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Varification of Phase Defect Correctability of Nano-structured Multilayer for EUV Reflection

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Abstract

Ru interfacial layer was inserted into Mo-on-Si interface to enhance the extreme ultra-violet (EUV) reflective multilayer properties. The stacking status and optical properties are analyzed using cross-sectional transmission electron microscope (TEM), and reflectometer. About 1.5% of maximum reflectivity can be acquired as predicted in optical simulation, which is thought to be originated from the diffusion inhibition property. Phase defect correctability of the multilayer can be enhanced by the insertion of Ru barrier layer.

Keywords : EUVL, multilayer, Mo/Si, barrier layer, reflectivity, Phase defect, correction

1. Introduction

Recently, extreme ultra-violet lithography (EUVL) [1] have been gathering a lot of attention from the world semi-conductor industry filed as the most promising candidate for next generation lithography (NGL) technology [2-7]. The advantages of the EUVL over other NGL technologies are superior resolution, high throughput, similarities with conventional optical lithography, and extendibility of the deep ultraviolet (DUV) resist. However, further improvement in throughput (>100 wph) is required for commercialization of EUVL.

Although there are several ways to attain the high throughput of EUVL process, increasing the EUV reflectivity of the multilayer mirror might be the simplest but still efficient solution for that. Since EUVL lithography system has at least 7 normal incident reflective mirrors, a slight increase of reflectivity in each mirror can give us a substantial improvement of throughput. For example, 1% reflectivity increase in each mirror can result in about 10% throughput increase. Therefore, many works to enhance the multilayer reflectivity have been reported and some of them are related to the addition of barrier layers, such as B4C and C to suppress the interdiffusion between Mo and Si layer [8]. On the other hand, there was a try of sub-multilayering of Mo with Ru insertion to reduce the multilayer residual stress [9]. The optical property enhancement by introducing the Ru into Mo/Si multilayer have been shown using optical simulation methods a couple of times, however, the exact role of Ru in reflective multilayer has not been clearly seen yet. Besides, Ru has been gathering people's interest for various applications in EUV mask such as buffer layer and capping layer. In our experiment, we inserted Ru into Mo/Si multilayer to improve reflectivity and examined the mechanism of improvement.

The defect control of the EUV mask has been also emerged as a major concern in the development of EUVL process. A couple of years ago, EUV-LLC defined two kinds of defect types (amplitude and phase defects) and proposed probable solutions for correcting them [10].

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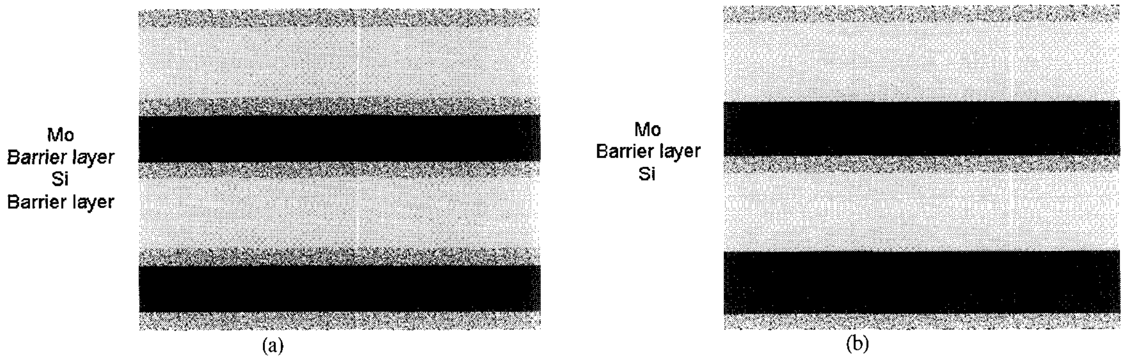
One is ion milling for amplitude defect and the other is e-beam local heating for phase defect. Although we still don't have sufficient empirical data about the correlation between actinic and non-actinic defect, it is worthy of inspecting the behavior of a multilayer during a defect correction step. Additionally, advanced EUV reflective multilayers (for example, B_4C or C or Ru containing multilayer) should be verified empirically whether they are correctable as normal Mo/Si multilayer.

