New BARC Materials for the 65-nm Node in 193-nm Lithography

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ABSTRACT

New fast etching bottom anti-reflective coatings have been prepared at Brewer Science, Inc. for 193nm lithography. These materials, EXP03087B and EXP03066, were targeted for first and second reflectivity minima thickness, respectively. The optical constants (n/k) of these materials were 1.70/0.50 for EXP03087B and 1.71/0.31 for EXP03066. After thermosetting, these materials were immiscible with photoresists and were not affected by base developer. Profiles utilizing these BARCs with JSR's AR1221J photoresist have shown 90-nm (1:1 line space) dense lines and 100-nm lines with FFA's GAR8105G resist.

1. INTRODUCTION

The demand for faster performing computer chips has forced integrated circuit manufacturers to create smaller feature sizes on chips to meet this demand. According to the semiconductor industry roadmap, feature sizes of 65 nm are slated to be in production within the next two years.[1] Although deep ultraviolet (DUV) lithography is currently the process most commonly used by manufacturers, the use of 193-nm lithography will continue to increase to meet the demand for smaller feature sizes. Use of shorter wavelengths of light requires the use of a mechanism to control reflections of light from the substrate surface. Bottom anti-reflective coatings (BARCs) will play an important role to control reflections and improve swing ratios, CD variations, reflective notching, and standing waves.[2,3,4]

This paper reports the development of new BARCs for 193-nm photolithography. Both first and second minima BARCs are discussed, and their properties described. The properties studied were resistance to photoresist solvents, optical properties, spin-bowl compatibility, and photolithography performance.

2. EXPERIMENTAL

2.1 Materials

The BARC materials used in this study were EXP03087B and EXP03066. They were prepared at Brewer Science, Inc. by reacting trisepoxypropyl isocyanurate with the appropriate aromatic carboxylic acid (Figure 1).

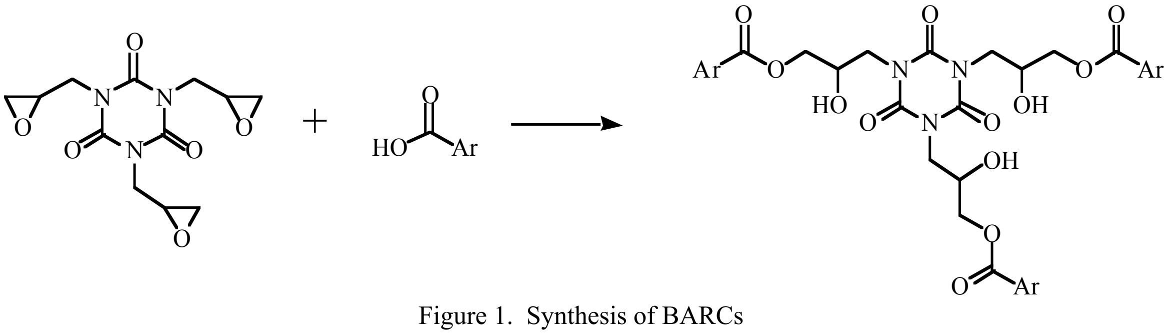

Figure 1. Synthesis of BARCs

2.2 Ethyl Lactate Film Strip Test

A BARC was spin applied to a silicon wafer at 1,500 rpm for 60 s and baked at 205°C for 60 s. After measuring the film thickness, the BARC-coated wafer was placed on a spinner, flooded with ethyl lactate, and allowed to puddle for 20 s. The wafer was then spin dried at 2,000 rpm for 30 s and bake at 100°C for 30 s. The film thickness was then measured again. The amount of stripping was the difference in the film thickness before and after flooding with ethyl lactate.

2.3 Interlayer Test

A BARC was spin applied to a silicon wafer at 1,500 rpm for 60 s and baked at 205°C for 60 s. The thickness of the film was measured. A photoresist was then cast on the BARC, and a post-application bake (PAB) of 130°C for 90 s followed. The photoresist was subjected to a blanket exposure followed by a post-exposure bake (PEB) of 130°C for 90 s. The photoresist was developed, and the thickness of the remaining film was measured.

2.4 Optical Properties

Optical constants, n and k, were measured with a Woollam variable angle spectroscopic ellipsometer (VASE). The optical constants generated from the VASE were used to create a simulated reflectivity curve with Prolith version 7.2 software (Klay-Tencor Corp.). The reflectivity curve was used to determine the minimum reflectivity on silicon substrates.

