Photoresist-induced development behavior in DBARCs

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ABSTRACT

Developer-soluble bottom anti-reflective coating (DBARC) BSI.W09008 has provided promising lithography results with five different 193-nm photoresists, with the accomplishments including 120-nm L/S (1:1) and 130-nm L/S through-pitch (i.e., 1:1, 1:3, and isolated line). This DBARC is not inherently light sensitive and depends on diffusing photoacid from the exposed photoresist for development. With undercutting being an issue for the PAG-less DBARC with some resists, the shapes of 130-nm lines (both dense and isolated) were improved by either a) incorporating a small amount of a base additive in the BSI.W09008 formulation or b) altering the structure of the DBARC's binder polymer. With selected photoresist(s) and/or resist processing conditions, either photoacid diffusion or photoacid activity is inadequate to give DBARC clearance and BSI.W09008 performs more as a dry BARC. The post-development residue obtained from BSI.W09008 on a silicon substrate is much less dependent on the initial DBARC film thickness and the exposure dose than for earlier-generation photosensitive (PS)-DBARC BSI.W07327A, using the same photoresist. BSI.W09008 also gives less post-development residue than BSI.W07327A using the same resist on a silicon nitride substrate at exposure doses of 14-25 mJ/cm^2.

Keywords: DBARC, PS-DBARC, 193 nm, photoresist-induced, post-development residue, sublimate, QCM, PAG

1. INTRODUCTION

A 193-nm bottom anti-reflective coating (BARC) will be required for implant layers at the 32-nm node and beyond to minimize reflectivity concerns.[1,2] In order to eliminate any reactive ion etching (RIE) damage to the implant layer during removal of the BARC, a developer-soluble material (DBARC) will be the preferred solution for that application. The exposed photoresist and DBARC are both removed in the same step in the aqueous tetramethylammonium hydroxide (TMAH) developer. As their resolution continues to improve, DBARC usage may expand to include not only implant but also the more resolution-demanding applications.[3] In this study, performance evaluations were conducted targeting 130-nm features. The latest generations of 193- and 248-nm DBARCs are typically light-sensitive and offer the potential for anisotropic development.[4] They usually contain a photoacid generator (PAG), which is the light-sensitive ingredient in the DBARC, a binder polymer, a crosslinker, and a quencher to minimize diffusion into the unexposed regions.[1] There are numerous types of PS-DBARCs,[5] including linear polymer with dye-attachment,[1] dye-filled using a polymeric binder,[3,6] and hyperbranched polymer systems with bound-chromophore.[7] The PS-DBARCs are typically thermoset during a hot plate bake to eliminate dissolution in the photoresist solvents. Differing from those families of PS chemistry, the DBARC platform to be highlighted in this paper is not inherently light-sensitive. These non-light-sensitive DBARCs, which are also thermosetting, are instead dependent on the diffusion of photogenerated acid from the photoresist into the DBARC layer for the de-protection and/or de-crosslinking that allows developer solubility.[5] In selected instances where there is minimal diffusion of the resist's photoacid and/or a relatively weak photoacid, and/or unacceptably low post-exposure bake (PEB) parameters, the DBARC's behavior becomes that of a dry BARC. The BARC film remains insoluble to developer after the exposure and PEB, and is then necessarily removed by RIE.

Photoresist selection, as well as processing parameters during lithography, are critical for optimum performance from the PAG-free DBARCs and even determine whether the anti-reflectants perform as DBARC or a regular dry BARC. Photoacid diffusion from the resist into unexposed areas containing PAG-less DBARC is low but can be further controlled by addition of an additive to the DBARC to reduce undercutting of features. The effects of acid diffusing into unexposed areas can also be mitigated by adjusting the structure of the BARC binder polymer to modestly change solubility in developer. Process conditions employed to manipulate photoresist performance, such as post-application

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bake (PAB) and PEB, can be used to adjust the DBARC performance. The potential advantages of this type of DBARC chemistry, as opposed to a PS-DBARC with built-in photosensitivity, include less sublimation, reduced residue after development, broad PEB window, and compatibility with a very wide variety of resists.

The BSI.W09008 chemical platform is presently the better characterized 193-nm PAG-less material among a series of such DBARCs and has provided good DBARC lithography performance with five different photoresists from four different resist manufacturers. Particular performance highlights for BSI.W09008 in this paper include a) a through-resolution performance example featuring 1:1, 1:3, and isolated L/S when using a resist A and b) an identified 8°C PEB window for 150-nm S/375-nm P using a resist B. Using yet a different resist C with BSI.W09008 makes it perform as a dry BARC when using two different sets of PEB parameters, though DBARC performance was achieved with an elevated PEB temperature. While the lithography with resist C may serve as proof-of-concept for a dry BARC from DBARC concept, both resolution and quality of lines and spaces must be significantly improved if such an advancement is to compete with state-of-the art 193-nm dry BARCs. As determined from a series of contrast curve measurements, using resist A with DBARC BSI.W09008 produces very low post-development residue on a silicon substrate. Differing from previous-generation 193-nm BSI.W07327A material, the amount of residue (monolayer) after development is not strongly dependent on DBARC film thickness or the exposure dose in the ranges tested. BSI.W09008 also gives less post-development residue than BSI.W07327A material at low exposure doses on a silicon nitride substrate, although at higher doses residue performances were similar. Sublimation from BSI.W09008 during a BARC bake was about one-tenth that observed from 193-nm dry BARC ARC® 29A-8 material. All of the above will be discussed in detail in the Results and Discussion section.

