Observation and modeling of asymmetric carbon contamination growth on SFET-exposed mask

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EUV mask contamination has a strong, negative impact on both throughput and printing performance in extreme ultraviolet lithography (EUVL). Our previous study using optical simulation analysis revealed that the impact depends on the optical characteristics of the contaminant layer and on the type of coverage (conformal or not)1). So we have to determine the nature of the carbon film and its coverage on an actual exposed mask to accurately evaluate the impact of contamination on lithographic performance.

We analyzed a mirror that was exposed for long time in the Small-Field Exposure Tool (SFET) to determine the nature of the carbon film. We used many surface analysis techniques, such as ellipsometry, microbeam X-ray diffraction, transmission electron microscopy (TEM), X-ray photoelectron spectroscopy (XPS), Rutherford backscattering spectroscopy (RBS), elastic recoil detection analysis (ERDA), and so on. The results showed that the contaminant film was amorphous-like carbon containing a large amount of hydrogen.

We also examined the carbon film coverage of an SFET-exposed mask by using CD-SEM and 3D-AFM (Veeco InSight 3DAFM). CD-SEM images of clean and contaminated masks (Fig. 1) revealed not only that contamination growth increased the line width, but also that the image of the contaminated mask had asymmetric features, i.e., the white band was wider on the sunshine side (arrows in figure) than on the sunshade side. Just as for the CD-SEM results, 3D-AFM profiles (Fig. 2) revealed an increase in pattern width, and also asymmetric profiles on the contaminated mask, i.e., the rounding of the top corner is more pronounced on the sunshine side than on the sunshade side. These observations suggest that carbon grows asymmetrically on the side walls due to the directionality of the off-axis EUV illumination. However, the film coverage cannot be accurately estimated from these observations because of the mathematical difficulty of calculating a 3D profile from 2D CD-SEM image data, and the lack of basic information on the relative positions of 3D-AFM profiles for clean and contaminated surfaces. So, we constructed a theoretical model of carbon growth on a patterned mask to understand how asymmetric growth originates.

The model involves three calculation steps: (1) The electric field strength in the near field of the mask pattern is calculated based on electromagnetic field theory. (2) The growth rate is calculated based on the assumption that it is proportional to the electric field strength at each surface point. (3) The change in the surface profile is calculated using a string model. When Step 3 is finished, we go back to Step 2 and calculate the growth rate on the new surface. Repeating this procedure yields the time-wise change in the contaminated surface.

The results (Fig. 3) show that coverage is almost conformal when the illumination is parallel to the mask pattern, although there tends to be a small overhang. On the other hand, clear asymmetry was obtained for perpendicular illumination: The contaminant film is markedly thinner on the sunshade side than on the sunshine side. In addition, the sunshade side has an overhang. These results are consistent with the experimental observations.

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References: 1. Y. Nishiyama et.al, Proc. SPIE 6921-41(2008).

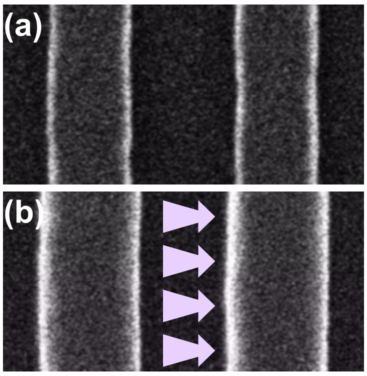

Fig. 1 CD-SEM images of (a) clean and (b) contaminated L/S patterns.

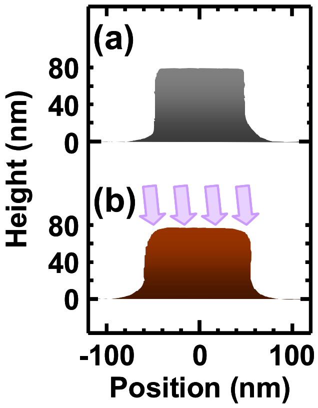

Fig. 2 3D-AFM profiles of (a) clean and (b) contaminated L/S patterns.

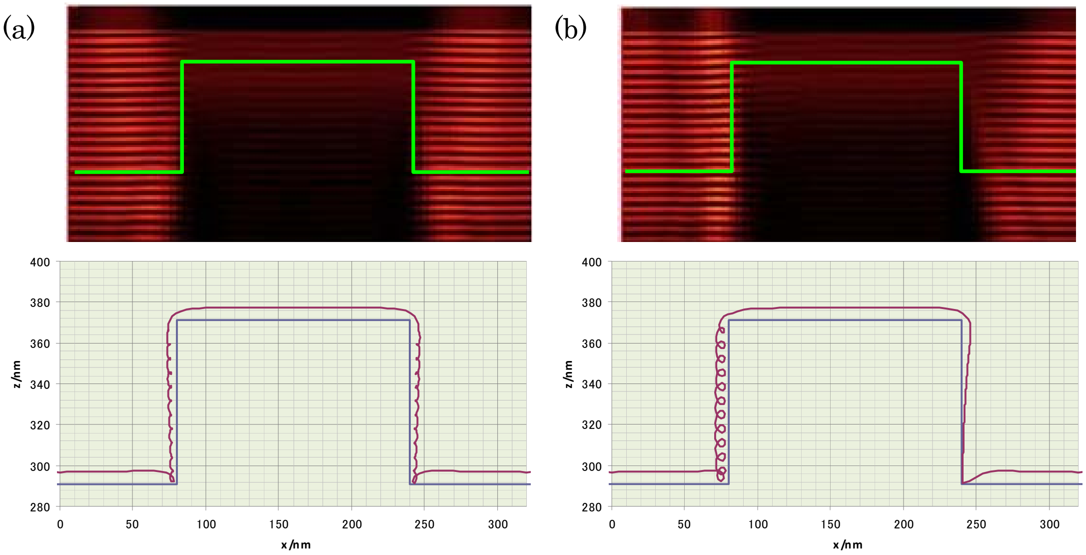

Fig. 3 Calculated electric field strength (upper figures) and contaminant coverage (lower figures) of line-and-space pattern on EUV mask for (a) parallel and (b) perpendicular illumination. The fine modulation on the side walls is caused by the standing wave effect of the multilayer.