A novel approach to fabricate extreme ultraviolet mask blanks based on BTD technique

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Abstract

Extensive optimization on the fabrication of Mo/Si multilayer system is carried out at 4Wave using bias target deposition technology. The process is being optimized including parameters such as uniformity, deposition parameters, reproducibility and layer composition. Reflectivity with values of around 69% are routinely achieved at normal incidence, demonstrating the capabilities of deposition process. Some evidence of sharpness to Mo/Si interface is given which is higher than that of others deposition techniques such as IBS, magnetron sputtering and e-beam.

Keywords: Mo/Si multilayer deposition, bias target deposition, reflectivity, uniformity, EUVL

1. Introduction

Extreme ultraviolet lithography (EUVL) is the leading next generation lithography (NGL) technology for optical lithography at the 32 nm nodes and beyond. Since it is not possible to obtain practical materials which transmit light at the wavelength of 13.5nm, EUVL has needed to employ an all reflective optical system. Sufficient light throughput is made possible by employing Mo/Si multilayer films, which have a high EUV reflectivity.

The ultimate performance of multilayer-coated EUVL technology depends critically on the multilayer coating technology and involves both the inherent wavelength-dependent physics properties of the multilayer system as well as the experimental ability to produce such a coating in a controlled process. An extensive optimization effort on the fabrication of Mo/Si multilayer systems in carried out at 4Wave using a patented technique called Bias Target deposition (BTD). This process is being optimized including parameters such as deposition parameters, the Mo/Si ratio, uniformity and the layer composition.

The development of suitable mask blanks is one of the greatest challenges facing the commercialization of extreme ultraviolet lithography (EUVL). The technical challenges coupled with tool costs present a hindrance for suppliers interested in entering the EUVL mask blank market at the current time. 4Wave has recently developed a unique technology, called bias target deposition (BTD) and related deposition system which is considered as a potential tool and technology needed for EUVL mask blank coating development. One of the key projects at 4wave is the development of next-generation mask blank coating tools and related growth process under this novel technology; this work is being performed in a partnership with a leading EUVL research organization, SemaTech. This paper is intended to highlight recent progress in the growth process of this effort.

2. Experimental details

Mo/Si multiplayer films were fabricated on 6-in. square mask quartz substrates by BTD technique on a commercially available 4Wave BTD Sputtering system which consists of the ion sources along with the Si and Mo water cooled targets, and the electrostatic chuck to hold the spinning masks during deposition. A primary end-hall ion source creates an Ar+ ion beam. The Ar ions are sequentially directed on the negatively biased Mo and Si targets to sputter material that is deposited on the mask blank substrates. Ar ions with an initial energy of around 30 eV and negative 500 V bias on targets were employed in this study. Typical deposition times are about 3 h to deposit the Mo and Si layers (40 bilayers) necessary to make a highly reflective mask. The ion source producing low energy ions can be likely play a critical role in mask blank substrate defect mitigation and substrate cleaning.

In BTD, a low energy ion source or downstream plasma flood source is directed at a negatively biased sputtering target (Figure 1). The ion source is capable of operating over a broad range of process pressures ($1x10^{-4}$ to $1x10^{-2}$ Torr) and can ionize reactive gases such as O_2 and N_2 as well as an inert sputtering gas such as Ar. The average kinetic energy (typically < 25eV) of the ions is less than the sputter threshold of the vacuum system materials. No effort is made to capture all of the ions on the target because ions that miss the target do not generate unwanted sputtering. The ion beam/plasma flood can be much broader than the target to improve target illumination uniformity, or to illuminate multiple targets. A plasma sheath develops at the surface of the negatively biased target that accelerates positive ions toward the target to produce sputtering. Because the sheath is very small (~2 mm) compared to the spacing between the ion source and target, the target bias has no substantial effect on the ion trajectories from source to target. Hence, for constant source operation, the illumination profile and the ion current reaching the target are nearly independent of the target voltage. [1, 2] A grounded shield surrounds the target to prevent undesired sputtering of the target mounting hardware that is also biased. DC or pulsed DC target bias is used depending on the target material and desired process. A large range of target voltages (~100 to 1400 V) can be used to adjust sputtering yields and further co control the growth rates. The selection of the target voltage, by virtue of its impact on sputtered atom ejection energy, has a profound impact on film density, grain size, atomic scale mixing at thin film interfaces and the overall roughness of the growing film. The source can also be used at higher ion energies, or with substrate electrical bias, to etch, clean and modify substrate surfaces prior to deposition. Recent work at 4Wave demonstrated the capability of BTD to co-sputter alloys and reactively deposit dielectric films from metal target. [3]