2. Experiment

The deposition of the multilayer was done by multi-target sputtering system that can deposit 3 materials simultaneously. The substrate was 4-inch, (100), p-type, Si wafer. The deposited multilayer was characterized and analyzed by using cross-sectional transmission electron microscope (TEM), and EUV reflectometer. We could measure the multilayer structure factors and observe the stacking status from cross-sectional TEM images. The d-spacing of the multilayer could be extracted reflectivity graph in Mo/Si and Mo/Ru/Si multilayer. We annealed our Ru inserted multilayer to evaluate its effects on multilayer. We also conducted localized e-beam heating and made cross-sectional TEM specimen by FIB etching step.

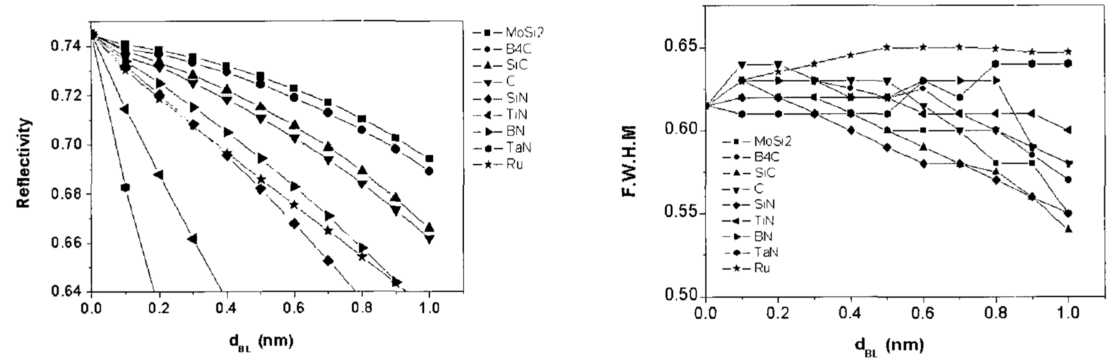
3. Result and discussion

Barrier layers can be inserted into Mo/Si multilayer in two kinds of way. Fig. 1 describes these two methods.



(a) (b)

Fig. 1. (a) The barrier layers are inserted into every interface between Mo and Si (b) the barriers are inserted into specific interfaces(in this case, every Mo-on-Si interface)



(a) (b)

Fig. 2. (a) Simulated reflectivity variation with the insertion of various barrier layer materials into every interface between Mo and Si. (b) Simulated full width half maximum (FWHM) change delivered by insertion of those multilayers.

In Fig. 1(a), the barrier layers are inserted into every interface between Mo and Si. Fig. 1(b) describes the case that the barrier layers are inserted into specific interfaces (in this case, every Mo-on-Si interface).

Figure 2(a) shows the reflectivity variation with the insertion of various barrier layer materials into every interface between Mo and Si. As a reference, the effect of $MoSi_2$ interfacial layer is also included. It appears that every barrier layer comes to degrade the maximum reflectivity when inserted into every interface. Fig. 2 (b) shows the full width half maximum (FWHM) change delivered by insertion of those multilayers. Ru barrier layer seems to extend the process window of the EUV mirror. On the contrary, it was found that the maximum reflectivity could be increased by specific way of insertion. As can be seen in Fig. 3, theoretical reflectivity increases when Ru layer is inserted only into Mo-on-Si interface and this result is in good accordance with simulation work by St. Braun et al. [8]. The increment is about 1.2% at 13.5 nm wavelength. According to the optical simulation results, unlike other barrier candidates, Ru seems to have great potential to be a good barrier material. Therefore we wanted to make sure that Ru can bring these improvements(increase in reflectivity & FWHM) when inserted in actual multilayer.

