Moore's Law had a remarkable run for decades, but the density of transistors on an integrated circuit not longer follows this trend. At the same time, generative artificial intelligence is fueling a renewed push to create denser and less power-hungry integrated circuits. A crucial part of the approach to tackling these problems is the use of ever shorter wavelengths of light in photolithography. Extreme ultraviolet (EUV) lithography has overcome a remarkable number of challenges in meeting fabrication nodes with ever finer pitches. Still, given its cost, EUV lithography will only ever be practical for high-volume applications. There are almost countless low-to-mid-volume applications, such as application-specific integrated circuits, that would benefit from the resolution that can be attained by EUV lithography. Additionally, new direct-write tools with higher performance are sorely needed in many areas of the semiconductor industry, such as advanced packaging and mask writing, and will also find many applications in the research laboratory. Electron-beam lithography offers one path towards addressing these needs, but this technique is slow and scale-up is limited by space-charge effects.

We and others have drawn inspiration from advances in optical microscopy to develop techniques for using near-infrared, visible, and/or near-UV light to perform photolithography far beyond the diffraction limit. Unlike EUV, light at these wavelengths is inexpensive to generate, does not need to travel in high vacuum, and is compatible with reflective optics. These multicolor lithography methods have reached the point that we believe that they will soon be attractive alternatives to current direct-write techniques that offer higher throughput and higher resolution at substantially lower cost. The first generation of multicolor techniques, 2-color lithography, employed one beam to activate a negative-tone photoresist and a second, phase-shaped beam to counteract cross-linking and improve resolution. Notable improvements in resolution have been achieved with 2-color techniques, but the fact that deactivation and crosslinking both proceed from the same state ultimately limits the resolution enhancement that can be achieved.

In recent years we have pursued a class of 3-color lithographic techniques that involve preactivation to a metastable state that is chemically inactive using one color of light, deactivation to the ground state by a second color of light, and activation of remaining preactivated species using a third color of light. This scheme decouples the processes of deactivation and crosslinking, greatly improving the theoretical resolution attainable.

I will discuss the current state of 3-color lithography, including the search for materials with ideal photophysics, the development of optical techniques to characterize the complex photophysical pathways in these system, and our state-of-the-art resolution achieved.