3D mask topographic effects in EUV lithography

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Extreme ultraviolet (EUV) lithography is expected to be the main candidate in the semiconductor manufacturing starting at 32 nm [1]. Due to the reflective mask and the reflective optics in EUV, the illuminating incident light should be oblique incidence. On the other hand, as the CD is getting smaller, the aspect ratio of the patterns on the EUV mask is becoming larger. The shadowing effect will become much more significant when keeping the same 4× mask magnification as proposed in ITRS 2006 edition [1]. The mask patterns with 3D topography should have a strong influence on the lithographic imaging results especially for the ever-demanding smaller CD. Therefore, 3D mask topographic effects for the sub-32 nm node were explored in this work. The rigorous coupled-wave analysis (RCWA) [2,3] was applied to analyze the optical diffraction from the 3D topographic periodic features.

Fig.1 shows the definition of the sidewall angle in an EUV mask. The mask substrate was assumed to consist of 40-layer pairs of Mo and Si with layer thickness of 2.8 and 4.15 nm, respectively. A Ru capping layer of 2.5 nm and a TaBN absorber of 70 nm were used in the simulation [4]. Assuming the use of a damage-free mask repair technology [5], no buffer layer is considered to minimize the shadowing effects. The optical constants of all materials were obtained from the database [6]. The illumination angle was set to be 6° in all the following simulations if not especially mentioned. Fig. 2 shows the diffraction efficiencies of 1:1 line/space patterns with various sidewall angles for the CD from 10 nm to 100 nm. The diffraction efficiency of the 0^{th} reflected light is decreasing with the smaller features. The patterns with a vertical side wall ($\alpha = 90°$) have the strongest diffraction efficiencies except for the 2^{nd} order reflected light. The TM-polarized light shows weaker diffraction efficiencies. To visualize the intensity distributions reflected from the 3D topographic features, the near field distributions of the masks were calculated as shown in Fig. 3(a). The features are the line/space patterns with 1:1 line to space ratio for a CD of 22 nm. The cases of the illumination with a normal incidence were also simulated for comparison. Fig. 3(b) shows the corresponding aerial images formed by the diffracted light from the mask. The NA of the EUV system was assumed to be 0.3 and the illumination is in the dipole configuration with σ_{center}=0.7 and σ_{radius}=0. The diffracted beams from the mask illuminated by each point source were rigorously calculated with RCWA. For a smaller sidewall angle, the near field image contrast is poorer because of a weaker 0^{th} and 1^{st} diffracted light. Although its 2^{nd} diffracted light is stronger, the 2^{nd} diffracted light is filtered out by the imaging system and cannot contribute to the image formation. The topographic effects for the contact/hole patterns can be even serious. Further results on the contact/hole topography and the sidewall angle effects to the aerial image formation will be reported.

1. ITRS 2006 edition, http://www.itrs.net/Links/2006Update/2006UpdateFinal.htm
2. L. Li, J. Opt. Soc. Am. A **14**, 2758-2767 (1997).
3. C. H. Lin, et al., Microelectronic Eng. **83**, 1798–1804 (2006).
4. J.M. Roberts, et al., Proc. SPIE **5751,** 64–77 (2005).
5. T. Liang, et al., J. Vac. Sci. Technol. B **23**, 3101–3105 (2005).
6. http://henke.lbl.gov/optical_constants/

