

# Diffractive neural networks enabling superoscillatory imaging without sidelobes

Guanghui Yuan\*

Department of Optics and Optical Engineering, School of Physical Sciences, University of Science and Technology of China, Hefei, China

Superoscillation enables sub-diffraction-limit focusing of light in the optical far field without requiring high-spatial-frequency evanescent waves. This capability is crucial for applications in super-resolution imaging, sensing, perception, and nanoscale metrology<sup>[1]</sup>. In the article “Superresolution imaging using superoscillatory diffractive neural networks,” Chen *et al.* proposed and demonstrated an innovative approach to super-resolution imaging through the development of superoscillatory diffractive neural networks (SODNNs)<sup>[2]</sup>. Unlike conventional methods, often hindered by high-intensity sidelobes, the SODNN offers superior control over sidelobe suppression and energy efficiency, resulting in greater imaging flexibility and performance.

The SODNN framework integrates diffractive modulation layers with computational optimization, enabling the design of optical fields with an expanded degree of freedom; see Fig. 1(a). Using a stochastic gradient descent algorithm, the relative heights and a number of diffractive elements can be tailored to achieve specific superoscillatory effects, including monochromatic and achromatic focusing and Bessel-like optical needles with extended depth of focus. A critical innovation is the introduction of 3D optical field constraints, which optimize focusing over a propagation range, ensuring that the superoscillatory region retains its properties beyond the designed focal plane; see Figs. 1(b)–1(d). The SODNN functions as a neuromorphic photonic processor, leveraging the interplay between optical interconnections and nonlinearities to achieve its objectives.

This research has profound implications for super-resolution imaging applications in fields like label-free biomedical imaging, optical microscopy, and remote sensing; see Figs. 1(e) and 1(f). The ability to resolve finer details at greater depths could revolutionize imaging technologies in these domains. Additionally, the SODNN’s robustness to chromatic variations positions it as a promising tool for multispectral and hyperspectral imaging, where precise control over multiple wavelengths is critical.

Despite its promise, practical implementation faces challenges such as fabrication precision for diffractive elements and the computational intensity of large-scale system optimization.

The generation of superoscillatory hotspot arrays with suppressed off-axis aberrations under oblique incidence also merits exploration for parallel scanning imaging applications. Further research could focus on integrating the SODNN with adaptive optics to enhance imaging capabilities and studying its interactions with vector optical beams, which have predefined polarization and phase distributions. Real-time optimization capabilities could also enable dynamic adjustments based on environmental changes.

Lastly, it is worth noting that similar super-resolution diffractive neural networks (S-DNNs) have been used by the same research group for direction-of-arrival (DOA) estimation with angular resolutions surpassing the conventional Rayleigh diffraction limit. This technique employs multilayer metastructures to process electromagnetic waves directly, achieving real-time sensing at the speed of light across a wide frequency range and with minimal latency<sup>[3]</sup>. Recently, Hu *et al.* proposed another compact imaging framework that utilizes a solid-immersion system and diffractive optical processors to achieve subwavelength resolution<sup>[4]</sup>. These advancements underscore the critical role of diffractive neural networks and deep learning algorithms in the evolution of super-resolution optical imaging and sensing technologies.

