Making Learned Diffractive Optics Manufacturable

Differentiable optics, an emerging paradigm that jointly optimizes optics and image-processing algorithms, has made many innovative optical designs possible across a broad range of imaging and display applications.[1,2] Many of these systems utilize diffractive optical elements (DOE) for holography, point-spread function engineering or wavefront shaping. Existing approaches, however, have mostly remained limited to laboratory prototypes, owing to a large quality gap between simulation and manufactured devices.

In recently published work,[3] we have addressed this design-to-manufacturing gap with a fabrication-aware design framework. We developed a super-resolved neural lithography model—a digital twin that predicts the three-dimensional surface actually produced by direct-write grayscale lithography followed by nanoimprint replication, a route suited to inexpensive mass production. Incorporating this model into the optical optimization loop allows the design to be optimized for the as-fabricated device rather than an idealized layout.

Scaling this approach to practical apertures creates another challenge: computation. Fabrication-aware wave simulations of centimeter-scale DOEs require enormous numerical grids that cannot fit on a single graphics processing unit (GPU). We have therefore developed tensor-parallel methods that split the neural fabrication model and large wave-propagation calculations across multiple GPUs. This enabled wafer-scale design of DOEs as large as 32.16 mm × 21.44 mm on grids containing up to 128,640 × 85,760 samples.

We demonstrated the approach in holography, beam shaping and broadband color imaging, with simulations closely matching fabricated prototypes. In the imaging experiment, a camera consisting of only a single DOE and an off-the-shelf sensor produced high-quality images using a simple one-step reconstruction based entirely on the simulated optical response—without calibration or fine-tuning using measurements from the fabricated prototype.

By integrating fabrication physics and large-scale wave simulation into the same differentiable design loop, the approach addresses two key barriers to practical learned diffractive optics: manufacturability and scale. It points toward computational optical systems that can be designed at practical aperture sizes and replicated efficiently, rather than remaining one-off laboratory demonstrations. OPN

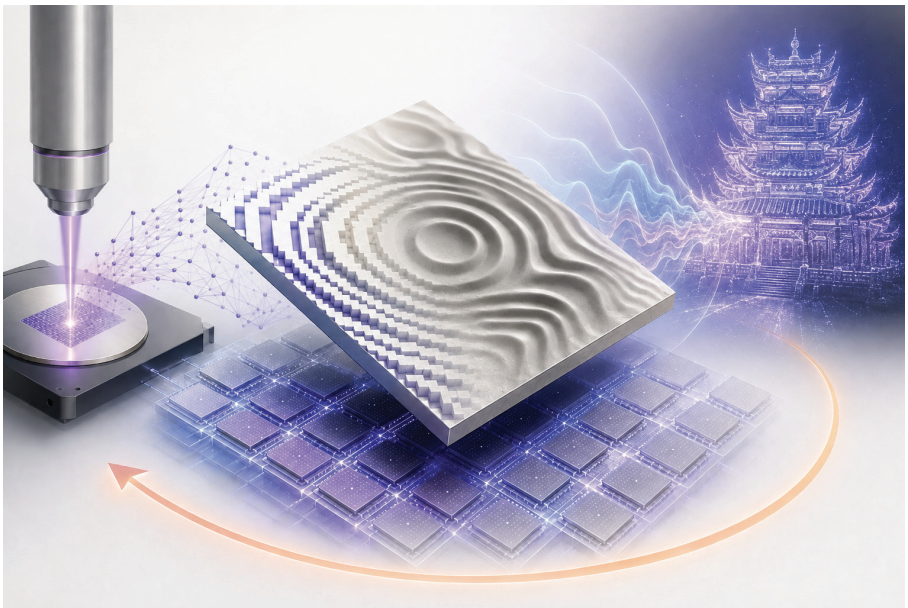
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REFERENCES

1. G. Wetzstein et al. Nature **588**, 39 (2020).
2. V. Sitzmann et al. ACM Trans. Graph. **37**, 4 (2018).
3. K. Wei et al. ACM Trans. Graph. **44**, 6, Article 243 (2025).



Artist's rendering of fabrication-aware, end-to-end design for large-area diffractive optics. A neural-lithography digital twin predicts the as-fabricated 3D surface, while tensor-parallel computation distributes high-resolution fabrication and wave-optics simulations across multiple GPUs.