# EDITORIAL

## IS THERE A FUTURE IN MICROLITHOGRAPHY?

This is the first issue of our journal in 2003. Looking over our publications up to the papers in this issue, practically all forms of microlithography have been covered, including extreme UV lithography (EUV), electron projection lithography (EPL), maskless lithography ($ML^2$), electron-beam and ion-beam systems, and of course, the mainstream reduction dioptric systems using KrF, ArF, and $F_2$ excimer lasers. The number of choices does not necessarily imply optimism. On the contrary, this is just the result of lacking a clear winner on which to focus our development efforts.

Take EUV as an example. It has, by far, generated much enthusiasm, gathered high momentum, and collected many strong advocates, including equipment vendors committed to fabricate prototype and manufacturing tools. To a respectable degree, there are activities on the mask infrastructure including mask blank supply and inspection. Of course, these could not have happened without consortia of potential users who contributed no less than a few hundred million dollars to take the initial risks of such an ambitious technology. However, what is the current confidence level on EUV lithography? A EUV scanner is projected to cost almost $50M for a prototype that has a wafer-per-hour throughput in the single digits. A light source to support double-digit wafers per hour has yet to be developed. The usable depth of focus at the 32-nm node is taxing the mechanical and optical limits of scanners, not to mention the unusually shallow image in the resist because of high resist absorption. Then, there is the contrast-robbing stray light due to roughness of optical surfaces at the EUV wavelengths, the aberrations due to insufficient surface precision, lack of mask pellicle coupled with extraordinarily expensive masks, possibilities of damaging the optical system beyond repair from resist out gassing, on and on.

Now, electron source technology is relatively mature, and electro-optics are easier to build than EUV optics. There is a long history and plenty of experience gathered in making stencil or membrane masks. Hence, we may even be able to recover some of the multi-hundred-million-dollar investment in proximity x-ray lithography. However, one should not forget that the field size in electro-optics is small. To attain a 26-×33-mm field, pattern stitching is inevitable. Stitching error follows. Moreover, achieving this standard scanner field calls for making a stencil mask out of a 300-mm wafer substrate. Currently, even the 200-mm stencil mask technology and infrastructure have barely started. The list of difficulties is not exhausted. Electron imaging suffers from space-charge effect, reducing resolution and common depth of focus. To combat space charge, the beam current has to be reduced, trading off the already meager throughput. Increasing the resist sensitivity to compensate for the lost throughput only raises the concern on shot noise just as with EUV lithography. Of course, a mask pellicle is still not possible just as with EUV lithography.

$F_2$ lithography using 157-nm light is closer and is expected to be the vehicle to deliver the 65-nm node. Similarly, many millions of dollars have been spent. Is it closer to reality? Take the $CaF_2$ lens material. It is a crystalline material. Thus, in addition to stress-induced birefringence, there is also intrinsic birefringence. The former has to be annealed and the latter compensated, both to a high degree of perfection. The crystal growth time is still in terms of months and the yield of $CaF_2$ for high-NA 157-nm lenses is still in the single digits. This not only makes lenses very expensive for $F_2$ lithography, but will also become a bottleneck for tool ramp-up. $CaF_2$ is by no means the only problem with $F_2$ lithography. $F_2$ resists have yet to show acceptable transmission and etch resistance. Nitrogen purging to get rid of light-absorbing oxygen and to prevent lens contamination from trace chemical vapors is not only a logistic concern but also a safety nightmare. Are we better off in mask pellicle compared with EUV and EPL? Somewhat! No polymer-type soft pellicle is available despite funded development efforts. One can at least use hard quartz pellicles at a much higher cost and compromised imaging performance.

Maskless lithography offers some hope, not simply for lack of competition but also due to cost. A set of masks commands approximately $500K at the 130-nm node. It is expected to cost upwards of $1.5M for the 90-nm node. Continuing the same rate of increase, the escalating mask cost is going to suffocate development in the future nodes. In addition, the mask error factor is running on the order of 4 or more due to strong resolution enhancement techniques (RET). Optical proximity correction (OPC) complicates the pattern to be written to the mask and increases pattern count and file size. All these are eliminated with $ML^2$. However, there are several things to keep in mind. The existing pattern generation technology barely suffices to write 4X masks. With $ML^2$, it is required to write 1X patterns directly. Even though it is no longer required to generate the jigs and jugs from OPC and subresolution assist features from RET, meeting the critical-dimension uniformity target and placement accuracy at 1X still needs much more development work. Increasing the throughput from 10 hours per wafer to 10 wafers per hour demands a rate increase of at least 8000 fold in writing speed and in data transmission, for 300-mm wafers.

Where does that leave microlithography for the 65-, 45-, and 32-nm nodes? Did I hear a whisper on 22 nm? Recently, in a 157-nm workshop, I presented the difficulties of $F_2$ lithography and showed strong evidence that 193-nm light combined with water immersion is equiva-

1537-1646/2003/$15.00

lent to wavelength reduction to 132 nm, one generation beyond a $F_2$ dry system. That means being able to take care of the 65- and 45-nm nodes without concern on $CaF_2$ quality and quantity, resist absorption and etch rate, nitrogen purging, as well as hard pellicles. As we have learned by now, nothing is perfect, straightforward, or inexpensive at this level of microlithography, especially with all the investments in the aforementioned exotic systems, looking for a way to recover loss of projected revenue. Technically, one has to keep the immersion fluid homogeneous during high-speed scanning and high-intensity exposures while maintaining an economically viable throughput. Resist out gassing has to be kept very low or eliminated completely. Nevertheless, these difficulties are David-size against the Goliath-size difficulties of the other technologies. Beyond 45 nm, economy will dictate that all exotic technologies give way to simple techniques such as multiple exposures and lithography-friendly designs. The bottleneck may no longer be microlithography. It may be the gate insulator, the chemical-mechanical polish, the etching, the low-k insulator, or even the metrology.

We now have some sensible and economical directions to pursue. Being less exotic by no means implies less exciting, interesting, or useful. Nevertheless, much work is needed to resolve the issues and develop the winning technology. This journal is dedicated to publish all good works, regardless of the degree of exoticism.

Happy reading! Hard working! Diligent writing!

**Burn J. Lin**
**Editor-in-Chief**