2. METHODOLOGY

Industry-accepted solvents were used in preparing the DBARCs. The DBARCs were end-point filtered prior to testing. The BARC bake was 160°C for 60 seconds (s), excluding one exception (190°C for 60 s), which is described in the Discussion. A Gaertner or Woollam M2000 ellipsometer was used to measure film thickness on silicon and silicon nitride substrates. To study the solubility of hot plate baked BARCs in photoresist solvents, an ethyl lactate (EL) stripping test was used.[6] The dark loss test, which measures solubility of a baked BARC in developer, was described in a prior Methodology Section.[5] The developer was 0.26N aqueous TMAH, with development time being 45 s, excluding an exception (60 s) as described in the Discussion (Figure 9). Optical parameters were measured using a variable-angle spectroscopic ellipsometer (VASE®) from J.A. Woollam. With one exception (49 nm) as highlighted in the Discussion, BARC film thickness for lithography was 52-55 nm. All lithography was carried out on silicon substrates, with the work being done at IMEC or Nissan Chemical Industries, Ltd. The scanning electron microscope (SEM) photographs of cross-sectioned wafers were prepared using a LEO 1560 from Carl Zeiss SMT Inc., although in one case (Figure 5) some photos were provided by another company. The photoresists that were used in this study were simply identified by capital letters as A, B, C, D, and E.

3. RESULTS AND DISCUSSION

3.1 BARC chemistry

The chemistry for PAG-less DBARC BSI.W09008 was described in a previous paper, with the material's characterization at that time consisting of lithography using an Amphibian™ XIS interferometer for the exposures.[5] The linear binder polymer for this DBARC was prepared by a free-radical solution polymerization utilizing three monomers, and the terpolymer was then purified prior to use. DBARC was prepared by combining the polymer with chemically attached chromophore and chemically attached acid function with a multifunctional crosslinker and solvents.

A hot plate bake step renders the DBARC solvent insoluble, assuring no BARC intermixing or removal during application of the photoresist. Exposure of a resist covering the BARC, followed by a PEB, results in either a) adequate diffusion of the photoacid into the BARC and de-protection and/or de-crosslinking, which induces DBARC performance or b) minimal de-protection and/or de-crosslinking of the BARC by the resist's photoacid, which induces dry BARC performance. The former (a) degrades the polymer films into developer- or water-soluble materials, while the latter (b) necessitates a plasma etch to remove the BARC. In one selected example to be discussed, a base quencher was included in the DBARC formulation to minimize the diffusion of photacid from the resist into non-exposed regions.

In a second example, the binder polymer was altered by including an extra (fourth) monomer in the polymerization mixture with the goal and achievement being to minimize undercutting of lines during development.

3.2 BARC film and optical properties

The film and optical properties data for three DBARCs are shown in Table I. After a 1500 rpm for 30 or 60 s spin and a 160°C for 60 s bake, all three PAG-less DBARCs exhibited good ambient temperature resistance to solvent EL and to developer (i.e., the latter being a dark loss measurement). A positive number for either of the tests indicates swelling, while a negative number shows loss of thickness. There was a PEB during the dark loss measurements of 110°C for 60 s. The film thicknesses that are shown are only from those wafers used for EL stripping. All of the data for BSI.W09008 are an average from three batches of the DBARC. The data for DBARCs BSI.W09008G and BSI.W09008N are from single batches. The DBARC coatings used for dark loss studies were not EL stripped nor did they undergo a post-application bake (PAB), simply the PEB. All of the BARC properties were comparable, excluding film thickness and k-value for BSI.W09008N.

Table I. DBARC film and optical properties.

BARC Identity	Film Thickness, nm	EL Stripping, %	Dark Loss, %	193-nm n/k
BSI.W09008	52	+0.8	+0.6	1.66/0.54
BSI.W09008G	52	+0.8	+0.6	1.65/0.54
BSI.W09008N	49	-0.4	+0.8	1.67/0.50

3.3 Sublimation from DBARC BSI.W09008 during BARC bake

Sublimation during the BARC bake step may result in unwanted contamination of the exposure equipment. As one part of DBARC characterization, a quartz crystal microbalance (QCM) was used to compare sublimation of BSI.W09008 during BARC bake with the amount of sublimate from two 193-nm dry BARCs. The standard 193-nm dry BARC control samples were ARC® 29A-8 and ARC® 162-304-2 materials. ARC® 29A-8 is considered acceptable for sublimation, and ARC® 162-304-2 is considered extremely low. For this test, the standard bake parameters for BSI.W09008 were 160°C for 120 s, and the dry BARC bake parameters were 205°C for 120 s. After the BARC bakes were completed using these parameters, coating thicknesses were 49.5 nm for the DBARC and 75.3 nm and 39.1 nm (respectively) for the dry BARCs. DBARC BSI.W09008 produced much lower sublimation than ARC29® A-8 material and about the same as ARC® 162-304-2 material. The sublimate comparison does not include any correction for the differences in baked BARC film thicknesses or the bake temperatures. Due to the absence of extra components in the DBARC formulation that would contribute to the sublimation, BSI.W09008 clearly produces very little sublimate. The data are shown as a bar graph in Figure 1.

