Feasibility of utilizing hexamethyldisiloxane film as a bottom antireflective coating for 157 nm lithography

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The feasibility of utilizing a bottom antireflective coating (BARC) layer composed of hexamethyldisiloxane (HMDSO) film for 157 nm lithography is studied. The vaporized liquid HMDSO is used as a coating material in a conventional electron cyclotron resonance-plasma enhanced chemical vapor deposition process. The required optical constants of suitable HMDSO films can easily be tuned by adjusting the gas flow rate ratio of O_2 to HMDSO. The swing effect is experimentally shown to be reduced significantly on Si substrates by applying either a single layer BARC or a bilayer BARC. Additionally, the bilayer BARC is shown by simulation to be capable of providing larger thickness-controlled tolerances than a single layer BARC. © *2001 American Vacuum Society.* [DOI: 10.1116/1.1417549]

I. INTRODUCTION

F_2 excimer laser based photolithography is a candidate for 70 nm nodes. A completely new class of single layer resist systems is under development in order to resolve issues related to strong absorption.[1,2] Because a single layer resist process is the clear favorite among potential industry consumers, a bottom antireflective coating (BARC) layer is therefore desirable to overcome problems of critical dimension control caused by highly reflective substrates.

Conventional spin-coated organic BARC[3] relies on the absorption of reflected light through a relatively thick film. It tends to planarize the topography on a substrate, resulting in varying BARC thicknesses and then different reflections from the substrate. As feature sizes continue to shrink into the subquarter-micron regime and the steeper projection system shifts toward shorter wavelengths, organic BARCs cannot easily meet the more stringent substrate and resist requirements. As a result, the use of chemical vapor deposition (CVD) deposited films has been proposed for BARCs for deep ultraviolet (DUV) lithographies.[4,5] CVD-deposited films can possibly completely eliminate reflectance for various highly reflective substrates due to the tunability of both their composition and thickness. Furthermore, CVD-deposited BARCs have been found to be conformal to topographic substrates so that critical dimension (CD) control is easily maintained during pattern transfer.[6]

Hexamethyldisiloxane (HMDSO) film has been demonstrated as a BARC layer in both 248 and 193 nm wavelengths.[7,8] Vaporized liquid HMDSO is used as a coating material in a conventional electron cyclotron resonance-plasma enhanced CVD (ECR-PECVD) process. Deposition is conducted at room temperature, and problems caused by the thermal effect inherent in other deposition methods can be avoided. The resist adhesion property of PECVD-deposited HMDSO films and related footing issues at the resist/BARC interface are evaluated.[9] Utilization of the HMDSO-based PECVD process offers the following advantages: a high deposition rate, low process temperature, easy film removal, potential cost reduction, and a nonhazardous process (compared with the SiH_4-based PECVD process). In this article, HMDSO-based PECVD films are studied for use as BARC materials for 157 nm lithography. The O_2/HMDSO gas flow rate ratios are varied to obtain HMDSO films with different compositions and their optical properties are characterized. The optical characteristics of various HMDSO BARC layers are simulated to obtain an optimized BARC structure. The swing effects in resist before and after adding a BARC in the form of either a single layer or bilayer are compared. The tolerance of thickness control is analyzed.

II. EXPERIMENT

A. Materials

HMDSO films were deposited on Si substrates by an ECR-CVD apparatus. The feed gases were HMDSO, O_2, and Ar. The ECR microwave power was set to 720 W and the dc bias of the rf power supply was fixed at 800 V. The chamber pressure during deposition was 7.0×10^{-4} Torr and the substrate was not heated during the process.

Ultrathin (<100 nm thick) JSR/K30G resist was used. All film thicknesses were obtained by an ellipsometer working at 632.8 nm wavelength.

B. Characterization and measurements

1. Optical properties of thin films

A vacuum UV (VUV)-VASE™ ellipsometer was employed to characterize the optical properties of the deposited HMDSO films and the antireflective coatings. The entire system was purged with dry nitrogen.