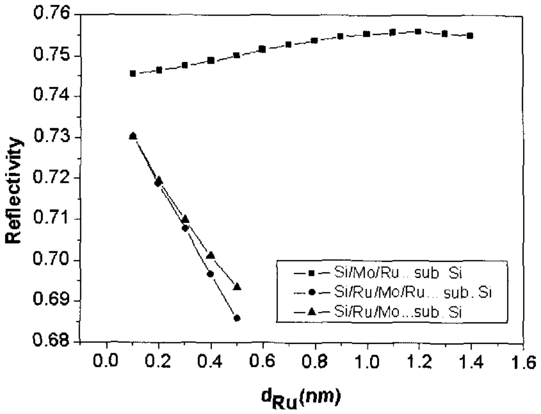


Fig. 3. Theoretical reflectivity when Ru layer is inserted only into Mo-on-Si interface.

Figure 4(a) shows the schematic diagram of this Mo/Ru/Si multilayer and (b) shows the cross-sectional TEM image of deposited Mo/Ru/Si multilayer. This sample was deposited at 1.5 mTorr and has clear and flat layer stacking through the whole layer stack. Above this pressure, the layer undulation is generated from

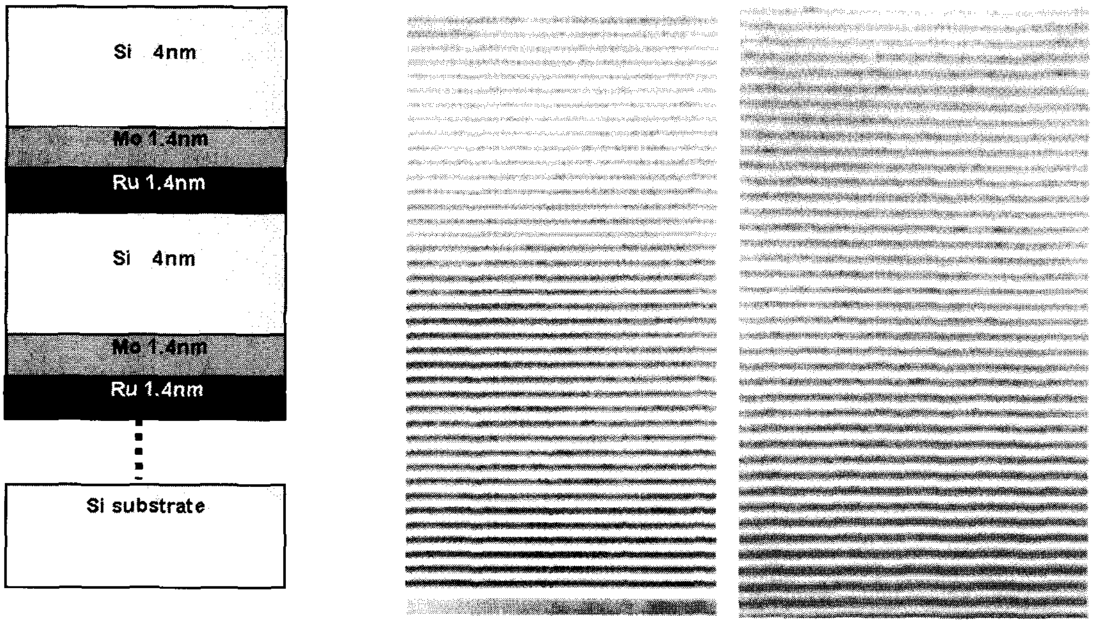
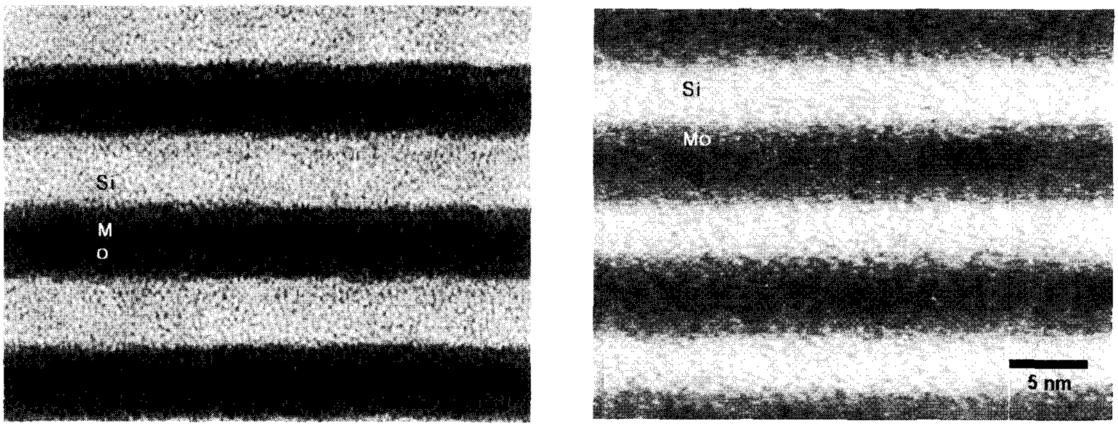


