Dose Requirements for LCDU Control at Blue-X Wavelengths

Ralph R. Dammel

EMD Electronics

Inspection of the x-ray photoabsorption cross sections of tin at Blue-X wavelengths (6.7 nm, 3.4 nm, 3.127 nm and 2.88 nm) shows that tin has very low absorption cross sections for all four wavelengths, which makes tin MORs a poor choice as a Blue-X resist. At the same time, chemically amplified resists are not expected to be able to achieve the required performance since they are limited by photocatalyst diffusion and have loitered at 12 nm HP final resolution for years. New resists will have to be developed for Blue-X, but it is difficult to estimate dose requirements without knowing resist composition and mechanism of action. This work attempts to provide a new method of doing so.

A 2019 paper by B. Geh introduced an equation that related LCDU to incoming radiation dose and photon energy. This work modifies Geh's equation in a way that specifically introduces resist absorbance as an additional parameter. This new modified Geh equation

$$LCDU = \frac{24}{\sqrt{\alpha d}} \frac{1}{NILS} \sqrt{\frac{h\nu}{D_i}} \tag{1}$$

is first tested on data from 13.5 nm EUV lithography experiments and then used to compare exposure doses and roughness values at 13.5 nm and Blue-X wavelengths using x-ray cross section data for these wavelengths.

Rearrangement of (1) gives the equation for the incident doses required to control LCDU = *f* CD, where *f* is the fraction of CD representing an acceptable LCDU.

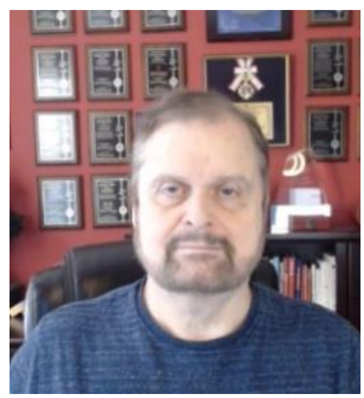
$$Dose = \frac{576}{\alpha\, d} \frac{h\nu}{f^2 CD^2 NILS^2} \tag{2}$$

Atomic absorption coefficients at Blue-X wavelengths are substantially lower than at 13.5 nm, and photon energies are substantially higher. For exposures at the water window wavelengths, photon energy is higher by a factor of 4, and absorbance is about ¼ of the one at 13.5 nm. In order to have the same or better LCDU, NILS must therefore be higher by a factor of ≥4.

Estimation of NILS values for Blue-X wavelengths is carried out using a NILS master curve of NILS vs. k_1=CD*NA/λ. This curve gives NILS values for all NA and wavelength combinations, from i-line to EUV. As expected from Fourier optics, the curve exhibits increasing NILS as new orders of diffraction enter the pupil, followed by plateaus between the entry of successive orders.

Combining these NILS values with the effects of absorbance, volume element length d and photon energy in the modified Geh equation shows that NILS values are only sufficient to overcome the contrary effects of low absorbance and high photon energy for larger features but not for CDs below 14 nm. Low NA systems will require very high, possibly impractical, dose increases in order to control LCDU. Dose increases for higher NA systems, e.g. 0.45 NA, are more moderate, although for all wavelengths including 13.5 nm, there is a geometric factor of $1/CD^2$ that leads to increased dose requirements at smaller CDs, e.g., a factor of 4 higher doses when going from 16 nm HP to 8 nm HP. In summary, this study suggests that the concept of using low NA exposure tools together with the shorter Blue-X wavelengths will lead to very, possibly impractically, high dose requirements in order to control LCDU. Current resist types may not work well at such high doses. Operating such systems at achievable doses will require highly effective post-development methods of reducing LCDU, such as rectification with directed self-assembly (DSA).

Presenting Author



Ralph R. Dammel received a Ph.D. in Chemistry from the J.W. Goethe University in Frankfurt/Germany in 1986. He has worked for EMD Electronics/Merck KGaA or its predecessor organizations in Germany, the US, Hong Kong, and Thailand since then, and is currently employed as Technology Fellow in the CTO Office of Merck KGaA's Electronics division.

Dr. Dammel is the author of over 200 scientific papers in chemistry and microlithography and is an inventor on about 500 patents in over 110 patent families in the field. His monograph "Diazonaphthoquinone-based Resists" is generally recognized as the definitive book on the subject. In spring 2009, Dr. Dammel was elected as SPIE Fellow. He received the Photopolymer Science and Technology Outstanding Achievement Award in June 2011, SPIE's Frits Zernicke Award for Microlithography in February 2015, and Merck KGaA's Science Award in 2020.