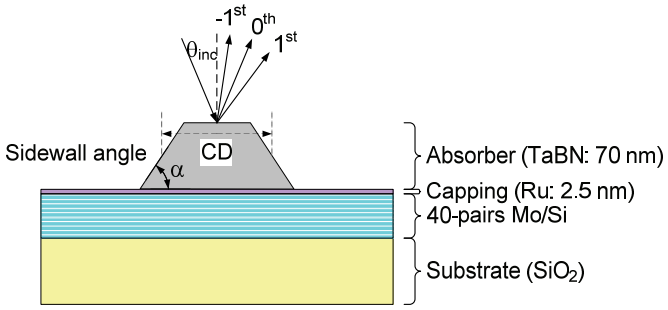
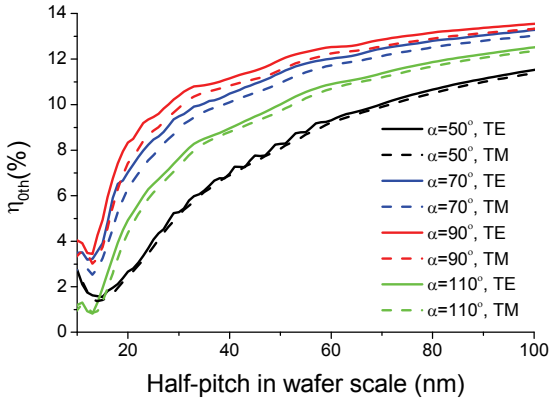
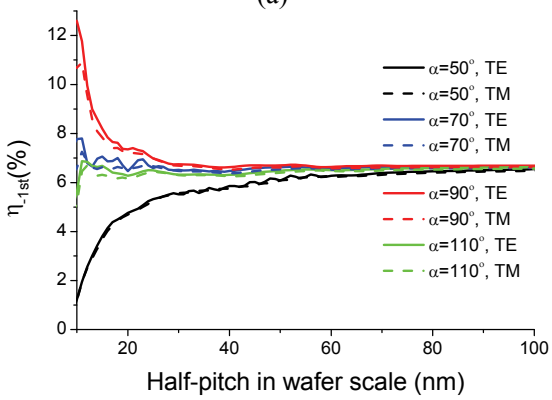


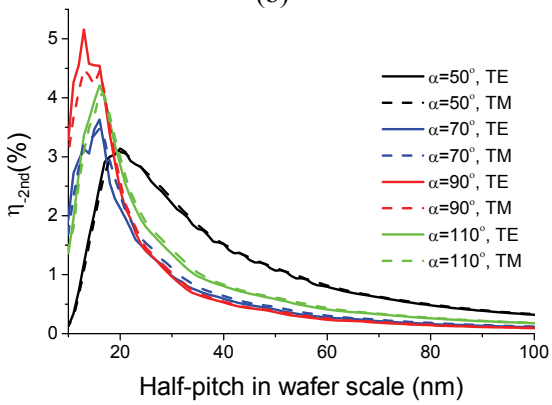
Fig. 1 Definition of the sidewall angle in EUV mask.



(a)

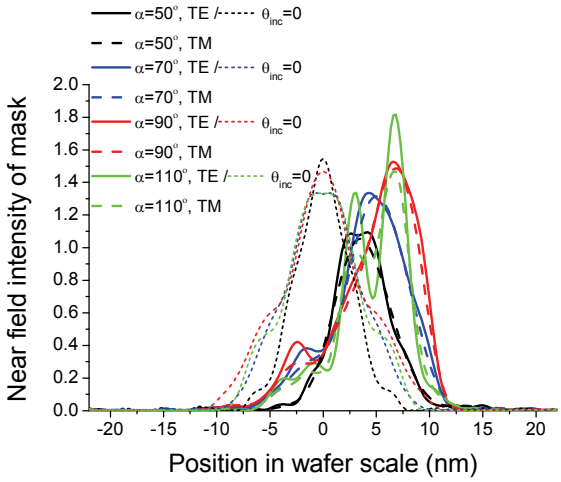


(b)

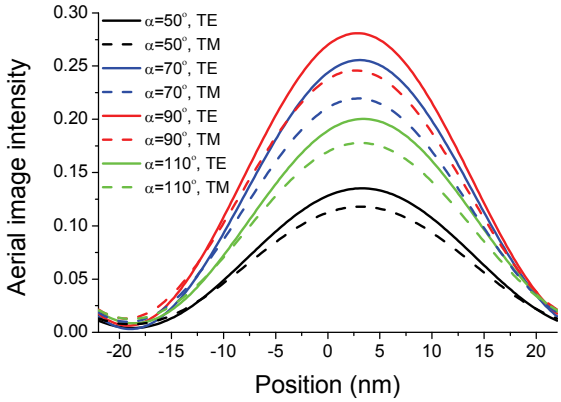


(c)

Fig. 2 Diffraction efficiencies of (a) 0^{th} order, (b) -1^{st} order and (c) -2^{nd} order from the line/space features with 1:1 line to space ratio for the CD from 10 nm to 100 nm.



(a)



(b)

Fig. 3 (a) Reflected near field intensity and (b) aerial image of an EUV mask with a 22-nm CD. The features are the line/space patterns with 1:1 line to space ratio.