2. Reflectance swing curve

The swing effect caused by optical interference between the fields reflected from both the air/resist and resist/substrate interfaces will lead to variation of the exposure

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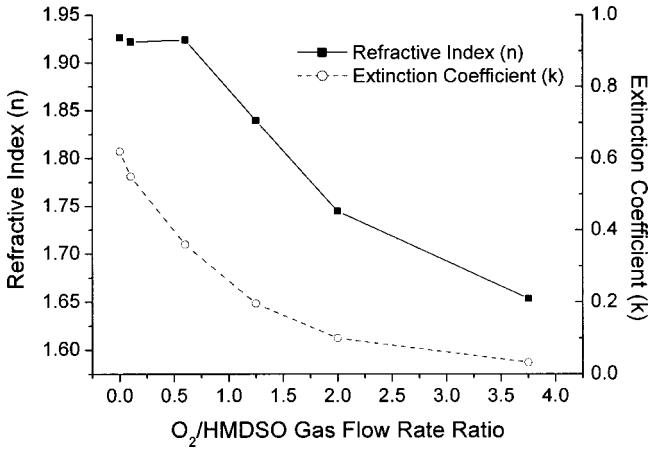


FIG. 1. Dependence of optical constants of HMDSO films on gas flow rate ratios at 157 nm.

dosage, and thus induce problems in critical dimension control in an optical lithography process. A CVD-deposited BARC can have a constant thickness over the topography of a substrate, but the resist film may have various thicknesses, leading to a familiar swing curve effect.

A simple model of resist reflectance swing ratio can be expressed as[3]

$$S \cong 4\sqrt{R_1 R_2} e^{-\alpha D}, \tag{1}$$

where R_1 is the reflectance at the resist/air interface; R_2 is the reflectance at the resist/substrate or resist/BARC interface depending on whether there is a BARC; α is the resist absorption coefficient; and D is the resist thickness. Therefore, it is important to reduce R_2 when a BARC structure is used. The reflectance swing curves of the resist coated on substrates with and without a BARC layer were simulated and measured. Reflectance measurement of films was also performed by using the VUV-VASE ellipsometer.