2.5 Spin-Bowl Compatibility

A BARC was spin applied to a silicon wafer at 1,500 rpm for 60 s, and the thickness of the film was measured. The sample was air dried at room temperature, in contrast to the normal procedure of baking the material at an elevated temperature to dry and crosslink the film. After 24 h, the film was flooded with solvents commonly used in the photolithography process (such as ethyl lactate, acetone, heptanone, propylene glycol methyl ether, and propylene glycol methyl ether acetate). After 20 s, the sample was spin dried at 1,500 rpm for 60 s and its thickness measured.

2.6 Etch Rates

Etch rates with CF_4 were determined with a Trion etcher using the following conditions: gas flow: 40 sccm, power: 50 watts, pressure: 50 mtorr, temperature: 20°C. Three wafers were coated with BARC, spun at 1,500 rpm, and baked at 205°C. The film thickness was measured. The BARC-coated wafers were then etched for 10, 20, or 30 s. The film thickness of each BARC was measured again. The loss in film thickness was plotted versus time and analyzed using a linear fit to give the etch rate of the BARC. Etch rates with HBR/O_2 were determined at IMEC.

2.7 Profiles

Each sample was evaluated for lithographic performance at IMEC with a high NA stepper (0.75NA : σ 0.89/0.59) with a binary mask. Each sample was hand dispensed and spin coated to the appropriate thickness (from the reflectivity curve for silicon) and hotplate baked at 205°C under vacuum for 60 s. The BARC was coated with the appropriate photoresist. The photoresist was then process under the recommended conditions and was then treated with TMAH developer for 60 s. Wafers were then cleaved, and cross-sectional SEM micrographs taken.

3. RESULTS AND DISCUSSION

3.1 Strip and Interlayer Tests

BARCs must be resistant to dissolution in photoresist solvents to prevent intermixing of the BARC and the photoresist, which could lead to undesirable interactions and/or photoresist poisoning. To determine the BARC's resistance to these solvents, a strip test and an interlayer test were performed. For each of the BARCs, a strip test with ethyl lactate showed a slight swelling of 2 angs. for EXP03087B and no change in film thickness for EXP03066 (Table 1). These results indicated good resistance of the BARC to resist solvents. The interlayer tests showed a gain in film thickness of 15 and 13 nm for EXP03087B and EXP03066, respectively. A gain in film thickness of 15 angs. was considered small. A gain in film thickness of 100 angs. or more would indicate a significant interaction between the BARC and the photoresist. Therefore, these results do not indicate significant interactions.

Table I. Results from Strip and Interlayer Tests

Sample	Initial Film Thickness (angs.)	Loss in Film Thickness During Strip Test (angs.)	Gain in Film Thickness During Interlayer Test (angs.)
EXP03087B	367	-2	15
EXP03066	775	0	13

3.2 Optical Properties

The real refractive indices were 1.70 and 1.71 and the imaginary refractive indices were 0.50 and 0.31 for EXP03087B and EXP03066, respectively. These values were used for simulations using Prolith version 7.2 software (Klay-Tencor Corp.) to obtain reflectivity curves on silicon or silicon nitride substrates (Figure 2). EXP03087B showed the lowest reflectivity (0.2%) at first minima thicknesses of 32 nm. EXP03066 showed the lowest reflectivity (0.6%) at the second minimum thickness of 88 nm on Si and at the first minimum thickness (0.01% reflectivity at 44 nm) on SiN. Each of these materials exhibited excellent reflectivity control, and they can be used for first or second minimum applications.