3.4 Comparing post-development residue from BSI.W09008 and PS BSI.W07327A on a silicon substrate

Current-generation DBARCs have faced challenges during integration, with post-development residue being a continuous concern. This residue issue and the desired application must be considered when developing a DBARC. To address the problem, the amounts of residue on a silicon substrate were compared for the DBARC and the earlier-generation PS-DBARC. Wafers were prepared using photoresist A with both BSI.W09008 and BSI.W07327A material and were processed using an ACT® 8 Tel track and an ASML PAS5500™/1100 scanner for the exposures. The PEBs used were the optimal for lithography, with the PEB being 106°C for 60 s for BSI.W09008 and 110°C for 60 s for BSI.W07327A material. A meandering dose matrix was created using open frame exposure with conventional illumination. After development, a Woollam M2000 ellipsometer was used to measure the remaining organic residue. This work showed that the post-development residue obtained from BSI.W09008 on a silicon substrate is much less dependent on initial DBARC film thickness than that obtained using the earlier-generation BSI.W07327A material, as shown in Figure 2. There was a slight trend showing a decrease in residue with an increase in film thickness for BSI.W09008. The data in Figure 2 also showed that BSI.W09008's residue was not as dependent on the exposure doses in the range of 15 to 61 mJ/cm^2, as was BSI.W07327A material. When DBARC is coated over topography, thickness variations result. Dose variations can also occur from reflections off of the vertical geometry and variations in substrate materials. So these data indicate that BSI.W09008 coated over substrate topography should cause fewer residue issues than BSI.W07327A material.

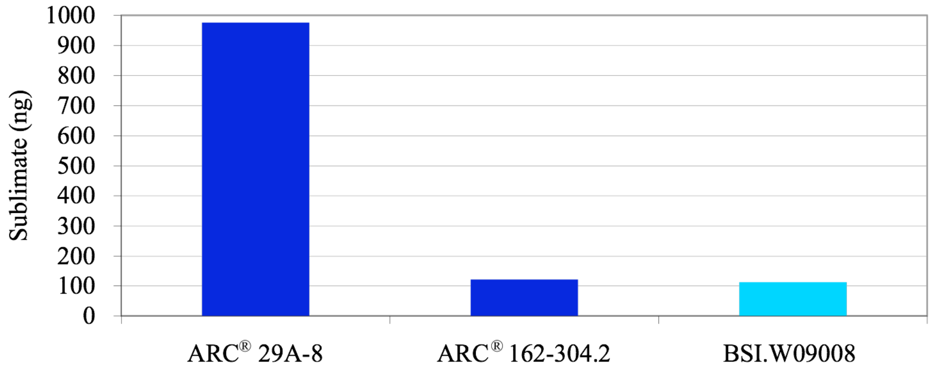
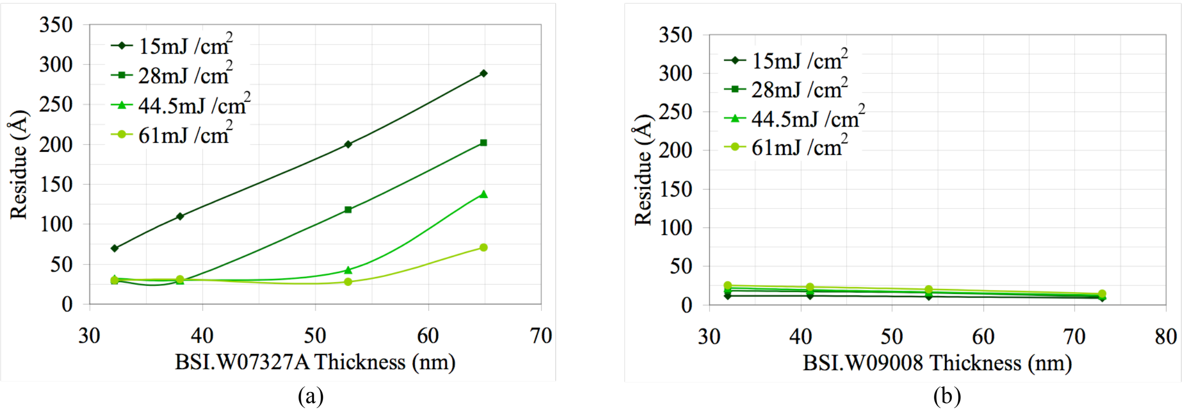


Figure 1. Comparison of the amount of sublimation from DBARC BSI.W09008 during the BARC bake process against the two 193-nm dry BARCs during their bake processes.



(a)

(b)

Figure 2. Residue on a silicon substrate versus BARC film thickness and exposure dose for a) BSI.W07327A material and b) BSI.W09008. PAB: 110°C for 60 s; a) 190-nm, b) 200-nm of resist A; ASML 1100-ArF scanner; conventional illumination; a) PEB: 110°C for 60 s, b) PEB: 106°C for 60 s.

