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Cleaning technology for EUV multilayer mirror using atomic hydrogen generated with hot wire

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Abstract

A method of removing contaminants from Ru-capped Mo/Si multilayer mirrors for extreme ultraviolet lithography has been developed. It employs atomic hydrogen generated by a heated catalyzer consisting of a W wire. A new experimental system was designed and constructed to examine the cleaning capability of atomic hydrogen transported through a quartz tube. The chemical state of an oxidized Ru surface was investigated by X-ray photoelectron spectroscopy before and after cleaning; and it was found that transported hydrogen radicals deoxidized the surface and reduced the amount of oxide to the level before oxidation. Although the time needed was longer, transported atomic hydrogen was found to be capable of deoxidizing an oxidized Ru surface. The dependence of the density of atomic hydrogen on W catalyzer temperature and hydrogen gas pressure was measured by a vacuum ultraviolet absorption technique; and the potential to increase the density, and thereby to reduce the treatment time, was demonstrated.

Keywords: EUV lithography; Ru-capped mirror; Cleaning; Atomic hydrogen; Deoxidization; Transport; Hydrogen radicals density

1. Introduction

Extreme ultraviolet lithography (EUVL) is one of the most promising lithography technologies for the fabrication of the next generation of ULSIs. The short wavelength of EUVL necessitates the use of reflective optics rather than a conventional optical lens system. The lifetime of the projection optics is a critical issue for the commercialization of EUVL [1]; that is, the reflectivity of the optics must remain high for over 30000 h under EUV irradiation in a partial vacuum and the reflectivity loss should be less than 1.6% in five years. Therefore, contamination control for EUV multilayer mirrors a very important subject.

The two primary contaminants that degrade the reflectivity of a multilayer mirror exposed to EUV light are carbon and surface oxide, which result from the photodecomposition of residual hydrocarbons and water, respectively. Cleaning methods to remove carbon contamination already exist, such as oxidation and atomic-hydrogen cleaning [2–8]; but there is currently no solution for oxide contamination. One way of suppressing the formation of surface oxide is to cap a multilayer with Ru, although its oxidation resistance is not really good enough [8,9].

We have been developing hydrogen-radical cleaning to remove both types of contamination. Our previous studies showed that atomic hydrogen generated by a heated catalyzer removed carbon contamination well enough to restore the reflectivity [2], and atomic hydrogen deoxidized the surface oxide contamination of Ru [10].

We also applied this technology to the cleaning of actual Ru-capped EUV multilayer mirrors and obtained the following results [11]. AES depth profiles of oxygen for the Ru cap layer showed that the sample surface had been lightly oxidized by ECR O_2 plasma, and then a 20-min treatment with atomic hydrogen deoxidized that surface to the level of the initial native oxide; but the thickness of the Ru capping was not changed during deoxidization. XPS spectra of the Ru 3d 3/2 and 5/2 peaks revealed how the composition of the Ru surface changed: ECR plasma oxidation increased the amount of RuO_x and reduced the amount of Ru metal, and then a 5-min atomic hydrogen treatment reversed that change. The average RMS surface roughness measured by AFM indicated that atomic hydrogen treatment did not increase the surface roughness. The

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measured reflectivity of a sample mirror showed that the surface oxidation degraded the reflectivity, but that atomic hydrogen almost completely restored it, with the change in the λ centroid being almost negligible. Thus, the treatment with atomic hydrogen seems to be an effective way of removing the surface oxide on a Ru cap layer and thus restoring the reflectivity of an EUVL mirror.

Two problems remain to be solved before this technique can be considered a practical cleaning method for use in an EUVL system. One is how to transport atomic hydrogen, which is an essential technique because a heated catalyzer cannot be placed inside an EUVL system or near EUV mirrors. Another is how to increase the amount of atomic hydrogen reaching the mirror surface to reduce the treatment time to a permissible level because atomic hydrogens recombine back into molecular form on the surface of materials, such as the wall of the transport tube.