Fig. 4. (a) Schematic diagram of the Mo/Ru/Si multilayer. The cross-sectional TEM images of Mo/Ru/Si multilayer (Ru : DC 50 W, Mo : DC 50 W, Si : RF 100 W) deposited at (b) 3 mTorr and (c) 2.5 mTorr.



(a) (b)

Fig. 5. (a) Cross-sectional image of Mo/Ru/Si multilayer structure. (b) Cross-sectional image of Mo/Si multilayer structure.

the lower part of the multilayer and propagated to the top of the multilayer (Fig. 4 (c)). This phenomenon has occurred at above 3 mTorr in Mo/Si case. [9] It is speculated that, the mitigation of surface undulation did not occur at higher pressure due to low kinetic energy of the incident atom.

Figure 5 compares the high-resolution cross-sectional images of Mo/Ru/Si and Mo/Si multilayers. We can find that the Ru-on-Si interface (a) is sharper as compared to Mo-on-Si layer (b).

Figure 6 compares the EUV reflectivity of optimized Mo/Si and Mo/Ru/Si multilayers. The conventional Mo/Si multilayer had maximum reflectivity of 62.5% and FWHM of 0.36 nm while Mo/Ru/Si multilayer had 64.2% and 0.54 nm. We could improve maximum reflectivity and FWHM by 1.5% and 50% respectively by inserting Ru layer. This increment of reflectivity can resulted in about 21.6% throughput in 7 incident mirror EUV lithography system. This is a quite significant improvement in the performance of multilayer mirror. Additionally, the increase of FWHM can give us substantial process latitude in matching of reflectivity optics and mask.

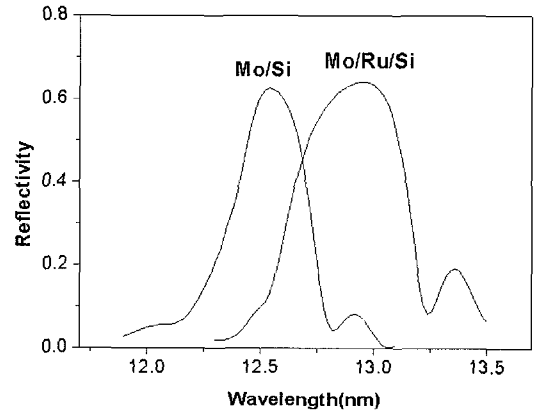


Fig. 6. EUV reflectivity comparison between Mo/Si and Mo/Ru/Si multilayer structures.

The effect of Ru insertion was also evaluated by annealing the Mo/Ru/Si multilayer. Fig. 7 are annealed cross-sectional TEM images of Mo/Ru/Si and Mo/Si multilayer, respectively. The annealing condition was 470℃ and 15 minutes. In the Mo/Ru/Si case, the layering structure is preserved after the annealing while the d-spacing was reduced about 5% On the contrary, the Mo/Si multilayer shows severe degradation of the multi-layer stacking structure under same annealing condition, though the decrease in d-spacing value was about 10%. This phenomenon comes from the fact that the Ru layer blocked the diffusion path, or Mo grain boundary, across the scatterer layer.

