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A Novel Bottom Antireflective Coating Working for Both KrF and ArF Excimer Laser Lithography

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Hexamethyldisiloxane (HMDSO) is used as coating material in a conventional ECR-PECVD process. By simply adjusting the gas flow rate ratio, the material can be varied to have suitable optical constants for making bottom antireflective coating (BARC) layers working at both 248 nm and 193 nm wavelengths. The measured reflectances lower than 1 % on a silicon crystal substrate at both wavelengths have been achieved. The swing effect in the resist is significantly reduced. We also show that an HMDSO-based multi-layer structure can be used for broadband AR coating in deep ultraviolet regimes.

1. INTRODUCTION

The KrF and ArF excimer laser based lithography is designated as the main technologies that would lead to 150 nm, 130 nm, and even smaller critical dimensions [1]. Since the control of critical dimensions caused by highly reflective substrates becomes stricter in deep ultraviolet regimes than in the previous longer ones. It is therefore important to find a high-performance BARC layer working in these spectral regimes.

Inorganic BARC materials have the advantage of composition and thickness tunability, thus providing the possibility of completely eliminating the reflectance from various highly reflective substrates. Materials such as amorphous carbon, silicon carbide, and silicon oxynitride have been reported for BARC applications at 248 nm, and silicon oxynitride for working at 193 nm [2-4].

Additionally, for easy processing it is always desirable to have a BARC structure that can work over broadband deep ultraviolet regimes, and the fabrication of such a structure should be simple; for example, it does not involve many different materials. We will demonstrate a new multi-layer BARC structure, which can be completed in one process step without changing to other materials.

2. EXPERIMENT RESULTS AND DISCUSSION

Organic liquid HMDSO is used as a BARC material in a conventional ECR-PECVD process to make film stacks. By simply adjusting the gas flow rate ratio of oxygen and HMDSO under a proper condition, the material composition can be varied to have suitable optical constants for making BARC materials working both at 248 nm and 193 nm wavelengths. The reflectance spectra are measured by using an optical spectrometer (Hitachi, U3501), and the optical constant of an HMDSO film is obtained by employing the R-T method [5].

The optical constants of various HMDSO films measured at 248 nm are shown in Figure 1. When the gas flow rate ratio increases, the extinction coefficient first decreases rapidly and then becomes

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floored. Conversely, the refractive index decreases slowly with the ratio. Similarly, the variations of optical constants for HMDSO films of various compositions at 193 nm are shown in Figure 2. The HMDSO films at 248 nm are found less absorptive than 193 nm. Therefore, the O_2 / HMDSO ratio should be decreased to obtain HMDSO films with suitable optical constants for BARC applications in 248 nm.

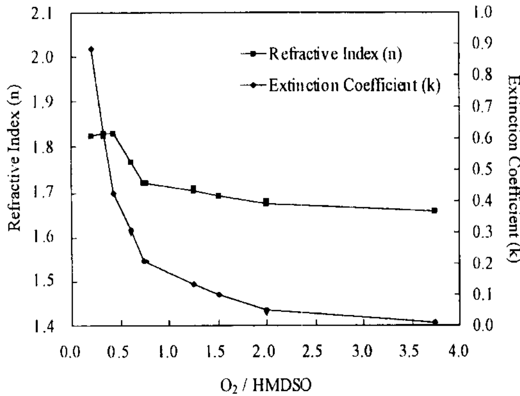

Figure 1 Dependence of optical constant on gas flow rate ratio at 248 nm.

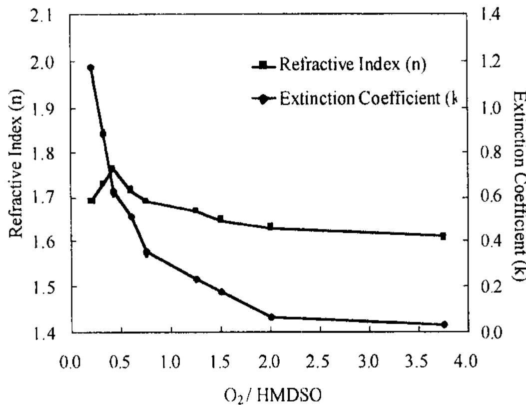

Figure 2 Dependence of optical constant on gas flow rate ratio at 193 nm.

To meet the requirement of a desirable BARC material, refractive index and extinction coefficient of such a film should be well controlled. In order to reduce the reflectance from a silicon crystal substrate, one should let the combined effective optical constant of a silicon crystal substrate and a BARC layer as close to the optical constant of the incident medium as possible. According to this rule, an HMDSO film fabricated to have a measured optical constant (1.832, 0.427) is used as BARC layer for 248 nm. After adding the BARC layer with an optimized thickness of 28.7 nm, the reflectance is decreased to less than 0.22 % at 248 nm as shown in Figure 3. Similarly, an HMDSO film with suitable optical constant and thickness can reduce the reflectance down to 0.23 % at 193 nm [6]. The measured results for both wavelengths are consistent with the simulated ones.

