Hydrogen Radical Cleaning of Carbon Contamination on EUV Mask

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In EUV optics, high energy photon irradiation has been known to cause carbon depositions (contaminations). Hence EUV masks are also likely to be contaminated during their usage. Since the carbon contamination causes an increase in the optimum exposures and in CD variations[1], the deposited carbon must therefore be removed. The hydrogen radical (H-radical) cleaning technique is known to be effective in removing carbon contaminations from EUV mirrors[2]; thus we have applied this technique for EUV mask as well.

By employing a SEM with a carbon source, used as a model carbon contamination, we deposited 1 μm□ carbon patches of various thicknesses on an EUV mask. Then, the mask was processed with H-radical. The result is shown in fig. 1. Both of the carbon layers deposited on the line and on the space of an L/S pattern were removed by the H-radical processing. The cleaning rate was 0.37 nm/min.

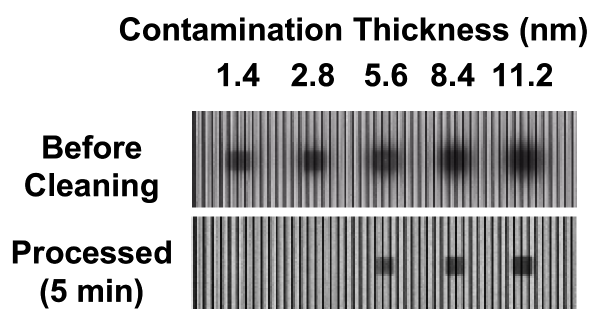

Fig 1: SEM images of contaminations on an EUV mask cleaned by hydrogen radical: L/S=180 nm/180 nm; Thickness of the pattern is 120 nm.

Unlike the EUV mirrors, here in the case of EUV mask various kinds of materials are used in its fabrication such as the absorber, LR (Low-Reflection) layer for the inspection, and so on. Thus, the effects of H-radical on these materials need to be addressed. So we examined those materials before and after H-radical irradiation. The examined materials were Ta_2O_5 as a model LR layer, Ta as a model absorber, and TaBN and TaSi systems as practical materials.

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[1] Y. Nishiyama et al., Proc. SPIE Vol. 6921-41 (2008) accepted.
[2] H. Oizumi et al., Proc. SPIE Vol. 5751, 1149 (2005).
[3] H. Oizumi et al., Jpn. J. Appl. Phys. 46, L633 (2007).

In fig.2, we show two XPSpectra from the Ta 4f semicores in Ta_2O_5 before and after 5 minutes of H-radical processing. The two spectra are found to be almost identical, thus showing that Ta_2O_5 is resistant to H-radical. This result is in contrast to that of Ru oxides where it can be reduced by H-radical [3]. One of the reasons of this difference may be due to the large enthalpy of the formation of Ta_2O_5, i.e. strong metal—oxygen bonding.

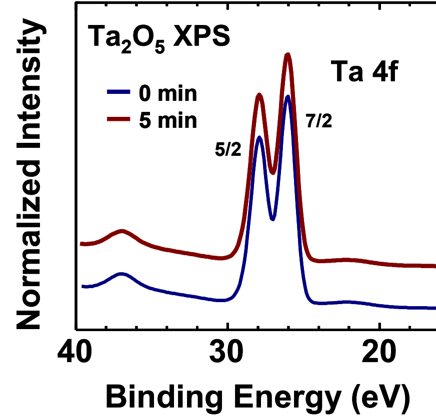

Fig 2: An XPS of hydrogen radical processed Ta_2O_5 film with a reference spectrum:

We then evaluated the RMS roughness changes with H-radical processing. The provisional results are summarized in table 1. In the case of the model materials Ta_2O_5 and Ta they show small change in their roughness but in the case of the practical materials the roughness change is barely noticeable.

Table 1: RMS roughness changes of EUV mask materials with H-radical processing.

Material	Ta	Ta_2O_5	TaBN	LR-TaBN	LR-TaSi
Reference (0 min)	0.76 nm	0.46 nm	0.28 nm	0.26 nm	(0.138 nm)*
Processed (5 min)	0.71 nm	0.48 nm	0.28 nm	0.26 nm	0.14 nm

*Published value

Fig. 3 shows the hardness changes with H-radical processing of Ta_2O_5 and Ta, evaluated by the nanoindentation method. The hardness of Ta_2O_5 remained unchanged after the H-radical process. On the other hand, in the case of the model absorber Ta, the H-radical process revealed some degradation by hydrogen absorption.

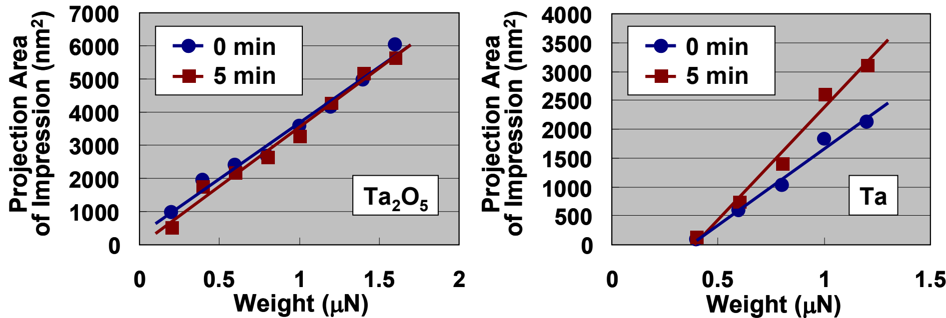

Fig 3: Weight—projection area plot of Ta_2O_5 and Ta films by nanoindentation method: An AFM with a 90° diamond-anvil on a stainless-steel cantilever is used.

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