From these results, we can suppose that the normal Mo/Si multilayer can show unwanted behavior in actual lithography process or phase defect correction step. To

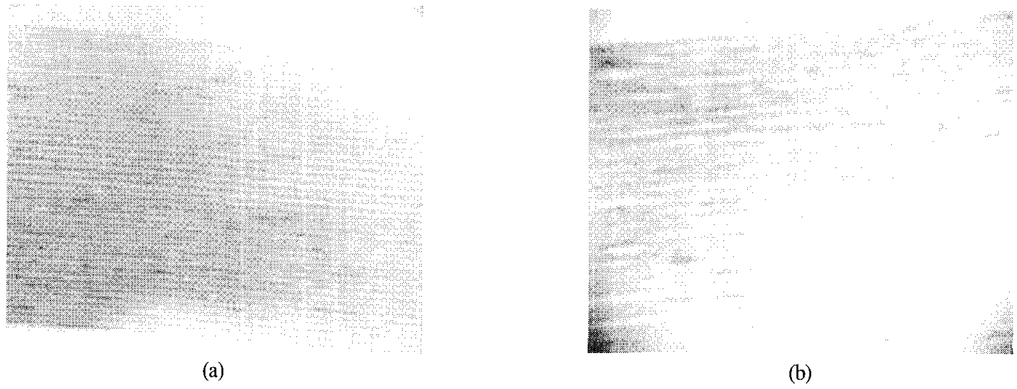


Fig. 7. (a) Annealed cross-sectional TEM images of Mo/Ru/Si multilayer. (b) Annealed cross-sectional TEM images of Mo/Si multilayer.

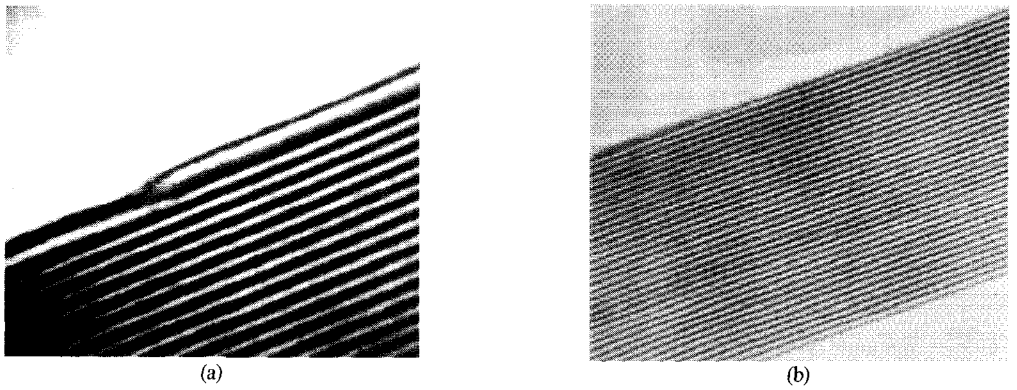


Fig. 8. TEM micrographs of e-beam exposed (a) Mo/Si and (b) Mo/Ru/Si multilayers.

verify this, we conducted localized e-beam heating and made cross-sectional TEM specimen by FIB etching step. The samples were coated by e-beam resist to find the exact exposure location. Fig. 8 shows the micrographs of e-beam exposed Mo/Si and Mo/Ru/Si multilayers. In Fig. (a) we can see the Si readily diffused out through the grain boundary of the Mo layer even by the low-dose e-beam exposure and as a result, two scatterer layers contacted each other. In contrast, Mo/Ru/Si multilayer didn't show any degradation of multilayer.

4. Conclusion

The properties of the Ru as a barrier layer was investigated and characterized. According to optical simulation, the theoretical reflectivity is expected to increase about 1.2% when Ru layers are inserted into Mo-on-Si interfaces. The actual increase of reflectivity and FWHM are 1.5% and 50% respectively. To evaluate the effect of Ru barrier layer, we made the sample that has specific stacking sequence and also annealed the Mo/Ru/Si multilayer comparatively. The results attained from those experiments commonly indicate that the Ru barrier layer inhibit the reaction of Mo and Si and act as a diffusion barrier inside the multilayer stack. Lastly e-beam exposing experiment shows that phase defect correctability of the multilayer can be enhanced by the insertion of Ru barrier layer.

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