing is the ideal technology for fabricating masters in tool-based manufacturing.

The presented process flow offers a scalable, adaptable, and cost-efficient approach to produce metal tools from 2PP 3D printed masters, outperforming current labor- and equipment-intensive machining methods. Thus, the process is ideal for small- and medium-scale production of high-resolution thermoplastic polymer parts.

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Femtosecond-laser-fabricated interfacial microrobots for versatile non-contact applications

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Abstract

We have introduced a novel robotic system named as the cooperative magnetic interfacial microrobots. This innovative system comprises microrobots made from polydimethylsiloxane (PDMS) and iron powder, meticulously arranged in a specific chain-like distribution. The femtosecond laser system was employed for precise cutting and modification of the iron/PDMS mixture layer. Orthogonal crossed line-by-line consecutive scanning was performed on both the upper and lower surfaces of the microrobots to create the surface microstructures. These microrobots possess the remarkable ability to navigate freely at the gas-liquid interface, transitioning seamlessly between capture and release states through the simple adjustment of a single permanent magnet's position. This system has enabled the realization of various applications, including the global control of multiple microrobots, the collaborative targeted transport of microrobot couples, and the removal of oil from interfaces.

Investigation on Mechanism of Starch-based Ultra Stable Foam for Potential Application of Sprayable Mulch Film

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Abstract

To address the environmental pollution caused by traditional plastic mulch, there is an urgent need to develop eco-friendly and biodegradable alternatives. In recent years, sprayable biodegradable foam mulch has attracted significant attention due to its environmental benefits, ease of application, and excellent thermal insulation and moisture retention properties. However, existing foam mulches suffer from several limitations: (1) they are often composed of non-biodegradable polyurethane, which may cause secondary soil pollution; (2) traditional biodegradable foam mulches exhibit poor stability; (3) they typically offer only a single functionality; and (4) the stabilization mechanisms of ultra-stable foam systems remain unclear.

This project proposes a "multilayer ultra-stable foam system", integrating biodegradable natural polysaccharides, surfactants, stabilizing agents, and functional additives to develop an environmentally friendly sprayable foam mulch. The study aims to elucidate the stabilization mechanisms of multi-component aqueous foam systems while imparting additional functionalities such as weed suppression and pest control. Furthermore, it seeks to uncover the key structural characteristics and microscopic mechanisms governing the multilayer foam system formed by polysaccharides, surfactants, film enhancers, and functional agents. By investigating the formation and evolution of ultra-stable foam mulch, this research provides a theoretical foundation for overcoming the inherent instability of foams and optimizing their stability design.

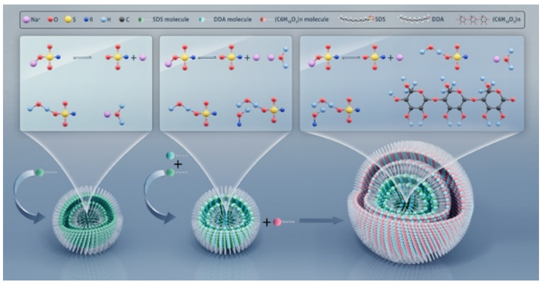

Figure 1. Schematic illustration of the interactions in the ultra-Stable multilayer foam system

New Challenges by high-precision laser manufacturing of 3D components with complex-shape: up-scaling inspection methodologies for control dimensions, a rea case study

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Abstract

The functional performance of many products/components is often determined by its surface. In particular, micro-nanostructured surfaces, also known as biomimetics surfaces in most of the cases, have proved to control phenomena of adhesion, friction, wear, lubrication, wetting phenomena, self-cleaning, antifouling and antibacterial phenomena. These properties make bio-inspired surfaces extremely attractive for a wide range of strategic sectors. Among the different industrially reliable and environmentally friendly technologies to produce these surfaces, laser surface texturing has been validated as a high throughput manufacturing technology. However, among the main challenges for an industrial implementation of the manufacturing approach is the upscaling of photonic metrology in-line system to provide uncertainly values of the feature dimensions providing feedback to the micromachining and promoting "first time right" strategy in laser texturing.

This study reports the current challenges in the development of laser micromanufacturing process of moulds inserts to produce advanced functionalized components. In a first stage, design, development of microfeatures and validation of final surface performance were carried out on flat samples. Once the microfeature topography was properly defined to fulfil functional surface requirements, the laser surface texturing process was upscaled to a 3D component as a demonstration of the final application. During this second stage, a digital manufacturing approach of the laser texturing process was evaluated to find the best laser texturing strategy to maximize the time in which the laser beam is in its optimum position on the surface to be processed. Once the surface of the 3D component was micro-manufactured, topographical inspection and surface functional characterization pointed to the lack of reliable functional performance of the final component. Later involves the need to i) assess the manufacturing tolerance to ensure target functionalities on final surfaces and how these biomimetic microfeatures need to be adapted to the part shape to guarantee optimum functional performance of the complete component; ii) up-scale in-line optical inspection system to ensure the final surface + component functionalities.

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