3.5 Comparing post-development residue from BSI.W09008 and BSI.W07327A material on a silicon nitride substrate

The DBARC, PS-DBARC, and resist A were spin-applied to identical silicon nitride (Si_3N_4) deposited substrates following processing conditions similar to those used in the silicon testing above. Open frame ArF radiation was applied using a Nikon NSR-S307E tool, followed by the optimal litho PEBs of 106°C for 60 s for BSI.W09008 and 114°C for 60 s for BSI.W07327A material. The higher-than-normal PEB temperature of 114°C (with 110°C being typical for this paper) for BSI.W07327A material might, if anything, be construed as a benefit in reducing residue. The residue data for both DBARCs are plotted in Figure 3 as residue thickness versus exposure dose. Variation occurred in the deposited nitride thickness across the wafers and ellipsometry modeling was difficult, so multiple measurements were taken and trends established by linear regression. The residue trends on silicon nitride were similar to those on silicon. BSI.W07327A material produced residue that changed through dose. Whereas BSI.W09008 gave residue that sharply decreased through dose until an asymptote was reached near 18 mJ/cm^2, then the residue was stable through dose. Thus, for ArF exposure doses of 14 to 25 mJ/cm^2, BSI.W09008 would be expected to produce less residue then BSI.W07327A material on silicon nitride substrates. Because the doses the DBARC films are exposed to during open frame and masked exposures are different, considering diffraction and interference of a mask, specific doses must be adjusted for the appropriate lithography conditions for comparison. At higher exposure doses, residue performance of the DBARCs were similar.

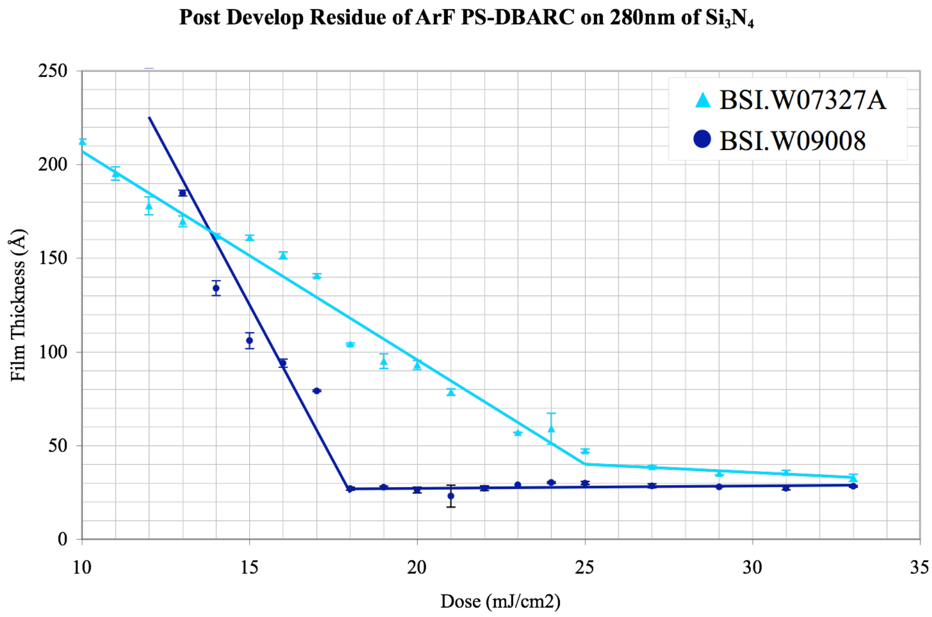


Figure 3. Residue on a silicon nitride substrate versus exposure dose for BSI.W07327A material and BSI.W09008. PAB: 110°C for 60 s; 190-nm of resist A; Nikon NSR-S307E; conventional illumination; a) PEB: 114°C for 60 s, b) PEB: 106°C for 60 s.

3.6 Lithographic performance for DBARC BSI.W09008 using photoresist A

The resolution performance of DBARC BSI.W09008 using resist A was studied using a scanner for the exposures, with a PEB of 106°C for 60 s providing optimum performance. SEM photographs of cross-sections were prepared at an SEM–cross-section–identified best exposure dose of 25 mJ/cm^2 and at 0.0 µm focus. The photographs for resolutions of 110 nm through 160 nm are shown in Figure 4a. Acceptable L/S (1:1, 1:3, and isolated lines) were achieved at 130-, 140-, 150-, and 160-nm resolutions. The dense (1:1) L/S were acceptable at 120-nm resolution, but the isolated lines were lost. Minimal residue was observed in the open areas. At 130-nm resolution, the iso/dense bias was about 18±3 nm. In all of the shown SEM photographs at resolutions of 120 nm through 160 nm, the lines exhibited an undercut or "pinch" at their bases. This result remains a concern for this photoresist/BARC combination, as isolated lines typically undercut more than the dense lines. With this resist, depth-of-focus (DOF) for the 102°C and 106°C PEBs was 0.30 µm, while the 110°C PEB gave a slightly higher DOF of 0.40 µm. As the undercut increases with an increase in PEB, the 114°C PEB only yields a 0.10 µm DOF. Figure 4b contains the lithographic results for the testing through-PEB. These data demonstrate that as the PEB increases, the DBARC undercuts more severely, indicating substantial acid diffusion into the unexposed areas. Combining this with the acceptable DOF measurements (at or above 0.20 µm), we consider this combination to have an 8°C PEB window. This photoresist results in consistent acid diffusion into the DBARC, as shown in the profiles in Figure 4. While we achieved a good balance of acid diffusion and consistent DBARC undercut, less undercut is desired. We can control this issue by changing the photoresist or by modifying the DBARC platform.