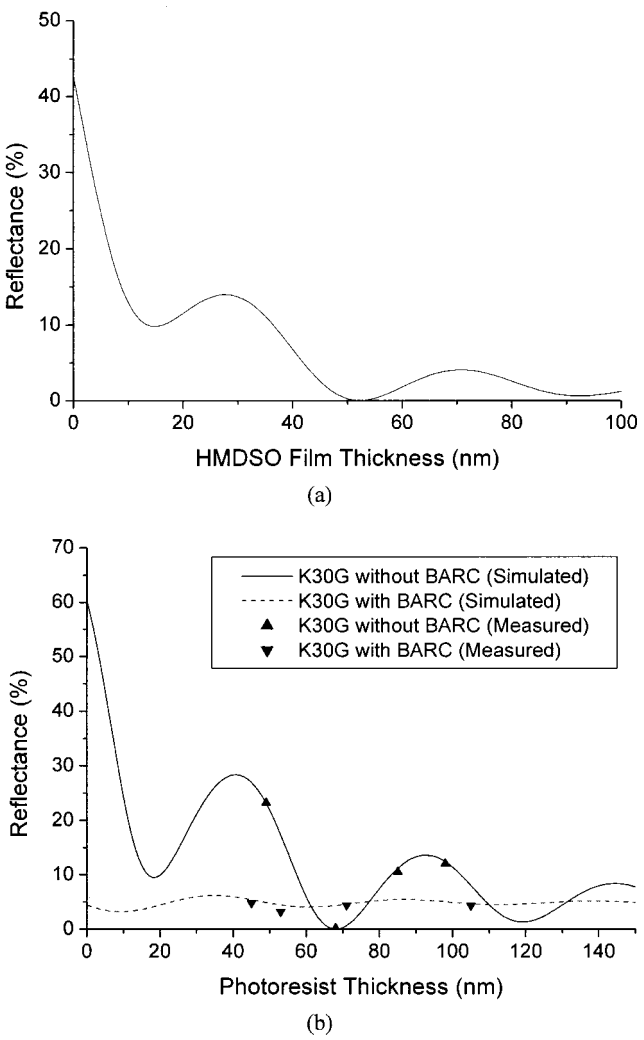


FIG. 2. (a) Simulated reflectance at the interface between K30G resist and BARC with various thicknesses on a Si substrate. (b) Simulated and measured reflectance swing curves of K30G resist coated on a Si substrate before and after the deposition of the single layer BARC.

III. RESULTS AND DISCUSSION

A. Optical properties of HMDSO films

Figure 1 shows the dependence of optical constants of HMDSO films on the O_2/HMDSO gas flow rate ratio measured at 157 nm. When the gas flow rate ratios increase, the extinction coefficients first decrease rapidly and then become saturated. Additional x-ray photoelectron spectroscopy (XPS) measurements reveal that the higher the ratio, the lower the carbon concentration, which leads to a higher O/Si ratio. This result in less absorption at higher O_2/HMDSO gas flow rate ratios. In this work, the required optical constants of suitable HMDSO films can be easily tuned by adjusting the gas flow rate ratio of O_2 to HMDSO.

B. HMDSO film as single BARC structure

The reflectance swing curves of resist coated on Si wafers are simulated and measured as shown in Fig. 2(b). Ultrathin (<100 nm thick) JSR/K30G resist was used and its optical constant was (1.527, 0.190) at 157 nm. The reflectance varies greatly for resist thicknesses ranging from 0 to 150 nm. To reduce the reflectance at the resist/Si substrate interface, we chose a HMDSO film with optical constant (1.924, 0.360) as the BARC layer. The optimized thickness of the BARC layer was 52.2 nm. After the BARC layer was added, the reflectance from the resist/Si substrate could be decreased to less than 1%, as shown in Fig. 2(a). In addition, the reflectance swing curve was simulated and measured as shown in Fig. 2(b), and has sinusoidal variation of from 3.2% to 6.2%. The results show that the HMDSO-based BARC layer can significantly reduce the swing effect in the resist.

The optical performance using HMDSO films as the BARC material for an Al–Si substrate was also simulated. The optical constant of aluminum was obtained from Ref. 10, and the measured optical constant of HMDSO film was assumed (1.924, 0.360). Figure 3 shows the reflectance at the interface between the resist and BARC with various HMDSO film thicknesses. The optimized thickness of the BARC layer was 52.0 nm, which is almost the same as in the

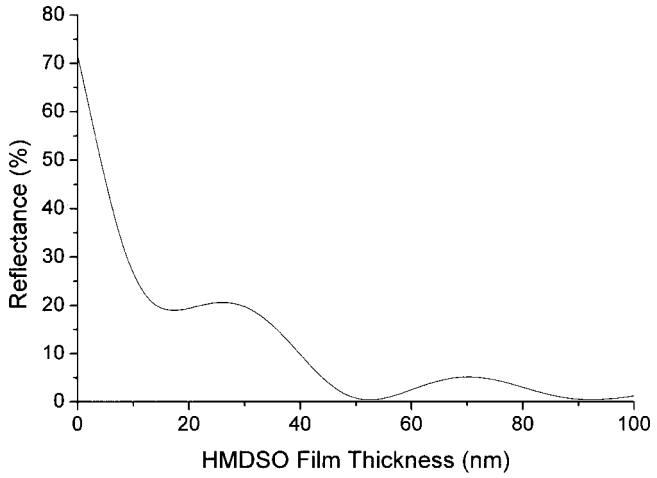


FIG. 3. Simulated reflectance at the interface between the resist and the BARC with various thicknesses on an Al–Si substrate.

case of a Si substrate. We expect that critical dimension control can be improved by the use of such a BARC layer.

