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Ru capping film on Mo/Si multilayers for EUV lithography

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Introduction

Extreme ultraviolet lithography (EUVL) is the most promising technology for large-scale integrated (LSI) devices fabrication of 32 nm node and beyond. It utilizes soft X-ray of about 13.5 nm wavelength. As most of materials have similar refractive index of about 1.0, an optical system for EUVL consists of reflective mirrors and a reflective photomask coated with Mo/Si multilayers (typically 40 pairs). For the top coating of multilayers, which is called capping, Ru film is popularly used.

In this report, we aimed to investigate optical characteristics of Ru film in the wavelength range used for EUVL, because oxidation of Ru capping seems to cause some reduction in EUV reflectance. First, we evaluated optical constants n (refractive index) and k (extinction coefficient) of Ru and RuO_x films by means of R-θ method [1]. Secondly, we measured spectral reflectance nearby 13.5 nm of Ru-capped Mo/Si multilayers with and without UV/O_3 treatment, which is a promising method to remove organic contamination.

Experimental

Ru and RuO_x films were deposited on Si wafers using a magnetron sputter system with sputtering gases of Ar or O_2 mixed Ar, respectively. For these samples, reflectance was measured at 13.5 nm by varying incident angle using an optical elements evaluation system at BL-12A. For the R-θ data, curve fitting analysis was performed for evaluation of optical constants on the basis of reflection theory for layered media and the least-squares method.

Mo(2.8 nm)/Si(4.2 nm) multilayers of 40 pairs were fabricated on quartz substrates using an ion-beam type sputter system. On the multilayers 2.5 nm thick Ru capping film was deposited using a magnetron sputter system. UV/O_3 treatment was carried out using excimer lamp of 172 nm wavelength for 20 minutes. Reflectance was measured for the samples before and after UV/O_3 treatment at an incident angle of 6° in the wavelength range from 12.01 nm to 14.55 nm.

Results

Table 1 shows the optical constants obtained for RuO_x and Ru films. In case of Ru film, fitting residue was improved with an additional fitting parameter of thickness of a RuO_x surface layer whose optical constants were fixed to the results of the RuO_x monolayer sample. Using the data in Table 1, reflectance of a Ru-capped multilayer can be calculated as shown in Fig. 1, comparing with and without surface RuO_x layer. Concerning UV/O_3 treatment, Fig. 2 shows that two reflectance curves are almost overlapped. More precisely, peak wavelength shifted to the shorter side (from 13.52 nm to 13.49 nm), and peak reflectance slightly increased (from 55.0% to 55.2%) after the treatment, which may be attributed to cleaning effect by UV/O_3. Additionally, through XPS analysis, we measured area ratio of O 1s to Ru 3$d_{5/2}$ at detection angles of 25° and 45°. For both angles the change of area ratio before and after the UV/O_3 treatment was within a measurement error. These results indicate that no remarkable oxidation occurred under the UV/O_3 treatment condition in this study.

Table 1: Optical constants of RuO_x and Ru films.

		RuOx	Ru	Ru
	Model	Monolayer	Monolayer	Bilayer
Film sample	thick(nm)	42.9	38.6	37.9
	n	0.921	0.887	0.881
	k	0.0247	0.0231	0.0227
Surface oxide thickness (nm)		–	–	1.61
Residue*) = Σ(Rmeas. - Rcal.)^2		0.0245	0.0704	0.0118

*) Rmeas.: Measured reflectance(%), Rcal.: Calculated reflectance(%)

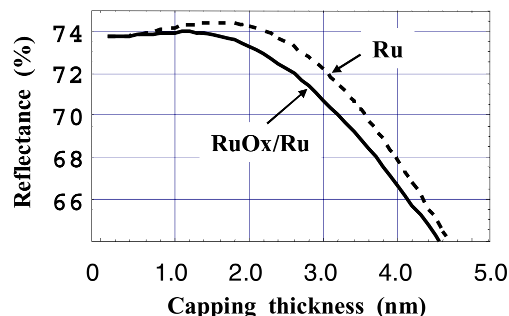

Fig.1: Calculated reflectances of a Ru-capped Mo/Si mutilayer with and without surface RuO_x (1.61 nm thick).

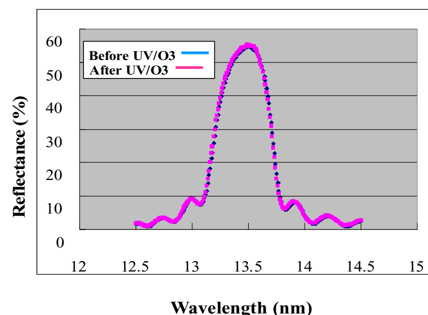

Fig.2: Reflectances before and after UV/O_3 treatment.

[1] M. Yanagihara et al., Appl. Opt. **30**, 2807 (1991)

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