12A/2005G120

Optical properties of Ti film for EUV attenuated phase shift mask

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Introduction

Extreme ultraviolet lithography (EUVL) is the most promising candidates 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 there is no refractive lens in EUV region, an optical system for EUVL is composed of reflective mirrors and a reflective photomask. EUVL mask consists of Mo/Si multilayers (typically 40 pairs) as high reflective region and absorber pattern as low reflective region formed on multilayers. On the other hand, attenuated phase shift mask (att. PSM) is one of the resolution enhancement techniques in photolithography. Att. PSM in EUVL requires absorber pattern producing appropriate reflectance (about 5~10%) as well as phase shift angle of 180 deg against the high reflective region.

In this report, we evaluate optical properties of Ti-based films in the wavelength (13.5 nm) used for EUVL, because Ti-based films seem to have appropriate optical properties to meet EUVL att. PSM requirements.

Experimental

Ti-based films (Ti, TiO*x*) were deposited on Si wafers using a magnetron sputter system with sputtering gases of Ar, or O_2 mixed Ar, respectively. For these samples, we evaluated optical constants n (refractive index) and k (extinction coefficient) by means of R-θ method [1].

Reflectance was measured at 13.5 nm wavelength 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. Moreover, att. PSM performance (phase angle and reflectance) is also calculated on the basis of reflection theory.

Results

Table 1 summarizes the obtained optical constants and fitting residue for TiO*x* and Ti films. In case of Ti film, fitting residue was improved with an additional fitting parameter of thickness of a TiO*x* surface layer whose optical constants were fixed to the results of the TiO*x* monolayer sample. Fig. 1 shows a fitting curve for the Ti film with a TiO*x* surface layer. Using the data in Table 1, we calculated att. PSM performance of Ti film shown in Fig. 2. In this calculation, we assumed att. PSM structure as follows; Ti film /Ru capping film (2.5 nm thick.) /Mo-Si mutilayers (40 pairs). As shown in Fig. 2, Ti film has higher reflectance as att. PSM. Moreover, reflectance at thickness of 180 deg phase shift angle is enhanced about 3% by considering surface oxide layer. It is not negligible to design EUVL performance.

Table 1: Optical constants of Ti-based films.

		TiO*x*	Ti	Ti
	Model	Monolayer	Monolayer	Bilayer
Film sample	thick(nm)	12.5	16.2	12.7
	n	0.952	0.955	0.954
	k	0.0247	0.0192	0.0167
Surface oxide thickness (nm)		—	—	4.68
Residue*) $=\Sigma(\text{Rmeas.}-\text{Rcal.})^2$		0.0387	0.0518	0.00547

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

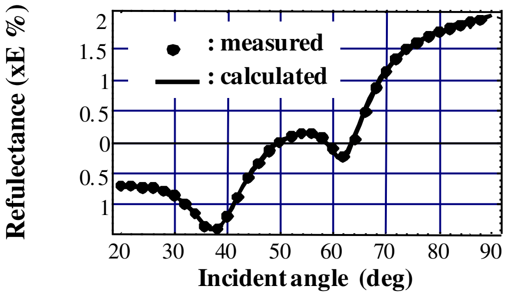

Fig. 1: Fitting curve for Ti film with surface oxide layer.

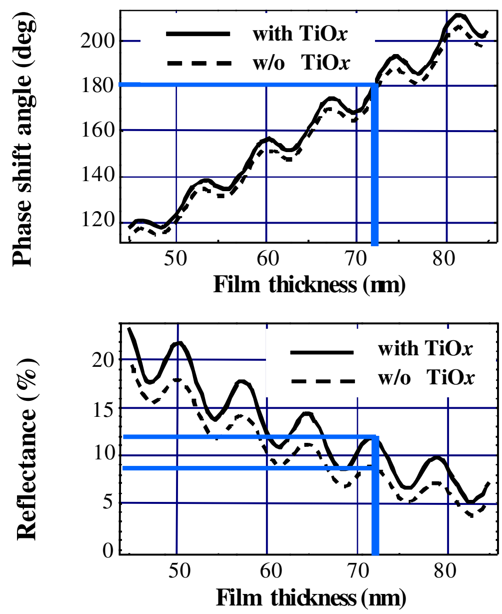

Fig. 2: Phase shift angle and reflectance of Ti film.

Reference

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

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