3.7 Lithography using photoresist B on DBARC BSI.W09008

A variety of PEB parameters were used in the lithography study using photoresist B on DBARC BSI.W09008, including 106°, 110°, 114°, and 118°C for 60 s. The exposure pattern was now 150-nm S and 375-nm P; the resulting SEM photographs of the cross-sections are shown in Figure 5. The DOF for these patterns was about 0.25 µm for all three of the lower PEB temperatures using exposure doses of 21, 20, and 20 mJ/cm^2 (respectively), but only about 0.10 µm for the highest PEB temperature at an exposure dose of 20 mJ/cm^2. These results represent an 8°C PEB window. The tops of the resist lines tended to be indented, and some slight undercutting occurred at the base of the lines. However, the undercutting appeared to be much less than with resist A. Even as the PEB temperature increases, the undercut of the DBARC is more consistent when compared to behavior with resist A, as shown in Figure 4b. Overall, photoresist B showed good compatibility with BSI.W09008, contributing enough acid to de-crosslink and deprotect the film while maintaining limited undercut into the unexposed areas. So while the PEB window was similar to that for resist A, the DBARC profile behavior was improved. A different source for SEM photographs was used to prepare photos for the three higher PEBs, as opposed to the lowest PEB.

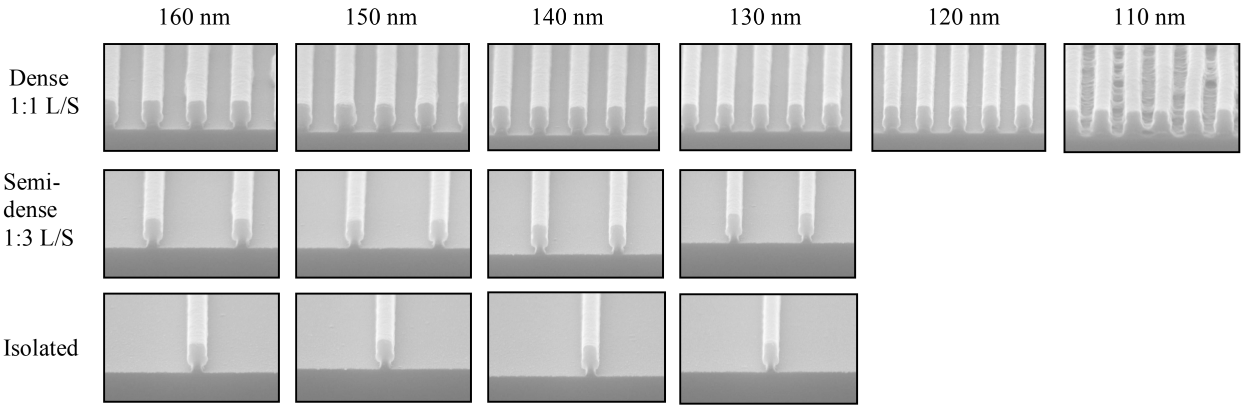
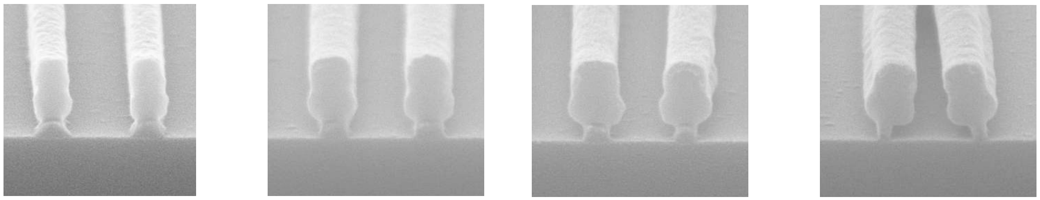
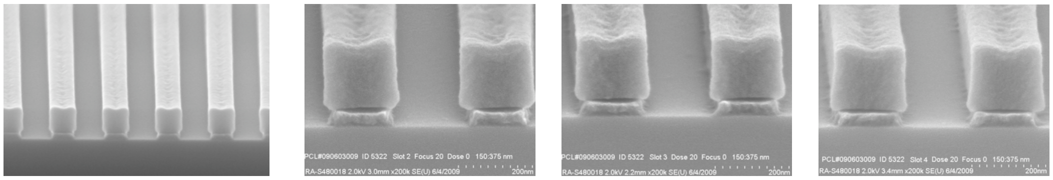


Figure 4a. Through-resolution lithography performance for DBARC BSI.W09008 using covering resist A. PAB: 110°C for 60 s; 190 nm of resist A; ASML 1100-ArF scanner; conventional illumination; NA of 0.75; sigma of 0.89; target CD 130-nm L/260-nm P (bright field); PEB: 106°C for 60 s.



