Status of 193 nm Technology

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Overview

Originally slated for 180nm, 193nm lithography will be introduced at the 130nm node. Still, some manufacturers question the readiness of 193nm for production because of the immaturity of 193nm resists and the scarcity of high-quality CaF2 lenses, which are affecting the availability of production tools. Recent improvements in 193nm resists and CaF2 yields suggest, however, that 193nm can support production lines.

This year, the semiconductor industry will meet yet another technological milestone — the introduction of 193nm lithography into production lines. Just a few years ago, 193nm was seen as the last gasp of optical lithography. Today, it is seen as a mere stepping-stone to the greater challenge of 157nm. The production engineers, however, are not so complacent. To them, 193nm is the next technology to wrestle into compliance — 193nm will be the first lithography technology to be introduced at a technology node smaller than the exposure wavelength. Originally slated for 180nm, 193nm lithography will be introduced at the 130nm technology node, though some argue that it will not be needed until the 100nm node.)

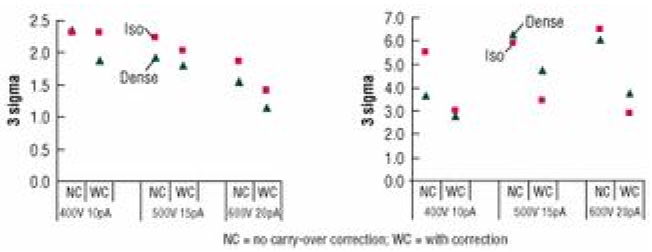

Figure 1. Using CD SEM with normal beam settings, the static precision for measuring 130nm dense lines and isolated lines in 193nm resist was <2nm.

The delayed introduction of 193nm lithography is possible because of the tremendous advances in resolution enhancement techniques (RET), leading some lithographers to consider sub-100nm gates using 248nm deep-ultraviolet (DUV) tools [1, 2]. In fact, DUV has been so successful that it has pushed 193nm out of first-generation 130nm node production lines. The fate of second-generation chips, with more complicated designs and a higher number of critical levels, is open to debate. The question is one of k1 vs. λ. In Rayleigh's equation (minimum resolution = k1 λ/NA); λ is the exposing wavelength; NA is the numerical aperture of the lens; and k1 is a process-related constant (factoring in resist performance and lithographic techniques). Lithographers can improve their resolution by lowering k1 with RETs such as off-axis illumination, OPC, and phase-shift masks. In doing so, they can continue to work with the mature DUV resists and exposure tools. Unfortunately, such techniques often require advanced and very complicated mask designs, which translate to long lead times and expensive reticles that are difficult to inspect for errors. These techniques also tend to exaggerate lens imperfections in the exposure tool, placing more demands on the tool set.

DRAM manufacturers, who work with highly repetitive mask designs and print a relatively large number of chips from a single mask set, are more likely to continue to invest the time, money, and effort into optical extension techniques than are logic manufacturers. Logic manufacturers are keenly interested in the transition from 248nm to 193nm exposure tools (improving resolution by decreasing l). Such a move delays the need for heroic optical extensions such as phase shift masks.

2000 ITRS targets for the 100nm node

	2000 ITRS Roadmap (100nm node)	ATDF experimental results
DRAM half pitch (nm)	100	100
Gate length (in resist) (nm)	70	70.5
Gate length (post-etch) (nm)	60	53.6
Contact size (nm)	115	100
Contact aspect ratio (stacked capacitor)	13:1	11:1
Gate CD control (3s) (nm)	6	12
DOF (µm)	0.5	0.4–0.6
Resist thickness (Å)	3000–4000	2700–3900

Over the past couple of years, however, 193nm lithography has faced some tough manufacturing questions. Some manufacturers have questioned whether 193nm will be ready for production in 2001: 193nm resists do not have the maturity of DUV resists, and production tools may not be available due to the scarcity of high-quality CaF2. Although the issue of lens compaction still looms, early 193nm tools have not shown the lens degradation issues that were once feared. Today, a number of stepper companies have announced 193nm production-level tools. Some scanners have been redesigned to reduce the amount of CaF2 needed and CaF2 availability has simultaneously improved. So despite the nay-sayers, according to Dataquest [3] more than one manufacturer is looking to move 193nm into pilot production by year's end.