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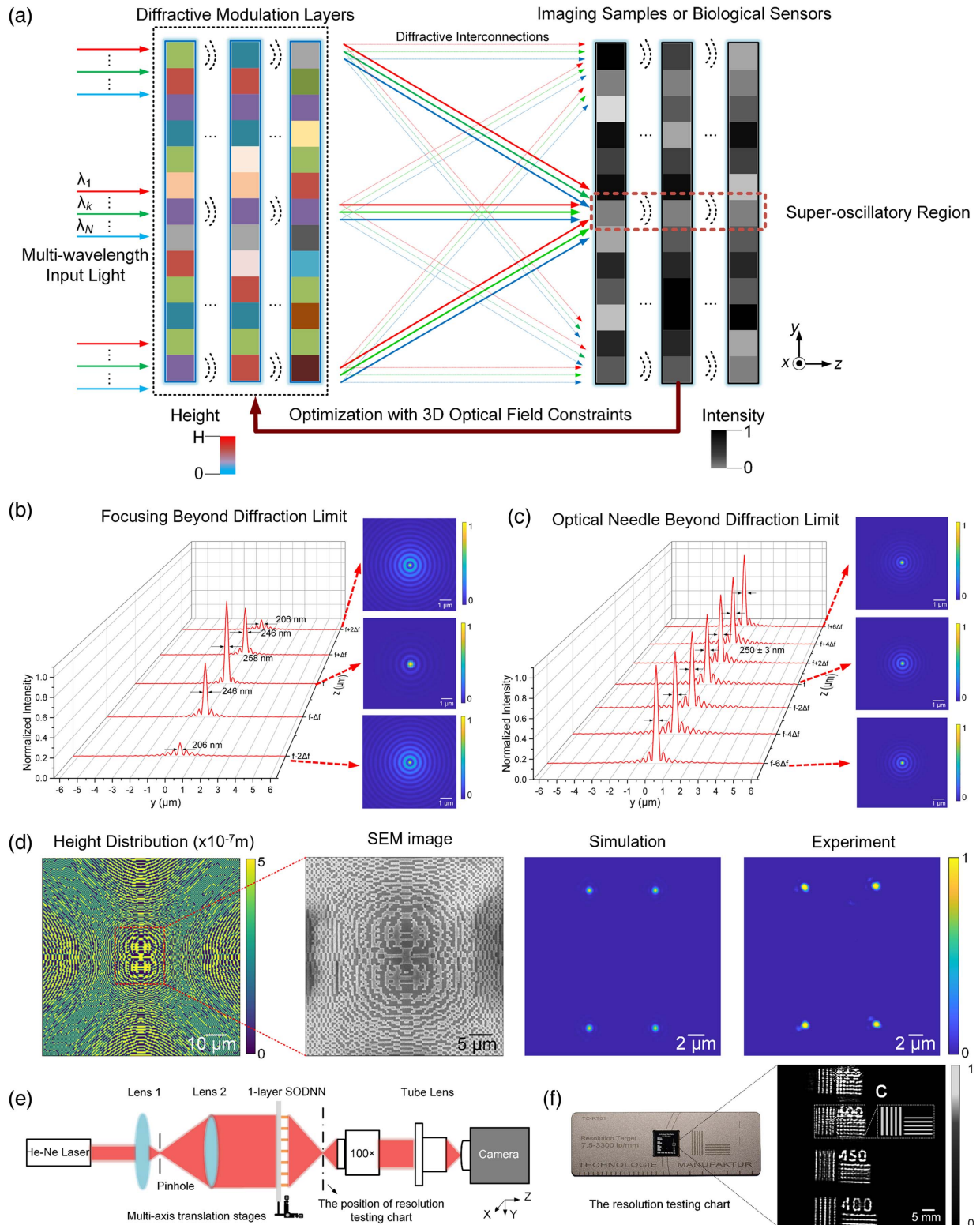
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\*Address all correspondence to Guanghui Yuan, [ghyuan@ustc.edu.cn](mailto:ghyuan@ustc.edu.cn)

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**Fig. 1** Superoscillatory diffractive neural networks (SODNNs) for super-resolution imaging without sidelobes<sup>[2]</sup>. (a) SODNN optimization procedures with 3D optical field constraints. (b) SODNN optimized optical superoscillatory spots and (c) an optical needle with long depth-of-focus. (d) Height distribution (column 1), scanning electron microscope (SEM) image (column 2) of the fabricated SODNN diffractive modulation layer, and its simulated (column 3) and experimental (column 4) focusing performance. (e) Schematic of experimental setup for imaging resolution testing. (f) Imaging results by the commercial objective and SODNN.