C. HMDSO film as bilayer BARC structure

For a single BARC layer, however, the thickness control needed to have optimal optical characteristics is quite tight. Therefore, a bilayer BARC structure with a more absorptive lower layer and less absorptive upper layer is introduced to minimize the reflectance at each BARC layer interface. The light reflected from a highly reflective substrate can be absorbed layer by layer and the thickness-controlled tolerance can be improved. A schematic diagram of the bilayer BARC structure is shown in Fig. 4.

1. Antireflective coating layer

To find the optimal structure for the bilayer AR coating, the simulated reflectance contour at the interface between the air and AR coating layers is shown in Fig. 5(a) for various thicknesses of layer 1 and layer 2 on a silicon substrate. The HMDSO films with measured optical constants (1.654, 0.032), and (1.927, 0.619) at 157 nm were chosen as constituents of the bilayer AR coating structure. The shaded regions are where the reflectance is less than 1%. Figure 5(b) shows the measured reflectance spectrum from a silicon substrate coated with the bilayer HMDSO films when the thicknesses of layer 1 and layer 2 are 22.22 and 22.96 nm, respectively. The measured reflectance at 157 nm is 0.229%.

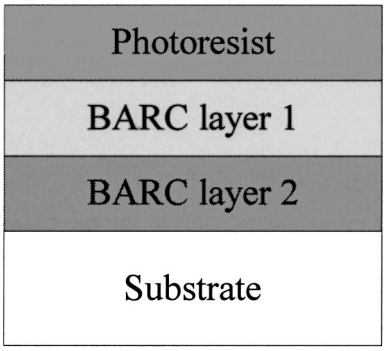


FIG. 4. Schematic diagram of a bilayer BARC structure.

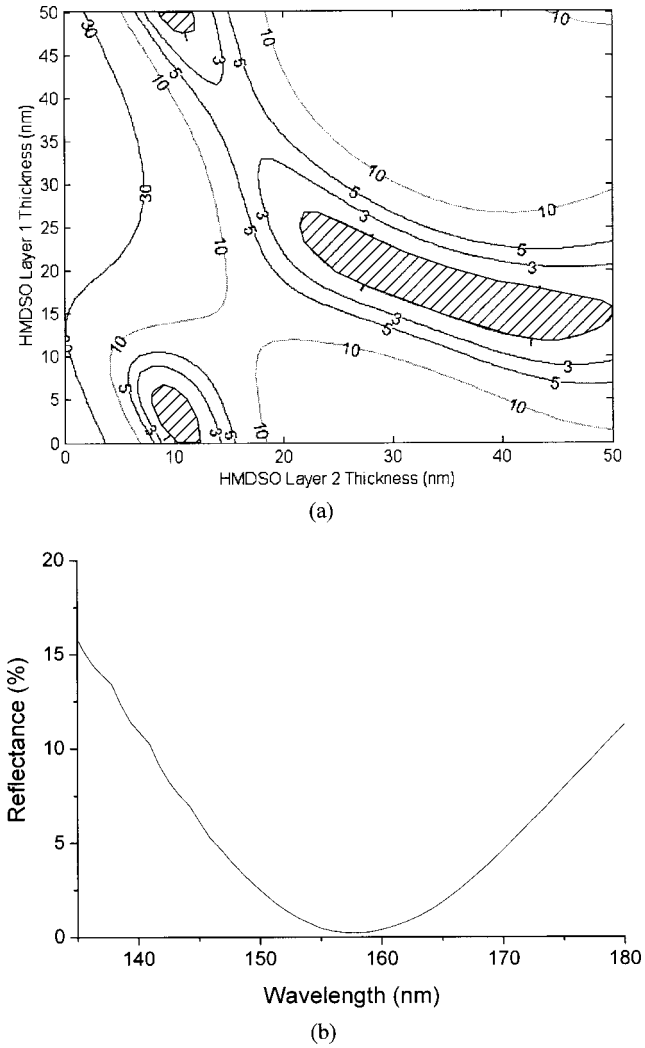
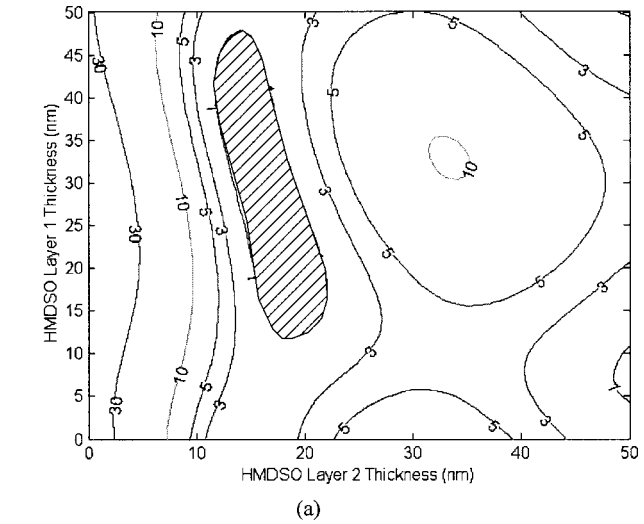