This article will discuss the state of 193nm lithography — whether it is ready for production and whether it is capable of supporting the 100nm technology node.

Resist performance

A prime criticism of 193nm lithography is that commercial resists are not yet ready for the production line. Developing 193nm resists has proven to be a challenge because a large number of chemical materials absorb 193nm light. The bulk of the resist material must be transparent to the exposure wavelength in order to yield straight sidewalls. The base polymer used in DUV resists absorb 193nm light due to a chemical structure wherein an aromatic ring is attached to the polymer backbone. Unfortunately, it is this ring system that gives DUV resists etch resistance. Removal of the aromatic group from the polymer in order to create a 193nm resist with good imaging properties is relatively straightforward, but, as expected, these resists perform poorly when etched.

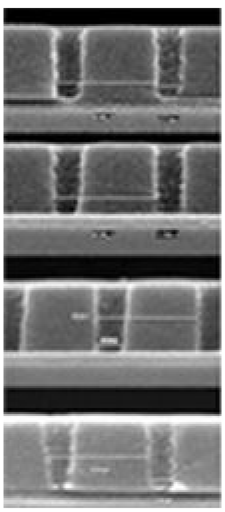

Figure 2. Cross section through focus shows post-etch 130nm contacts at best dose. The contacts were exposed on 193nm equipment with a 6% attenuated PSM.

A new strategy emerged in which a different kind of ring system was incorporated into the 193nm polymers — rings that would not absorb 193nm light but could still keep the polymer intact during etch. Imagine firing bullets (etching species) into a bunch of strings (polymer molecules); a string will be cut in half each time it is hit with a bullet. Now if some loops are tied in the string (chemical ring systems), the string can be cut by a bullet and still remain intact. These new polymers, called cyclo olefin-maleic anhydrides or COMA polymers, provided improved etch rates but lacked the needed resolution. This led to a dual approach that is still playing out, in which resist chemists improve etch resistance in acrylic resists with no decrease in resolution, or enhance resolution in COMA resists without sacrificing etch resistance.

The Advanced Technology Development Facilities (ATDF) at International Sematech has benchmarked several recent 193nm resists and noted considerable improvement over the past 12 months [4]. The newer resists show large improvements in problem areas such as line-edge roughness and line slimming (the shrinking of lines during top-down CD measurement). Though not equivalent to mature DUV resists, current 193nm resists show better overall performance than many early production-level DUV resists. Further, though a single platform has yet to emerge, some vendors are demonstrating considerable advances in resolution and etch, claiming their latest 193nm resists have resolution/etch performance rivaling their i-line resists.

Line slimming: A resist and metrology issue

One notorious characteristic of 193nm resists is their tendency to shrink when exposed to the electron beams of SEMs. This "line slimming" can affect top-down CD measurements and even the sidewall profiles of metal-coated cross sections [5]. Resist suppliers have worked on their resist chemistries to minimize line slimming, and recent benchmarking at the ATDF has shown two- to threefold improvements over last-year's resists [4]. SEM suppliers, as well, are looking for ways to temper the effect of e-beams on these volatile resists. New focus algorithms, lower beam energies, and ways of minimizing beam/sample interaction time are three common examples [6]. Though line slimming has gained much attention with 193nm resists, top-down CD SEMs have always changed the dimension of the feature that they are measuring. When the rate of change is very slow, as in etched poly, it hides in the noise of the tool during the first several dozen measurements. When the rate of change is very fast, as in some of the less hardy 193 resists, the feature shrivels before one's eyes.

