GUEST EDITORIAL

POLARIZATION AND HYPER-NA LITHOGRAPHY

Optical lithography remains a key engine of productivity and performance for the global IC industry. For the foreseeable future, the industry will rely upon evolutionary optical lithography techniques to deliver integrated circuits with dimension to 45 nm and lower. Optical lithography has undergone quite a technology evolution since its inception. Years ago, no one would have used annular illumination and partial coherence filling values less than 0.5. High numerical aperture optics meant a $\mathrm{NA}>0.4$ and was definitely considered unpolarized. Now, with the expectation of optical lithography meeting the IC fabrication challenges into the future, NAs will drive above 1.0 and electromagnetic effects thought to be insignificant will take center stage.

Some of the earliest experimentation on polarized illumination for lithography was done by the guest editors while working at IBM in the early 90s. The NA at the time was 0.55 with an exposure wavelength of 436 nm. The lens was considered a milestone in optical design and questions started to arise about the effects of the high NA and the role polarization might play in image formation. To test the theories, we inserted linear polarizers in the illuminator and applied extraordinary experimental design techniques with exposure system machinations to reveal a scant 1% statistical significant difference between polarized and unpolarized light in the wafer exposures. In comparison, with today's lenses, at $\mathrm{NA}=0.93$, polarized light experiments easily show the physical and electromagnetic effects from illuminating the object with polarized illumination. Given the potential future importance of these polarized light effects in lithographic image formation, a theory for lithographic imaging with polarized light had also been developed at this time, to identify major issues associated with using lenses as high as $\mathrm{NA}=0.95$. This was compared to experimental results using interference lithography to verify the theory with what we thought was an incredible $\mathrm{NA}=0.85$! At SPIE conferences of the day, this work was largely considered "academic" and typically received skeptical snickers about the use and value of such high NA optics. Comments such as "you guys are nuts" were not uncommon.

Today, we are going well beyond what was once imagined into the hyper-NA regime or NAs above 1.0. With the use of new fluids and possibly solid immersion lenses the NA might easily approach 2.0 or beyond before optics runs out of steam. No longer an academic curiousity, these NAs are required for meeting the challenges of optical lithography and the associated polarization effects critical for fabricating next generation ICs.

To acknowledge the importance of polarization effects in modern lithography imaging, this special section presents papers that explore various aspects of polarization and hyper-NA imaging in current state-of-the-art technology. While the use of this technology in manufacturing is still very much in its inception, semiconductor manufacturers and the vendor infrastructure have seen this as the latest development to possibly extend optical resolution down to 32 nm.

Donis Flagello
ASML

Christopher J. Progler
Photronics, Inc.

Guest Editors