To study these problems, we constructed a new experimental chamber system that was designed for both transport experiments and radical-density measurements. The transport of atomic hydrogen was demonstrated with a bent quartz tube. To optimize this cleaning method, the conditions for the generation of atomic hydrogen were examined by measurement of the density of hydrogen radicals with a vacuum ultraviolet absorption technique [12,13].

2. Experiments

The samples were standard EUV multilayer mirrors consisting of 50 thin bilayers of Mo and Si deposited on a Si (100) wafer by magnetron sputtering, with a cap layer of 2.7-nm-thick Ru subsequently deposited on top. The samples were slightly oxidized with electron cyclotron resonance (ECR) O_2 plasma

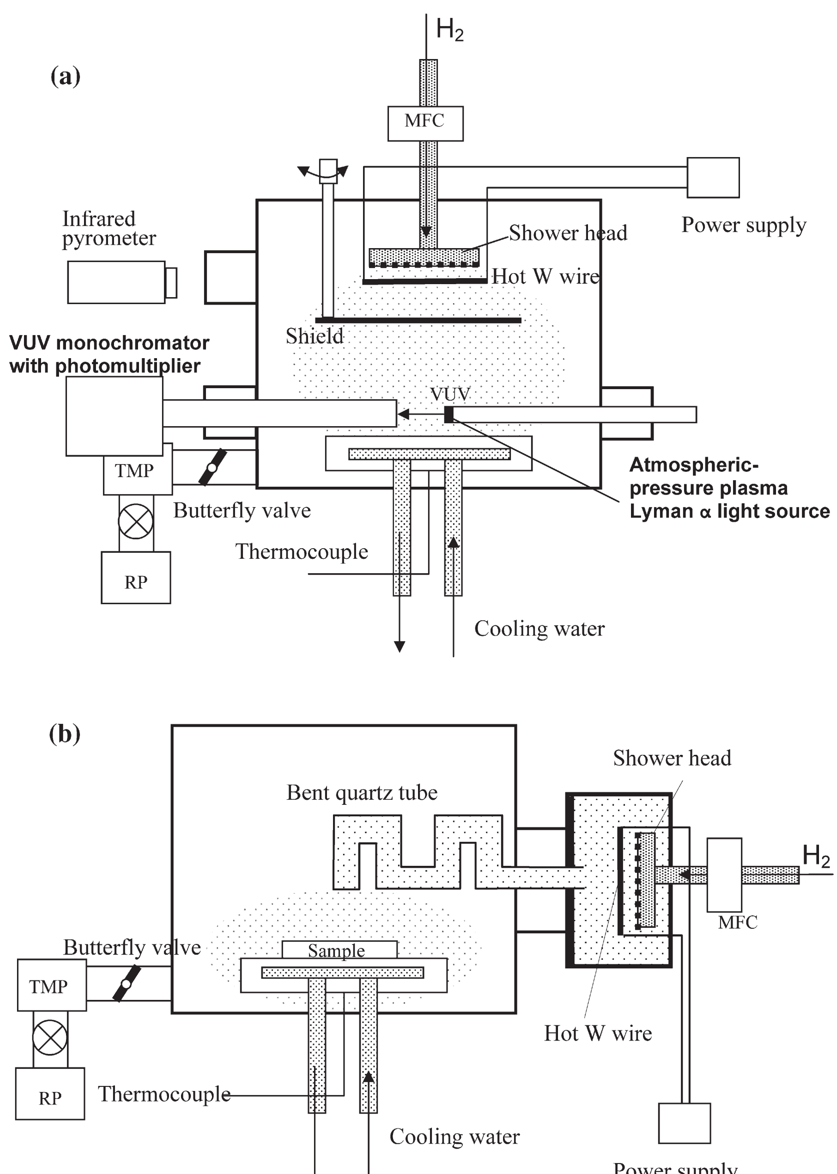

Fig. 1. Apparatus of new experimental system for atomic-hydrogen cleaning: (a) for normal sample treatment, for which a radical monitor can be installed; (b) with transport unit attached.