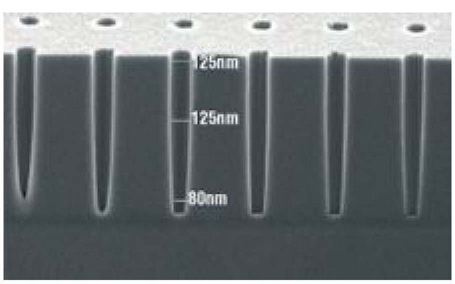

Figure 3. Cross sections of 130nm contacts in 10K oxide indicate good profiles and CD uniformity, demonstrating that a hard mask is not required for all 193nm processes.

Whether the CD change is fast or slow, the amount of change is primarily a function of the number of measurements. Studies on select 193 resists at Sematech have shown that the ITRS critical dimension precision requirements can be met if the number of top-down CD SEM measurements is limited. Reducing the beam energy — voltage and current — of the CD SEM will reduce the rate of change of the CD measurement.

Fab metrologists and SEM suppliers seem to agree that lower beam energies are the short-term solution to measuring sensitive 193 resists, but this approach sacrifices some precision. Assuming that the CDs of a wafer site need to be obtained only once and not revisited multiple times (a reasonable assumption for manufacturing), we searched for the beam conditions under which the best precision could be achieved (2nm, 3σ being a typical result for 248nm resist).

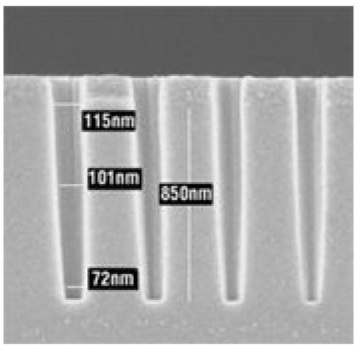

Figure 4. A nitride hard mask was used in processing 100nm contacts in oxide with an aspect ratio of 11:1.

At the lower beam energies, there was significant measurement noise and pattern recognition failures. However, we found that with normal beam settings, the static precision for the measurement of 193nm resists, even those with severe line slimming, was less than 2nm (Fig. 1).

These results show that line slimming, though still undesirable, does not present manufacturing with a problem in obtaining precision CD measurements. This finding, in combination with the fact that vendors have improved their resists, suggests that line slimming is not a serious production problem.

The 100nm node

As discussed above, some manufacturers may choose RETs and DUV at the 130nm node instead of 193nm lithography. No matter how things play out at 130nm, however, 193nm will be the dominant technology at 100nm. The table shows the 2000 ITRS definition of the 100nm node, scheduled to enter production in 2003. The ATDF has explored the ability of 193nm to support the 100nm node with a 0.6 NA, 193nm scanner linked to a DNS SK2000 resist track system. As the k1 for this work is 0.31, an alternating phase shift mask was required for the line features and a 6% attenuated phase shift mask for contact features. Patterns consisted of 65nm isolated lines, 100nm dense (1:1) lines, and 100nm and 130nm contacts. The results are compared to ITRS specifications in the table.

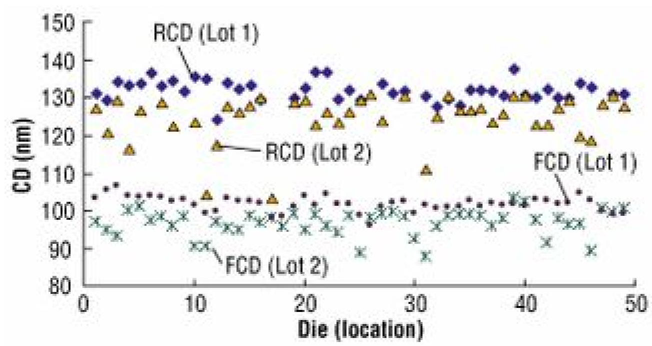

Figure 5. Pre- and post-etch CD uniformity data for 100nm contacts show acceptable preliminary results.