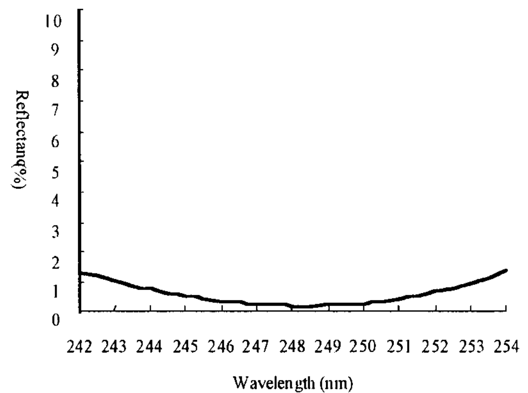

Figure 3 Reflection spectrum of a silicon substrate after adding a BARC layer for 248 nm.

The swing effect caused by optical interference between the fields reflected from both the air / resist and resist / substrate interfaces will induce the control issue of critical dimension in optical lithography. The reflectance swing curves of the JSR K2G resist coated on a silicon wafer with and without adding the BARC layer are simulated and measured for 248 nm as shown in Figure 4. The reflectance exhibits a sinusoidal variation from about 8 % to 50 % for the resist thickness ranging from 300 to 600 nm when no BARC layer is added.

In order to reduce reflectance, an HMDSO film having an optical constant (1.828, 0.614) and a thickness of about 35.4 nm is chosen as BARC layer. As also depicted in Figure 4, the reflectance variation is then reduced to about 4 % to 7 % when the BARC layer is applied to the resist. Similar results are also obtained for 193 nm [6], which indicates that the same BARC material can significantly reduce the swing effect at both 248 nm

and 193 nm.

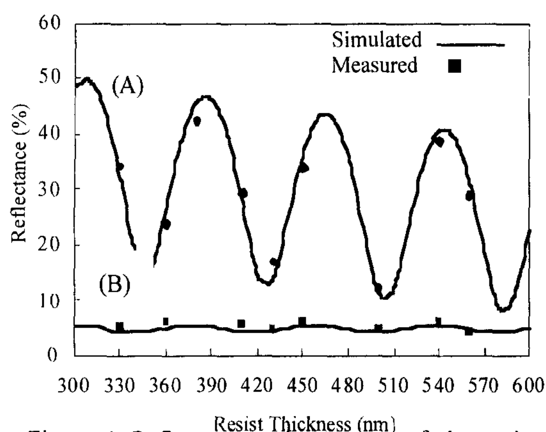

Figure 4 Reflectance swing curves of the resist coated on a silicon wafer (A) without (B) with a BARC layer at 248 nm.

For an HMDSO-based single BARC layer structure, the reflectance less than 1 % at 248 nm and 193 nm can be easily achieved. However, the reflectance increases rapidly as the exposing wavelength is deviated away from the design wavelength. In Figure 5, the experiment results show that the reflectances originally designed for BARC at 248 nm and 193 nm are larger than 15 % and 45 % for the wavelengths around 193 nm and 248 nm, respectively.

In order to fabricate a broadband antireflective coating layer stack, we optimize a multi-layer HMDSO structure by utilizing simulated annealing [7]. The HMDSO films with optical constants (1.612, 0.035), (1.716, 0.517) and (1.691, 1.18) are chosen as three-layer structure, and the optimized thickness of the three layers are found to be 11.3 nm, 11.4 nm, and 16.3 nm, respectively. As shown in Figure 6, the simulation result shows that the reflectance is less than 1 % at both 248 nm and 193 nm. The measured result shows that the reflectance of less than 2 % at both 248 nm and 193 nm can be obtained, confirming the broadband AR function.

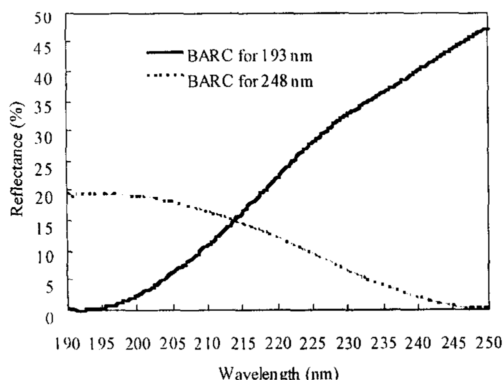

Figure 5 Reflection spectra of a silicon substrate added with a single BARC layer for 248 nm and 193 nm.

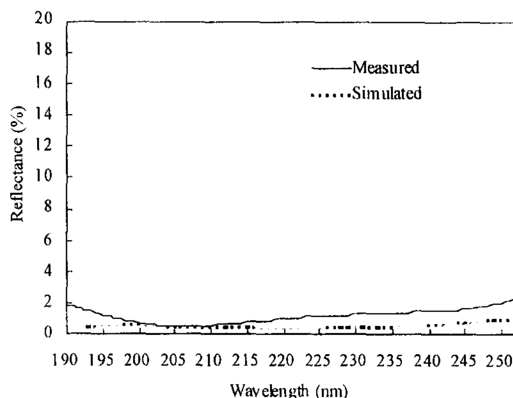

Figure 6 Simulated and measured spectra of a silicon substrate added with a multilayer BARC structure

4. CONCLUSION

The HMDSO film deposited by the conventional ECR-PECVD process is found appropriate as a new BARC material for both KrF and ArF excimer laser lithography. The composition and optical characteristics of HMDSO films can be controlled by varying the oxygen / HMDSO gas flow rate ratios. The swing effect in the single layer resist coated on a silicon substrate is shown significantly reduced by adding the HMDSO based BARC layer. We also show that the HMDSO-based multi-layer structure has a great potential for broadband AR coating in deep ultraviolet regimes.

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