The high purity silicon target and Mo target were used in our experiments. The vacuum chamber was initially evacuated to a base pressure of high10^{-8} Torr by a Cryo pumping system. Thereafter, Mo/Si multiplayer films were grown on 6-in. square mask quartz substrates. In order to reduce contamination, Si and Mo targets were cleaned by pre-sputtering for 20 min prior to the film growth. The deposited multilayer films were characterized and analyzed by Transmission Electron Microscopy (TEM), Atomic Force Microscopy (AFM), and EUV reflectivity.

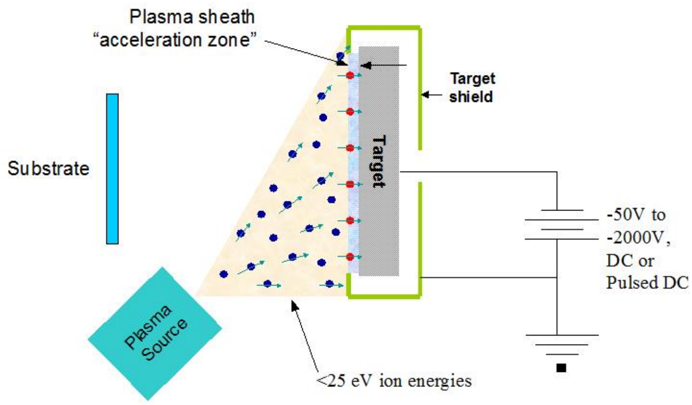
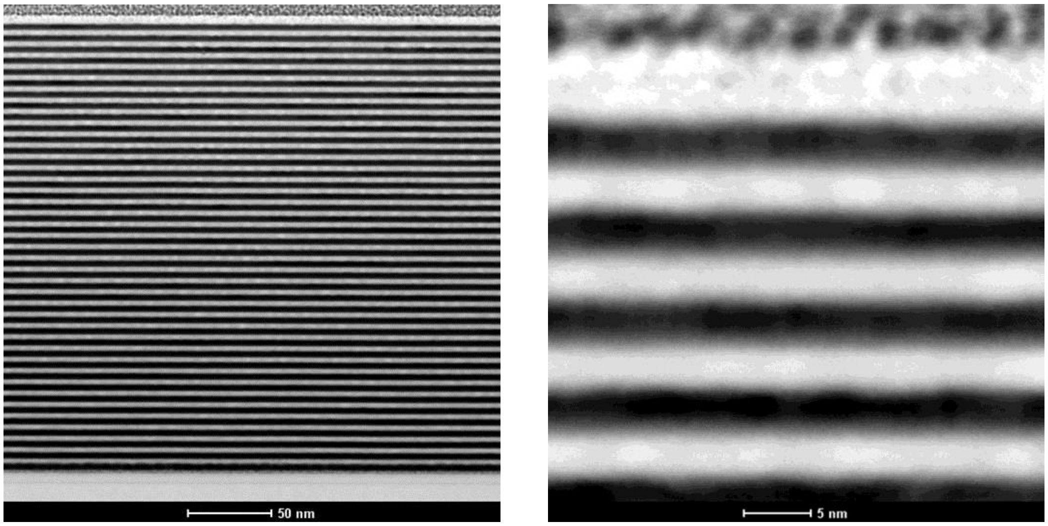


Figure 1. Concept of BTD sputtering

3. Results and Discussion

A Mo/Si ML film, consisting of 40 bi-layers of Si and Mo, and a Si capping layer was deposited on 6-in. square mask quartz substrates using BTD method. The Si capping layer with a thickness of 4 nm was formed to prevent oxidation of the underlying Mo layer. Periodic length of Mo and Si layers and thickness of Si capping layer were measured on the ML blanks using small angle X-ray diffraction. Since the surface roughness is supposed to degrade the reflectivity of the multilayer, an atomically smooth surface is essential for maximum reflectivity. The surface morphology of single layer of Si and Mo measured by AFM give highly smooth surfaces with a root-mean-square (rms) roughness of ~1A, which satisfies the mask specification.