Contacts

At the 100nm node, it is the contact features, not the gates, which will test the skill of the lithographer. Contact features don't lend themselves to many classic RET strategies and may be the deciding factor for many manufacturers to move to 193nm lithography. The 1999 ITRS roadmap put the contact-holes at 130nm for the 100nm node. With that goal in mind, 140nm contacts were imaged at the ATDF on a 10,000Å oxide/1000Å nitride stack using a 3900Å-thick resist (Sumitomo PAR-722) and a 6% attenuated PSM (Fig. 2). A bottom anti-reflective coating (Brewer ARC25) was needed, but no hard mask was used. The lithography required a large bias of 160nm on the mask. The features show a 0.6µm depth of focus (DOF), which falls within the ITRS specifications. The contacts were then etched through the oxide film, stopping on the nitride. Cross sections of the 130nm etched features showed excellent profiles with good CD uniformity (Fig. 3), demonstrating that a hard mask is not required for all 193nm processes.

The recent 2000 update of the ITRS roadmap tightened the specification for contact size to 115nm. It was not possible to meet this target by lithography alone, using a 0.6 NA exposure tool and a conventional 6% attenuated PSM.

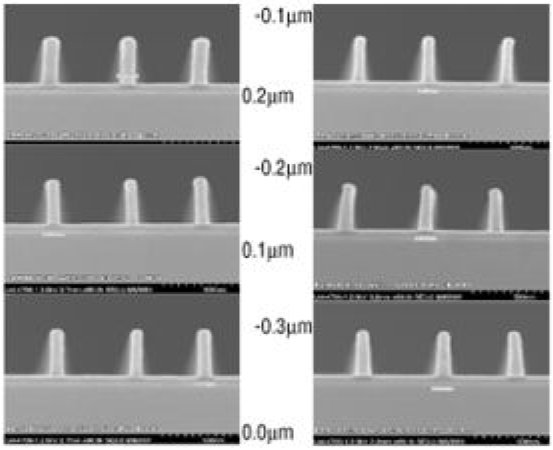

Figure 6. The depth of focus at best exposure was found to be 0.5µm for critical dimensions of 70nm isolated lines on polysilicon.

However, 100nm contacts could be created by modifying the etch process to undersize the etched contacts. Initial results show that we are able to improve patterning performance through the use of a hard mask. By adding a 1000Å nitride hard mask to the stack, 130nm contacts in the resist could be etched to a size of 100nm (360nm pitch) with an aspect ratio of 11:1 (Fig. 4). Process optimization should improve the pitch and bring the aspect ratio to the target aspect ratio of 13:1. Figure 5 shows that the CD uniformity across the wafer was large, but acceptable for an infant process, with 3σ numbers of 19.2nm for resist features and 12.3nm for the final etched features [7]. It is important to note that with 193nm resists, we are able to reduce CD due to negative etch bias (etched features are smaller than resist features). Such etch bias is more prominent in trench etch where we were able to etch 90nm trenches in 2200Å oxide.

Iso/dense lines

Although Sumitomo AX-4837 was designed for dense line features, it proved effective for isolated lines, with a good process window. Patterning was carried out on a 1500Å-thick polysilicon layer using a strong shifted PSM and an organic BARC. Strong shifting PSMs are difficult to implement in manufacturing, but production 193nm scanners will have an NA higher than 0.6 and therefore should be able to achieve 70nm gates without the use of strong shifters [8].

