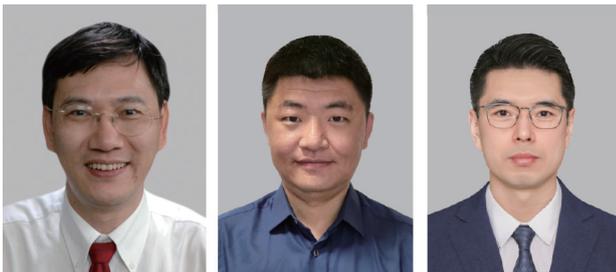




## Editorial

## Editorial for the Special Issue on Laser Micro/Nano-Manufacturing

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The rapid evolution of laser micro/nano-manufacturing techniques has transformed precision manufacturing, enabling the creation of complex micro/nano-structures. These techniques are crucial for multiple industries, including electronics, photonics, and biomedical engineering, owing to their unmatched precision and versatility. The ability to manipulate materials at such scales has unlocked new possibilities for innovation, thereby facilitating the development of advanced components and devices with enhanced performance and functionalities.

The articles collated in this special issue cover diverse topics, including advanced laser micro/nano-manufacturing techniques and applications. Firstly, Minghui Hong et al. provide in-depth views on advancing manufacturing limits. Nanofabrication advancements driven by miniaturization demands have led to the introduction of high-density, high-performance components in chip manufacturing techniques and quantum devices. Moreover, techniques such as electron beam and nanoimprint lithography offer nanoscale precision. The industry, led by Taiwan Semiconductor Manufacturing Company (TSMC; China), Intel (USA), and Samsung (Republic of Korea), targets 2 nm processes by 2025. We are particularly pleased to include a comprehensive review on laser three-dimensional (3D) non-printing by Xiong et al. Multi-photon 3D nano-printing enables high-resolution nanoscale fabrication and is widely used in optics, biology, and engineering. Despite its promise, its industrial adoption is limited by slow speeds and material constraints. This review summarizes advances in optical methods and material challenges and

proposes strategies for improving productivity, cost efficiency, and cross-scale processing in future applications. In this research direction, Ma et al. present a review particular to precision medicine applications. Multiphoton polymerization (MPP) enables the high-precision, non-contact fabrication of micro/nano-scale tools for precision medicine, overcoming the limitations of conventional 3D printing. Furthermore, this review summarizes MPP fundamentals, materials, and biomedical applications, and discusses the challenges and future directions in material design, process optimization, and practical implementation.

Metasurfaces and quantum optics represent two forefronts of modern photonics, where laser micro/nano-manufacturing plays a pivotal role. In this special issue, several groundbreaking contributions are showcased. Zhang and Li et al. report on tungsten-based metasurfaces utilizing hierarchical laser-induced periodic surface structure/nanoparticle (LIPSS/NP) nanostructures to achieve polarization-sensitive, vividly colorful, and infrared camouflage displays. A proof-of-concept inspired by Van Gogh's "Starry Night" and a preliminary experimental validation illustrate the potential of this approach. Nishijima et al. present a notable work in which they experimentally determined the complex permittivity of a high-entropy alloy composed of five noble metals—Au, Ag, Cu, Pd, and Pt. This alloy demonstrates strong potential for use in perfect absorber/emitter metasurfaces spanning the ultraviolet to mid-infrared wavelengths. Rahmani and Xu et al. introduce a dynamic non-linear wavefront-shaping method by integrating genetic algorithms and spatial light modulators with a silicon metasurface. This approach allows the flexible, alignment-free control of third-harmonic generation patterns, as well as advances in optical computing and information processing capabilities. Luo et al. present a simplified and robust quantum measurement technique for nanoscale alignment, achieving an impressive 2.2 pm resolution and an experimental precision of 1 nm. By employing a mode-converting metasurface, their method bypasses the conventional multi-beam interferometry and offers a practical and accurate solution for nanofabrication, sensing, and imaging.

Additionally, laser micro/nano-manufacturing plays a fundamental role in diverse applications ranging from surface friction control to radiative cooling. Mei and Cui et al. present a study in

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which a nanosecond-laser-irradiated scanning nearfield optical microscopy tip enables mask-free, sub-wavelength nanostructure fabrication on Au films, achieving  $\sim 83.6$  nm linewidths. This stable and reproducible technique offers precise and economical nanolithography for a wide range of materials. Yang and Chen et al. performed a bioinspired study in which ultradurable scale-armored-sliding surfaces (SASSs) were fabricated using femtosecond laser electrodeposition. By mimicking fish scales, these structures exhibit excellent impact resistance, liquid repellency, and anti-fouling properties, which are ideal for harsh environments and multiple substrate materials. Guo and Jia et al. present a highly practical solution for thermal management—a reusable, flexible, and magnetic radiative cooling film with polymer metasurfaces. This film ensures optimal thermal contact and achieves a significant cooling effect of  $15.2$  °C under sunlight, with a radiative cooling power up to  $259 \text{ W}\cdot\text{m}^{-2}$ , even on irregular metallic surfaces. Finally, Cao et al. introduce a study on dynamically reconfigurable Tamm plasmonic color filters. By integrating  $\text{Sb}_2\text{S}_3$ , a phase-change material, the filter offers reversible, non-volatile, and energy-efficient color tuning with an approximately 50 nm spectral shift, thereby offering new

opportunities for compact photonic systems and advanced display technologies.

Laser-based micro/nano-manufacturing stands at the forefront of future technological advancements, offering a versatile suite of methods tailored to meet the specific needs of diverse applications. Subtractive techniques, such as laser ablation, etching, and precision cutting, involve material removal to create precise structures. These methods are well-known for their accuracy and efficiency, making them ideal for high-precision applications. Additive approaches, including laser-induced chemical vapor deposition and laser micro-cladding, are used to build material layers with complex geometries. These techniques are particularly valuable for creating components with customized properties as they allow for the controlled addition of materials with specific characteristics. Hybrid methods integrate additive, formative, and subtractive techniques to address various requirements of multi-functional flexible micro/nano sensors. This approach accommodates different scales, dimensions, and materials, thereby enabling the fabrication of intricate structures that are difficult to achieve using a single method.