A cross-sectional TEM image of 40 periods of the Mo/Si multilayer is shown in Fig. 2. The interfaces at Mo-on-Si and Si-on-Mo show very distinct and sharp which is greatly favorable for EUV mask blank and results in the higher EUV reflectivity. On the other hand, the ion beam sputtering (IBS) shows a broad interfacial layer, moreover the interfacial layer thickness depends on the stacking sequence and was measured be ~1.2 nm at Mo-on-Si and ~0.8 nm at Si-on-Mo [4,5]. It is speculated that heavier Mo atoms can penetrate deeper into the amorphous Si underlayer, resulting in an enhanced interface mixing [6].



(a) (b)

Fig. 2. (a) Cross-sectional TEM image for the Mo/Si multilayer. (b) A magnified TEM picture showing two different interfacial layers, the most top layer is Pt.

The centroid wavelength at which the multilayer's reflectivity is very important for EUVL. The centroid wavelength of interest is currently approximately 13.5 nm; Centroid wavelength can be easily adjusted by varying the thickness of the bilayer period. In order to maximize the throughput of multi-component EUVL optical system, it is of paramount importance to obtain the best performance of the individual multilayer coating. Thus, one of the most relevant properties of the coating process applied is the ability to achieve a high peak reflectivity. Figure 3 indicates the status of the reflectivity of our multilayer systems to date: reflectivity of 66.8%, as measured at 13.458nm deposited by BTD technique. The gain in reflectivity with respect to previously reported values of 64.8% deposited ion beam sputtering technique.

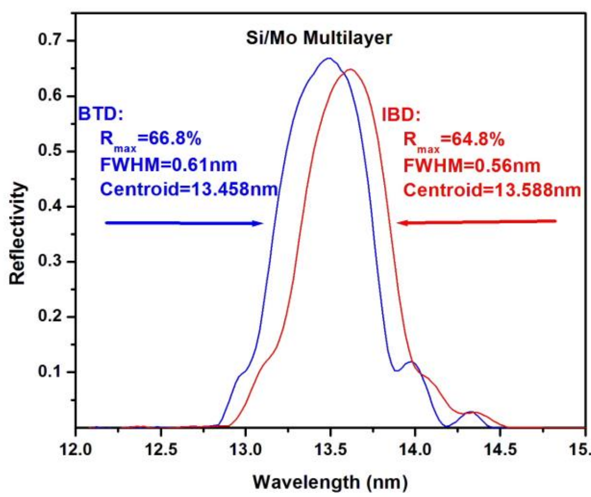


Fig.3. EUV reflectivity of a Mo/Si multilayer structure deposited by BTD and IBS, respectively.

Another more important parameter of interest is the centroid wavelength uniformity at which the multilayer's reflectivity is measured. As previously noted in different research groups [5, 8, 9], the d-spacing is a critical factor in developing multilayers; accordingly, an effective d-spacing measurement technique is required in evaluating the multilayers. The low-angle XRD peaks generated from the multilayer stack can describe many important characteristics, such as the d-spacing and the centroid wavelength uniformity of the layer. The bilayer period thickness was calculated from the diffraction peak positions by use of a corrected Bragg's Law's equation for low angle diffraction. In Fig. 4, a sample of the low-angle XRD peaks of the deposited multilayers is shown at different positions across the mask blank from center. The uniformity of the multilayer stack can be estimated from the regularity and the sharpness of the peaks.