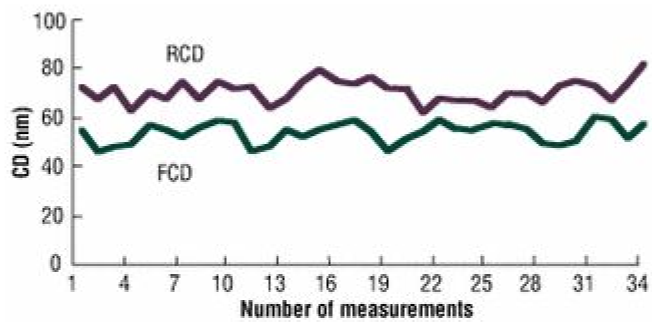

Figure 7. CD uniformity and litho-etch bias for 65nm isolated lines, from etch through the polysilicon film, shows an average final CD of 53.6nm.

The DOF at best exposure was found to be 0.5µm (Fig. 6). Critical dimensions of the isolated lines were determined for 17 die/wafer; each die was measured twice. The average CD was 70.5nm (3σ = 13.8nm). Following etch through the polysilicon film (stopping on 20Å of oxide) in Fig. 7, the average final CD was 53.6nm (3σ = 12.6nm). Linewidth control falls short of the ITRS specification of 6nm, though it could probably be improved with some process optimization in the polysilicon etch and by reducing the 4:1 aspect ratio of the resist features.

Using the AX-4837 resist with a hard-shifting PSM, 100nm 1:1 dense features were imaged. In order to avoid pattern collapse, the resist was coated to a thickness of 2700Å. A 600Å organic BARC layer was used and the DOF to pattern 100nm dense lines on oxide was found to be 0.5µm. After exposure under the same conditions cited above, the average linewidth was 105nm (3σ = 8.8nm). AX-4837 has demonstrated a reasonable oxide etch rate, and a suitable etch process for these features is in progress.

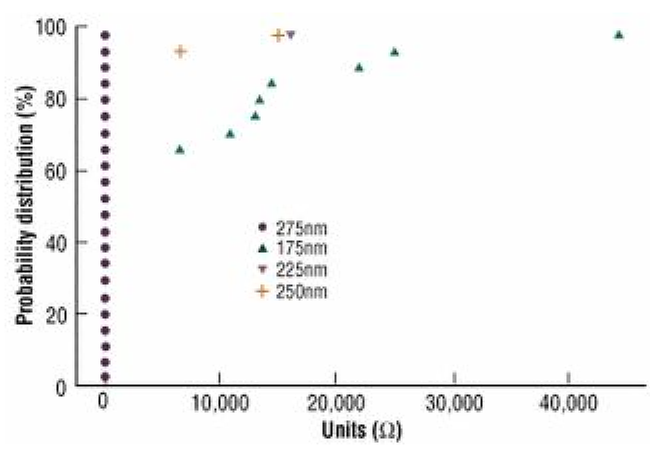

Figure 8. From the probability chart for 360K via chain, a 60% yield for 180nm contacts was achieved and over 90% yield for the remaining via sizes.

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One cannot talk about the 100nm node and not mention copper. At the ATDF, a dual 250nm-node damascene copper baseline has been used to monitor the health of processing tools and provide the benchmark for advanced copper and low-k development. At present, 248nm resists are used to image critical dimensions of 250nm and via chains 360K long. For patterning via chains of 220, 200, and 180nm, 193nm resists with binary masks and conventional illumination are used. Initial results give a 60% yield for 180nm contacts and over 90% yield for the remaining via sizes (Fig. 8). Work is in progress to improve the yield at the 180nm node and then quickly to move the copper baseline to 130nm contacts.

Conclusion

A move to 193nm in production lines will not be without headaches. As with any move to a new technology, issues anticipated and unforeseen will keep production engineers' pagers ringing for the next few years. The last year, however, has been very productive in addressing major issues. In particular, photoresists have shown tremendous improvement and the drive to prepare the industry for 157nm lithography has assisted 193nm by improving the yield and quality of CaF_2 optics. As with any new technology, production begins on less than solid ground, and it is up to the engineers to step forward and meet the challenge of fine-tuning and working out the final bugs. Such will be the case with 193nm lithography.

Acknowledgments

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