Pupilgram control for optical proximity effect matching

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New imaging software can optimize both pupilgrams and conventional imaging parameters to get optimal lithography performance.

Source mask optimization is one of the most important techniques available for extending the capabilities of argon fluoride (ArF) immersion lithography. ArF immersion lithography is a mature, cost-effective technology, and the most likely one to be used for next-generation semiconductor manufacturing. The combination of freeform light source shapes (pupilgrams) and complex mask patterns, determined by source mask optimization, can extend the practical resolution of a lithography system to produce finer details than would otherwise be possible.

The imaging contrast becomes very low when working at the extreme end of ArF immersion lithography’s capabilities. Low contrast, also expressed as a small k1 factor (≤0.3 or smaller), makes the process very sensitive to many imaging parameters, such as illumination reference shape errors, lens aberrations, process properties, etc. The pupilgram has to be adjusted to compensate for these. We use an optical proximity effect (OPE) curve to inform our adjustment of the pupilgram. OPE curves are widely used in lithography to test the characteristics of specific tools or setups. Here we define the OPE curve as the minimum feature size in the pattern versus the pitch (the distance from one line to the next). Essentially, OPE curves measure the difference between the source pattern and the one actually generated on the wafer. The differences are caused by limitations inherent to the equipment and can act as a ‘fingerprint’ to identify a specific tool or manufacturer. Once we see this fingerprint, we can adjust the pupilgram to compensate.

In order to create a freeform pupilgram, we used our illuminator, which has many degrees of freedom for pupilgram adjustment. Examples of pupilgrams generated by the illuminator are shown in Figure 1. The many degrees of freedom can be used not only to find a pupilgram solution for source mask optimization, but also to enable high accuracy OPE matching by re-adjusting the pupilgram.
Figure 3. Optical proximity effect (OPE) master performance validation based on exposure test for a freeform pupilgram shown above. Line width orientation (H: Horizontal. V: Vertical.) and pattern pitch are noted in nanometers at the bottom of the graph.

of these polynomials are graphically described in Figure 2. We can optimize the pupilgram to minimize the OPE matching error with relatively small modifications of the original pupilgram. Compared to grid-based optimizations, the proposed method better retains the pupilgram’s original source mask characteristics. To perform these pupilgram modulations for OPE matching, we developed an imaging application software, ‘OPE Master.’ This software will be publicly released later this year, and it can optimize coefficients of the pupilgram modulation functions in addition to conventional imaging parameters, such as lens numerical aperture and illumination numerical aperture.

Finally, we validated the performance of the OPE software with exposure tests, using the illuminator with freeform pupilgrams for a typical static-random-access-memory cell and the corresponding source mask optimization result. Figure 3 shows the validation of the OPE optimization and the freeform pupilgram of the source mask optimization. Zernike intensity modulations 4, 5, 9, 12, 16, 17, 21, and 25 and Zernike distortion modulations 3, 5, and 13 are adapted. The OPE residuals are improved from 2nm rms to 0.7nm rms.

In conclusion, we developed a new OPE matching software for a fast and accurate OPE matching procedure. By using the proposed pupilgram modulation model, our OPE software can achieve satisfactory OPE matching performance. This is confirmed by exposure tests using an intelligent illuminator modulation with appropriate degrees of freedom. The next step will be to show that the software works to reduce turn-around time during the actual lithography tool set-up procedure.

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References