The uniformity was measured over 100 mm across the mask blank. The results are shown in figure 5 which presents the normalized thickness to the center thickness of each sample. It was observed that a good Mo/Si uniformity has been achieved about 1.2% at a stage position of 4.5 through BTD method, and the optimum uniformity could be achieved between a stage position of 4.5 and 5.5 (approximate 4.83) where Mo/Si uniformity could be achieved about 0.9 %, comparable to that achieved through IBS under an optimized conditions. [7]

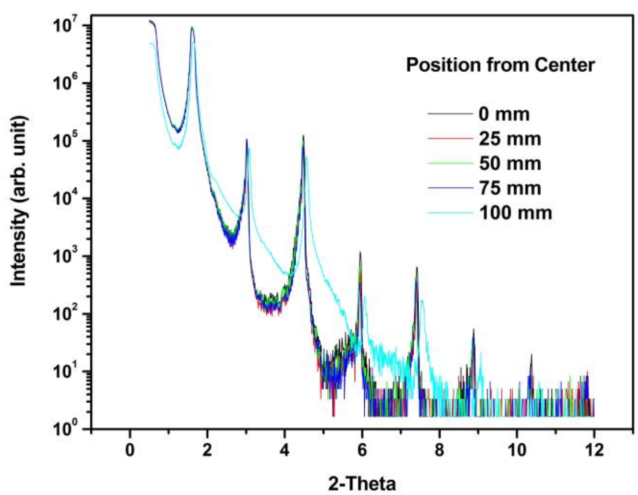


Fig.4. Low-angle XRD peaks for Mo/Si multilayer samples deposited by BTD at different positions across the mask blank from center.

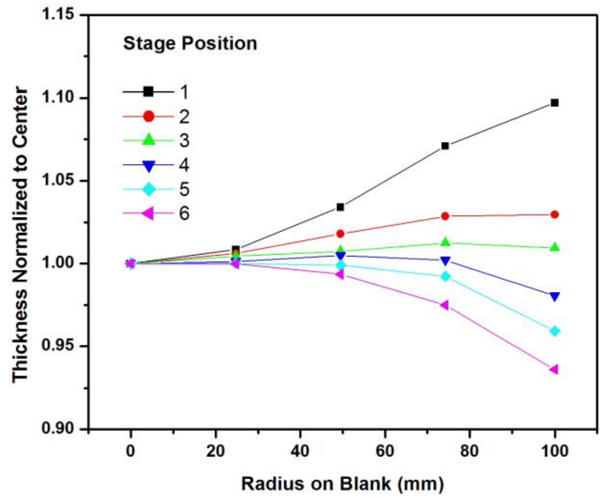


Fig.5. Normalized thickness uniformity of Mo/Si Multilayer structures deposited by BTD across the mask blank

Another important issue is the fabrication stability of the multi-layer coatings. Figure 6 shows repetitive thickness measurements of bi-layer (Mo/Si) of five samples with a silicon top layer (plus the native SiO_2 caused by exposure to air) under the same deposition conditions. Within the measurement uncertainty of ±0.2%, the five samples show no change of thickness of bi-layer, indicating that the deposition process results in stable multilayer systems, consequently this technology and tools are assessed for high repeatability of the process.

4. Conclusions

EUV reflective Mo/Si multilayers were deposited through BTD method and characterized. The coatings deposited optimized conditions showed excellent surface smoothness (RMS=~1 Å) and a well-defined multilayer structure. The maximum reflectivity of the deposited film through BTD technique was measured to be about 67% at 13.45nm which is better than that of values obtained through IBS under optimized conditions. Demonstrate of coating uniformity of 1.2% over a 100 mm area has been given which is comparable to the values obtained through IBS and is acceptable for the current EUVL development. Cross-sectional TEM analysis gave a d-spacing smaller than that obtained from the EUV reflection peak while low-angle XRD gave a comparable value. This discrepancy mainly originates from the difference in the probing direction. Moreover, cross-sectional TEM analysis gave a distinct and sharper interface than those generated by other techniques, thus enhancing the maximum reflectivity. Therefore, 4Wave has been able to deposit the critical components (mask blanks) through the novel BTD technology that are accelerating progress in EUVL development. Its component research and suggested improvements should be able to enable the next-generation deposition tool.

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