The effects of wet and dry cleaning methods on the chemical composition and morphology of the Ru capping layer of the extreme ultraviolet (EUV) mask blanks

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EUV lithography is being developed as a leading technology for patterning nanostructures for high volume semiconductor device manufacturing. The reflection of EUV light is enabled by the use of Mo-Si multilayer (ML) stacks. Contamination removal and lifetime improvement for masks and mirrors without adverse effect to the ML surface are some of the key EUV challenges related to ML technology. In order to develop damage free processes for surface cleaning, it is important to understand the surface chemistry and structure changes under process conditions.

The surface effects of wet and dry cleaning methods of EUV mask blanks were studied using surface sensitive methods. Two types of EUV mirrors capped with 3 nm and 6 nm Ru layer on Mo-Si multilayers were systematically treated with wet and dry cleaning methods: Piranha solution, ozonated water, oxygen plasma and ozone under ultraviolet irradiation. The chemical composition of EUV mask blanks were characterized with x-ray photoelectron spectroscopy (XPS) after various cleaning methods. Atomic force microscopy (AFM) was used to reveal the influence of cleaning methods on the surface morphology and roughness. The chemical analysis of the EUV mirrors after these treatment show two major processes affecting their reflectivity: increase in the subsurface oxygen concentration and grow of the ruthenium oxide. It was found that the Piranha treatment shows the lowest increase in the subsurface oxygen concentration and RuO_2 growth. Moreover, the surface roughness undergoes only very minor changes, after piranha cleaning. The O_2 plasma and ozone with UV exposure treatment shows noticeable increase in the subsurface oxygen and ruthenium oxide. We will discuss the molecular scale mechanisms to describe the differences in the surface composition and morphology after oxygen rich cleaning methods.