FIG. 5. (a) Simulated reflectance contour at the interface between the air and AR coating for various thicknesses of layer 1 and layer 2 on a Si substrate. (b) Measured reflectance spectrum from a Si substrate coated with the bilayer AR coating.

2. Reduction of swing effects in resist

The reflectance contour at the interface between the resist and the BARC is also simulated in Fig. 6(a) for various thicknesses of layer 1 and layer 2 on a silicon substrate. The HMDSO films with measured optical constants (1.654, 0.032) and (1.927, 0.619) at 157 nm were chosen as constituents of the bilayer BARC structure. It is found that layer 1 with thickness of around 20 nm and layer 2 with thickness of around 18 nm can serve the purpose. Note that the total thickness of a bilayer BARC can be smaller than that of a single layer BARC. Figure 6(b) shows the reflectance swing curve of K30G resist coated on a silicon substrate before and after the deposition of the single BARC layer. After adding the bilayer BARC, the variation of the simulated reflectance



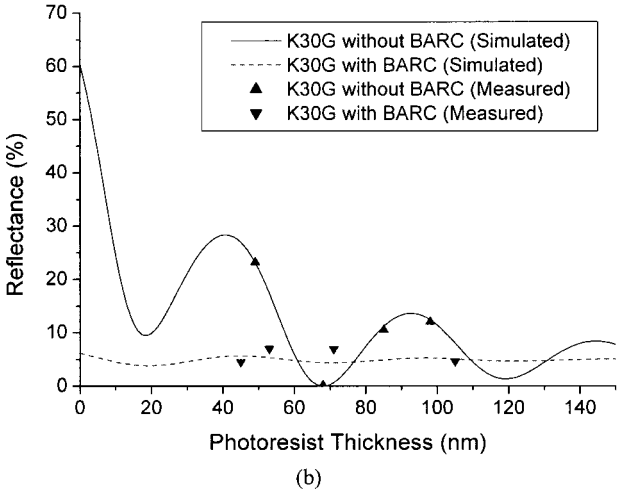


FIG. 6. (a) Simulated reflectance contour at the interface between the K30G resist and the BARC for various thicknesses of layer 1 and layer 2 on a Si substrate. (b) Simulated and measured reflectance swing curves of K30G resist coated on a Si substrate before and after the deposition of the bilayer BARC.

swing curve is reduced from 3.8% to 6.2%. Because the thicknesses of layer 1 and layer 2 are 16.85 and 15.82 nm, respectively, in our experiment, the measured results show larger variations than the simulated results.