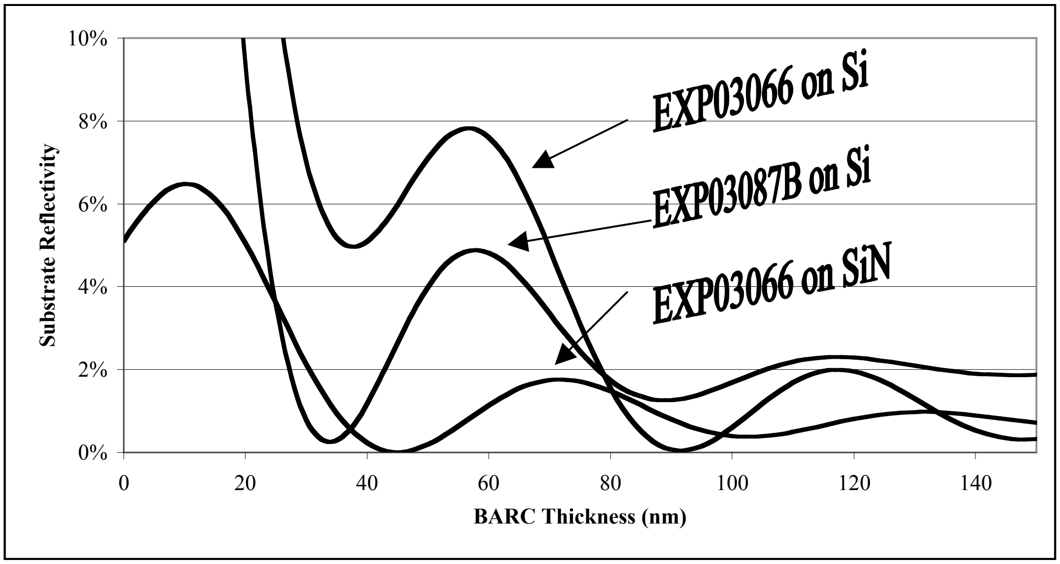

Figure 2. Reflectivity curves for EXP03087B and EXP03066 on silicon or silicon nitride substrates.

3.3 Spin-Bowl Compatibility

A spin-bowl compatibility test was performed to study the solubility of the material prior to crosslinking at elevated temperatures. EXP03087B and EXP03066 were tested for spin-bowl compatibility with various solvents: ethyl lactate, acetone, heptanone, propylene glycol methyl ether, and propylene glycol methyl ether acetate. Each sample showed 100% removal with each solvent, indicating good spin-bowl compatibility. These results show that the materials can be used on the same spinner and in the same spin bowl as the photoresist, which decreases the required equipment costs.

3.4 Etch Rates

Etch rate for EXP03087B and EXP03066 were measured in CF_4 or HBr/O_2 and compared to ARC-29A. The etch rate EXP03087B with CF_4 was 42 angs./s. This rate is slightly faster than ARC-29A (40 angs./s). However, the first minimum thickness of EXP0087B (34 nm) gives a significant etch bias compared to ARC29-A (82 nm). EXP03066 exhibited etch rates of 63 and 68 angs./s for CF_4 and HBr/O_2, respectively. Compared to ARC-29 (40 and 52 angs./s for CF_4 and HBr/O_2, respectively), EXP03066 showed a significantly faster etch rate.

3.5 Profiles

Photolithography with EXP03087B and EXP03066 was performed at IMEC on a silicon substrate. The photoresists used in this study were JSR’s AR1221J and FFA's GAR8105G1 and GAR8107. Profiles with JSR'1221J resist were targeted at 90 nm and profiles with FFA's GAR8105G1 and GAR8107 resist were targeted at 100 nm and 80 nm, respectively. EXP03087B exhibited square profiles with good clearing between the lines and little line edge roughness with AR1221J and GAR8105G1 (Figures 3). These results are excellent and show good compatibility of the BARC with the resists. Profiles utilizing EXP03066 gave square profiles with good clearing with GAR8105 (Figure 4). However the profiles with AR1221J exhibited a light footing, indicating too much interaction between the BARC and the resist. Each of these materials showed a DOF of 0.5 to 0.6 for each resist. These results are good since they are within the limit of the photolithography with a binary mask.

4. CONCLUSION

New BARCs have been prepared for first and second minimum reflectivity application. All of the BARCs were spin-bowl compatible and exhibited reflectivity of less than 0.2%. EXP03066, a second minimum reflectivity BARC, exhibited excellent performance with FFA’s GAR8105G1 photoresist, resulting in 100 nm dense. EXP03087B was a first minimum reflectivity BARCs. When used with AR1221J or GAR8107, EXP03087B produced 90 nm or 80 nm dense lines, respectively. Subsequent work with these materials will include evaluation with additional photoresists and formulation optimization.

5. ACKNOWLEDGMENTS

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Resist: GAR8107
80 nm 1:1 L/S
DOF 0.5 µm

AR1221J
90 nm 1:1 L/S
DOF 0.5 µm

Figure 3. Profiles Utilizing EXP03087B with AR1221J and GAR8105G1

Resist: GAR8105G1
100 nm 1:1 L/S
DOF 0.6 µm

AR1221J
90 nm 1:1 L/S
DOF 0.5 µm

Figure 4. Profiles Utilizing EXP03066 with AR1221J and GAR8105G1

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