PEB: 102°C for 60 s PEB: 106°C for 60 s PEB: 110°C for 60 s PEB: 114°C for 60 s

Figure 4b. Lithography with resist A and BSI.W09008 through-PEB, 130-nm L/260-nm P at best focus. PAB: 110°C for 60 s; 190 nm of resist A; ASML 1100-ArF scanner; conventional illumination; NA of 0.75; sigma of 0.89; target CD 130-nm L/260-nm P (bright field); PEBs: 102°, 106°, 110°, and 114°C for 60 s.



PEB: 106°C for 60 s PEB: 110°C for 60 s PEB: 114°C for 60 s PEB: 118°C for 60 s

Figure 5. Lithography using resist B on DBARC BSI.W09008 through-PEB at 0.0 µm. PAB: 110°C for 60 s; 230 nm of resist B; ASML 1250-ArF scanner; conventional illumination; NA of 0.85; sigma of 0.5; target CD 150-nm S/375-nm P (dark field); PEBs: 106°, 110°, 114°, and 118°C for 60 s.

3.8 Lithography using resist A on DBARC BSI.W09008G

To minimize photoacid diffusion into non-exposed areas and eliminate the undercutting being observed for DBARC BSI.W09008 in lithography with resist A, a small amount of quencher was included in the DBARC. This new formulation was DBARC BSI.W09008G. The 130-nm dense (1:1) and isolated lines (in particular) are now much improved as compared to those from BSI.W09008, showing less undercutting at the base of the lines (see Figure 6). DOF for both dense and isolated lines at an exposure dose of 27 mJ/cm^2 is about 0.3 µm. The spaces are clean. In contrast to the lithography using BSI.W09008, described in Sections 3.6 and 3.7, the illumination for this process was annular. Using the "G" DBARC formulation and annular illumination produced less undercutting than DBARC BSI.W09008 with conventional illumination. With its reduced undercut behavior, BARC BSI.W09008G offers promise for providing even smaller CDs. This DBARC performs well and shows that with this PAG-less system, further diffusion into the DBARC can be mitigated.

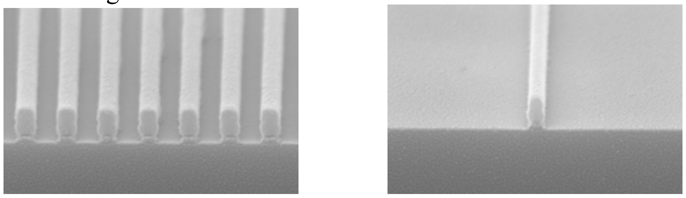


Figure 6. Lithography for resist A on DBARC BSI.W09008G at best focus, 130-nm resolution. PAB: 110°C for 60s; 190 nm of resist A; ASML 1100-ArF scanner; annular illumination; NA of 0.75; sigma of 0.85:0.57; target CD: 130-nm L/260-nm P (bright field); PEB: 106°C for 60 s.

3.9 Lithography using resist A on DBARC BSI.W09008N

To change developer solubility of the DBARC in unexposed regions while maintaining adequate developer solubility of the product under the exposed resist, the structure of the binder polymer for BSI.W09008 was altered by including a fourth monomer. The standard polymerization procedure was used. The fourth monomer contains a pendant polycyclic aromatic function in addition to crosslinking sites. By incorporating this monomer, the film may be more hydrophobic, rendering it less susceptible to developer in the unexposed areas. This also allows us to modify the crosslink density of the film, thereby making a film that is more difficult to de-crosslink. The purified polymer was incorporated in the standard BARC formulation to produce the new DBARC BSI.W09008N. In contrast to the other lithography described in this paper, the BARC film thickness was only 49 nm. The best lithography for this DBARC using resist A required a PEB of 110°C for 60 s, as a lower-temperature PEB of 106°C for 60 s produced dirtier spaces for both dense L/S and isolated lines. SEM photographs of cross-sections showed 130-nm L/S (1:1 and isolated lines) with about 0.2 µm DOF for both dense and isolated lines at an exposure dose of 25 mJ/cm^2. The spaces for the dense patterns are ever slightly dirty, even with the 110°C PEB, as compared to BSI.W09008 and BSI.W09008G. Line shapes are very good. Again, the illumination was annular. The SEM photographs of cross-sections are shown in Figure 7.

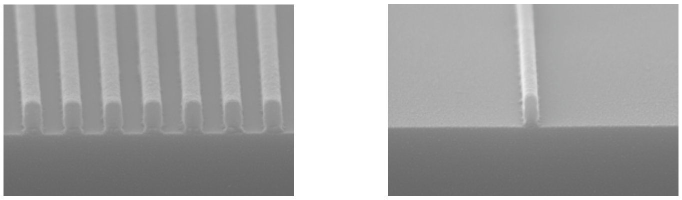


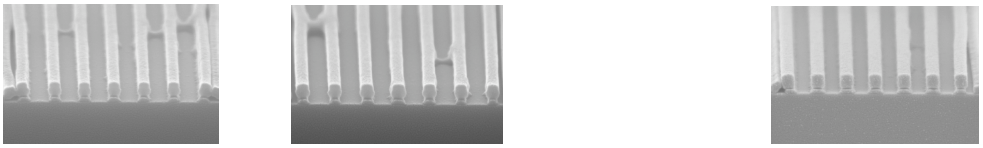
Figure 7. Lithography for photoresist A on DBARC BSI.W09008N, 130-nm resolution. PAB: 110°C for 60 s; 190 nm of resist A; ASML 1100-ArF scanner; annular illumination; NA of 0.75; sigma of 0.85/0.567; target CD 130-nm L/260-nm P (bright field); PEB: 110°C for 60 s.

