

Maskless lithography: photons rather than electrons

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An optical-lithography system employs independently focused light beams for manufacturing custom semiconductors.

Many sectors of the semiconductor, photonics, and nanotechnology industries are inhibited by the high cost and inflexibility of the mask-based optical-projection lithography (OPL) typically employed in high-end semiconductor manufacturing. To overcome the cost limitations of OPL, many researchers have been exploring maskless lithography techniques. The most widely anticipated approach to maskless lithography would employ thousands of independently scanned electron beams focused onto the substrate. However, the problem of spurious deflection of electrons due to mutual repulsion, substrate charging, and other sources of instability make achieving patterning accuracy problematic, severely limiting adoption of such systems. As such, a low-cost maskless-lithography system that could realize high levels of accuracy would be a welcome innovation, even if its throughput were only a fraction of that produced with OPL.

For lithography, photons have enormous advantages over electrons: mutual repulsion is absent; lens performance is both stable and predictable; shot noise is negligible; phase, amplitude, polarization, and nonlinear effects can be controlled to improve resolution; and photons produce minimal damage to the substrate. These observations led our group at the Massachusetts Institute of Technology (MIT) to explore an entirely different approach to maskless lithography, called zone-plate-array lithography (ZPAL).^{1,2} ZPAL employs 1000 or more parallel optical beams focused onto a substrate by an array of diffractive-optical lenses.³ As illustrated in Figure 1, the intensity of the focal spots is individually controlled by an upstream spatial-light modulator. Patterns of arbitrary geometry are written in a dot-matrix fashion by scanning the substrate in the focal plane of the zone-plate array, in synchrony with the data delivered to the spatial-light modulator.

The proven efficacy of ZPAL^{4,5} motivated us to form a small company, LumArray Inc., to make this technology available

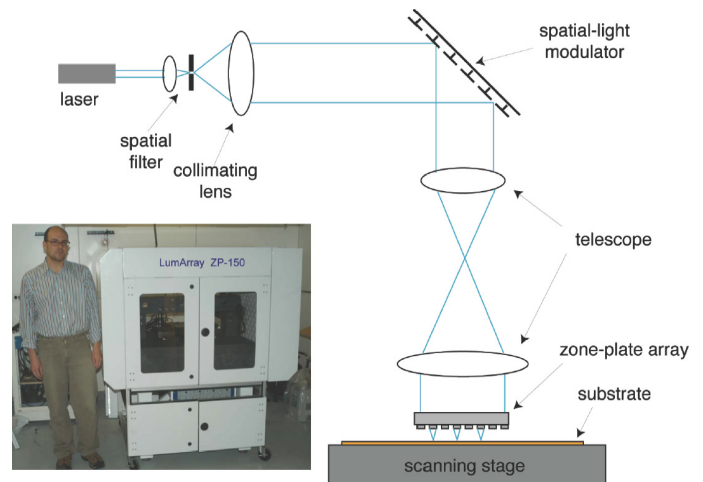


Figure 1. Schematic of LumArray's zone-plate-array-lithography system, the ZP-150, and a photograph of the commercial system. The system uses 1000 independent light beams focused onto a substrate by 1000 high-numerical-aperture zone-plate lenses. Patterns of arbitrary geometry are written in a massively parallel dot-matrix fashion by moving the stage under computer control.

to the entire community with the hopes of radically changing the way lithography is done in all segments of the industry. LumArray's first system, the ZP-150TM, achieves 150nm-dense lines and spaces using a 400nm source. Furthermore, because the individual focal spots of ZPAL have no coherent relationship, intensities are additive, which greatly simplifies the pattern-processing software and optical-proximity-effect correction. Throughput, which is limited by the number of pixels in the spatial-light modulator and by its incrementing rate, is suitable for research and development, low-volume manufacturing, and mask making.

To achieve higher resolution than conventional optical imaging would allow, we will employ an innovative approach called absorbance modulation (AM), in which a layer of photochromic molecules is placed on top of the photoresist.⁶ The photochromic

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molecules squeeze the diameter of the light transmitted into the photoresist. This provides a simple and effective approach toward achieving resolution of 20nm and lower.

A maskless lithography system that provides patterning accuracy, high resolution, flexibility, and quick turn-around time is urgently needed in many different industries. Our research indicates that photon-based multibeam systems substantially outperform systems that employ electrons and can provide flexible lithography to manufacturers and researchers. LumArray anticipates meeting this need with the ZP-150, and with future models having higher throughput and resolutions of less than 20nm.

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