The optical performance using HMDSO films as the BARC material for an Al–Si substrate was also simulated. The HMDSO films with measured optical constants (1.654, 0.032), and (1.927, 0.619) at 157 nm were again chosen as the BARC material. Figure 7 shows the reflectance contour at the interface between the resist and the BARC for various thicknesses of layer 1 and layer 2 on an Al–Si substrate. The region of reflectance of less than 1% overlaps that for the case of a Si substrate. Critical dimension control can also be expected to improve by use of such a bilayer BARC.

D. Thickness tolerance analysis of the BARC layer

Thickness tolerance was analyzed for both single layers and bilayers. For a HMDSO-based single layer BARC structure like that above, the reflectance between the resist and BARC layer interface can be reduced to 0.0297%. The result of a thickness tolerance analysis is shown in Table I(a). When the thickness tolerance is greater than ±20%, the reflectance can increase up to ~5%. In a similar way, Table I(b) shows a thickness tolerance analysis for a HMDSO-based bilayer structure. For a ±20% thickness tolerance of

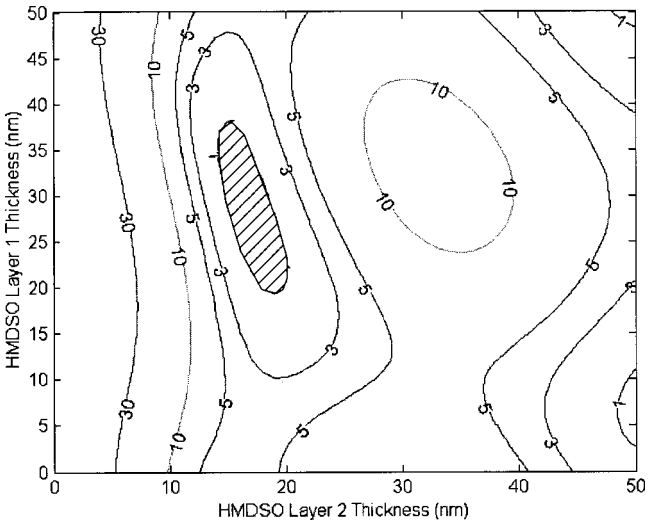


FIG. 7. Simulated reflectance contour at the interface between the K30G resist and the BARC for various thicknesses of layer 1 and layer 2 on an Al–Si substrate.

TABLE I. Thickness tolerance analysis of (a) single layer (b) bilayer BARC structures on Si substrates.

Thickness tolerance (%)	Reflectance (%)	Thickness tolerance (%)	Reflectance (%)
(a) Single layer			
0	0.0297		
−10	1.3453	+10	0.9392
−20	5.1420	+20	2.6627
−30	9.9511	+20	3.8834
(b) Bilayer			
Thickness tolerance of (layer 1, layer 2) (%)			
Reflectance (%)			
(0,0)			
0.1220			
(−10,−10)	(−10,+10)	(+10,−10)	(+10,+10)
0.7177	0.3281	0.3532	0.3679
(−20,−20)	(−20,+20)	(+20,−20)	(+20,+20)
2.0783	1.1165	0.8949	1.4301
(−30,−30)	(−30,+30)	(+30,−30)	(+30,+30)
4.0764	2.6497	1.6373	3.1479

each layer, the reflectance is shown to remain less than ~2%, indicating that the bilayer structure can significantly increase thickness-controlled tolerance.

IV. CONCLUSIONS

A HMDSO film deposited by the conventional ECR-PECVD process is found to be an appropriate BARC material for 157 nm lithography. One can control the composition and optical characteristics of HMDSO films by varying the O_2/HMDSO gas flow rate ratio. The swing effect in the single layer resist coated on a Si substrate is shown to be significantly reduced by adding either a single or a bilayer HMDSO based BARC. Thickness-controlled tolerance was also analyzed for both single layers and bilayers. The bilayer BARC simulated is shown to be capable of providing larger thickness-controlled tolerance than a single layer BARC.

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