The acid diffusion was mitigated, specifically in this system, by rendering the unexposed area less soluble in developer. However, to thoroughly study the impact that the photoresist has on the DBARC film, further investigation was done with the standard PAG-less DBARC, BSI.W09008.

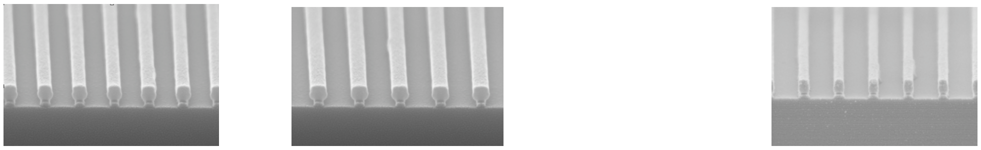
3.10 Lithography using other 193-nm photoresists, i.e., resist D and resist E

After a promising DBARC/photoresist combination had been developed to show excellent DBARC performance, other photoresists were screened. Because BSI.W09008 is dependent on acid diffusion from the photoresist, it is necessary to evaluate the contributions of several photoresist platforms. While the best lithography to date using DBARC BSI.W09008 has been with resists A and B, other photoresists have provided promising results and are deserving of future optimization studies. Selected through-resolution lithography results with photoresist D are shown in Figure 8a at 0.0 µm focus. A higher-temperature PEB of 114°C for 60 s was used in optimizing performance of this resist and DBARC system. Other than resist microbridging, the 130- and 140-nm dense L/S are not bad. The spaces are clean for the 150- and 180-nm dense L/S, but the lines are undercut or pinched. At the conditions tested, resist D shows comparable acid diffusion performance as resists A and B.

Figure 8b shows selected lithography results with same PAG-less DBARC BSI.W09008 and resist E. The PEB in this case was 110°C for 60 s, and the resolution was 130 nm at 1:1 and 1:1.5 L/S at +0.1 µm focus. While the spaces would preferably be cleaner, for dense L/S in particular, the targeted CD was actually 80-nm L/160-nm P as an artifact of studying dry BARC performance. This suggests an opportunity for improving the 130-nm L/S for DBARC performance. With this resist, the DBARC shows slightly more footing than the others. While acid diffusion could be controlled by the PEB, overall, this resist displays less photoacid diffusion/activity. This behavior brings to light the continuing problem for PS-DBARCs, that is, the necessity to match resist and BARC performance. However, DBARC BSI.W09008 displays promising compatibility with a variety of resists.



130-nm L/S (1:1); 140-nm L/S (1:1); 1:1 L/S



150-nm L/S (1:1); 180-nm L/S (1:1) 1:1.5 L/S

a) Resist D on DBARC BSI.W09008, resolution (1:1) at 0.0-µm focus.

b) Resist E on DBARC BSI.W09008, 130-nm L/S (1:1 and 1:1.5) at +0.1-µm focus.

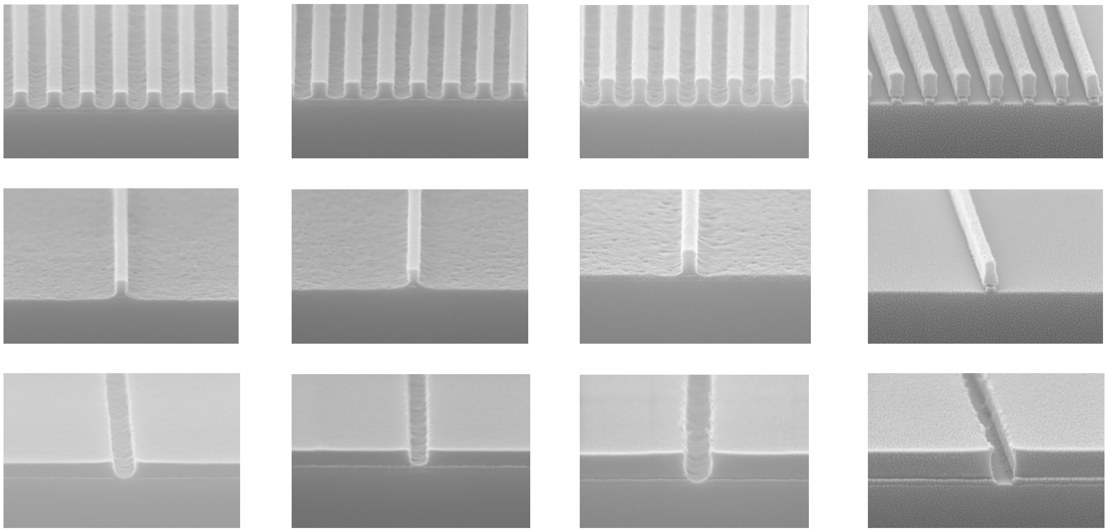
Figure 8. Lithography for resists D and E on DBARC BSI.W09008. a) PAB: 110°C for 60 s; 130 nm of resist D; ASML 1100-ArF scanner; conventional illumination; NA of 0.75; sigma of 0.89; target CD of 130-nm L/260-nm P (bright field); PEB: 114°C for 60 s. b) PAB: 105°C for 60 s; 155-nm of resist E; ASML 1100-ArF scanner; dipole35Y illumination; NA of 0.75; Sigma of 0.89:0.65; target CD 80-nm L/160-nm P (bright field), PEB: 110°C for 60 s.

3.11 Lithography using resist C on DBARC BSI.W09008 (dry BARC performance)

Whereas we have shown that a DBARC shows good compatibility with a variety of resists, we also investigated the novelty of performance as a dry BARC. This type of dual-purpose DBARC would enable a user to quickly go from one application, such as implant, to another that requires dry BARC performance, using the same material and only process tuning. Based on the nature of the BSI.W09008 platform, if it is paired with a resist that exhibits low acid diffusion, especially at lower-temperature PEBs, then the DBARC should not be rendered soluble and therefore yield dry BARC properties. In contrast to the lithography work with resists A, B, D, and E, photoresist C exhibited dry BARC performance from DBARC BSI.W09008 using a PEB of 105°C for 60 s and targeting 130-nm CD patterns. This performance was with the standard BARC bake of 160°C for 60 s. Slight footing occurred at the base of the lines, and a rough pattern was produced in the spaces, with both traits being undesirable for a dry BARC. A visual examination of the dense spaces and isolated trenches suggests that there was minimal development of the BARC and incomplete development of the resist. Possible causes for the footing and roughness in the spaces might include a) resist and BARC intermixing during application of the resist, b) chemical interactions between resist and BARC, and c) inadequate diffusion/activity of the resist's photoacid. In response to the possible intermixing, the BARC bake was increased from the standard 160°C for 60 s to 190°C for 60 s in an attempt to achieve more efficient crosslinking; results are shown in Figure 9. This change did not, however, improve L/S/trench (T) quality.

Using a BARC bake of 160°C for 60 s, PEBs at temperatures of 98°, 112°, and 120°C for 60 s were then compared for performance. The lowest PEB in this series was aimed at even further decreasing photoacid migration. At an exposure dose of 37.0 mJ/cm^2 (maximum for this test), the lines were still slightly underexposed, with linewidth of about 138 nm for dense L/S per CD-SEM. The higher PEB temperatures, in response to the possibly inadequate photoacid diffusion/activity of the resist, were expected to increase photoacid migration and activity and possibly even provide DBARC performance. At the lowest exposure dose (25 mJ/cm^2) used with a PEB of 112°C for 60 s, the CD was on target for dense lines by CD-SEM and we are able to migrate back to DBARC performance. Line collapse was observed when the exposure dose was higher than 25 mJ/cm^2. At the highest PEB temperature of 120°C for 60 s, all patterns were lost, and only faint line traces were visible.

If using a dry BARC to achieve isolated trenches or lines is desired, this combination delivered promising initial results, as shown in Figure 9. Resist C provides dry BARC performance at PEB temperatures of 98° and 105°C for 60 s, but developer-soluble BARC performance at 112°C for 60 s for both types of isolated features. While the concept of achieving dry BARC performance from a DBARC by resist selection and lithography processing parameters was proven, the quality of lines and spaces in these examples needs improvement. State-of-the-art 193-nm dry BARCs provide resolution that is much superior to 130 nm (i.e., a much smaller CD) and no footing or roughness in the spaces. However, this material shows promise as a dry BARC candidate, especially for applications with relaxed CD requirements.



160°C BARC bake
105°C for 60 s PEB

190°C BARC bake
105°C for 60 s PEB

160°C BARC bake
98°C for 60 s PEB

160°C BARC bake
112°C for 60 s PEB

Figure 9. Lithography for resist C on DBARC BSI.W09008 (dry BARC performance). PAB: 100°C for 60 s; 145 nm of resist C; Nikon NSR-S307E; conventional illumination; NA of 0.85; sigma of 0.93; target CD 130-nm L/260-nm P (bright field); PEBs: 98°, 105°, 112°, and 120°C for 60 s; 0.0-µm focus; 0.26N TMAH for 60 s.

CONCLUSIONS

We have demonstrated that the selection of photoresist and/or processing parameters during lithography determines the performance of PAG-free anti-reflective product BSI.W09008, even including DBARC versus dry BARC. Five different 193-nm photoresists have given promising DBARC performance from this material, with dry BARC performance observed for one of the resists at two different PEB temperatures. The best through-pitch resolution achieved from DBARC BSI.W09008 and resist A was 130 nm, which included dense, semi-dense, and isolated lines. The shape and robustness of dense and isolated 130-nm lines using resist A were improved by a) incorporating a base additive in the DBARC or b) altering the DBARC binder polymer's structure. DOF for the former (a) was 0.3 µm, for both dense L/S and isolated lines. DBARC BSI.W09008 produced much lower sublimation during the BARC bake step than dry BARC ARC® 29A-8 material, and the DBARC's post-development residue on a silicon substrate is much less dependent on a) initial film thickness and b) the exposure dose than previous-generation 193-nm PS-DBARC BSI.W07327A material. DBARC BSI.W09008 also produced lower post-development residue than BSI.W07327A material on silicon nitride at exposure doses of 14-25 mJ/cm^2.

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