Controlling Contamination in Mo/Si Multilayer Mirrors by Si Surface-capping Modifications

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INTRODUCTION

The present experiments helped determine the influence of the Si capping layer thickness in Mo/Si multilayer mirrors (MLMs) on the initial carbon (C) buildup on the mirrors when used in an extreme ultraviolet (EUV) + low pressure hydrocarbon (HC) vapor environment. The intent of this work was to broaden the approach taken to fabricate multilayer mirrors, by proposing that MLMs be made so that they have not only high initial reflectances but also low C buildup when used in EUV + HC environments. Carbon buildup is undesirable since it absorbs EUV radiation and reduces MLM reflectivity.

Previous work [1-4] on non-multilayer optical elements in synchrotron beamlines has shown that the “cracking” of hydrocarbons adsorbed on the optical surfaces leads to deposition of carbon onto these surfaces. “Cracking” is the name given to the process in which adsorbed, potentially volatile hydrocarbons are transformed into stable carbonaceous species on a surface. In these previous studies [2-4], it was determined that this cracking was caused by photoelectrons emitted from the metallic optical surfaces.

When EUV radiation is incident onto a MLM there is a sinusoidally varying, standing wave electric field both inside and outside the MLM structure. This incident photon radiation creates a standing wave, electric field intensity (and similarly modulated photoemission) with a period of half the wavelength of the incident EUV light. Since the cracking of adsorbed hydrocarbons is likely caused by photoelectrons [2-4], in principle the initial carbon contamination on MLM surfaces could be reduced by appropriately adjusting the electric field intensity at the uncontaminated MLM/vacuum interface so the field intensity is near a minimum.

One way to vary this intensity at the MLM/vacuum interface is through intentional changes in the thickness of the MLM Si capping layer. A set of Mo/Si MLMs deposited on Si wafers was fabricated such that each MLM had a different Si capping layer thickness ranging from 2 nm to 7 nm. Each was deposited such that maximum reflectance occurred at normal incidence for photons of 13.4 nm wavelength and had Mo/Si bilayer pairs about 6.9 nm thick, with Mo/(Mo+Si) thickness ratios of 0.4. These samples were used in subsequent EUV+HC tests.

RESULTS

It was found that the capping layer thickness affected both the initial MLM reflectivity and the “carbonizing” tendency on the MLM when exposed to EUV(13.4 nm, ~ 0.5 mW/mm^2) + HC vapors (pressures estimated to be $< 10^{-8}$ Torr). Measurements of the uncontaminated, absolute reflectivities were performed on the Calibration and Standards beamline at the ALS and are given in Figure 1 below. Figure 2 below shows the relative reflectivities (reflectivity/original reflectivity) for all samples which were subsequently exposed to EUV + HC vapors.

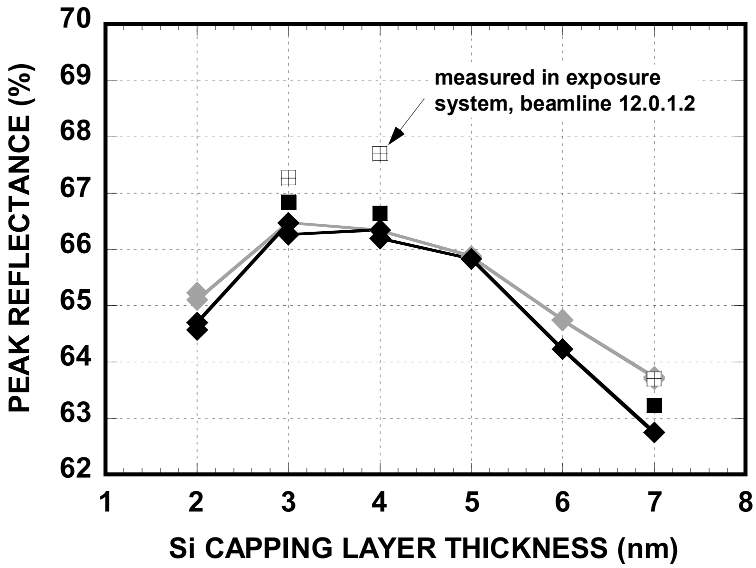

Figure 1. Absolute reflectances of all samples in used in this study. Reflectances were measured in regions not exposed to EUV+HC vapors. Values measured on beamline 12.0.1.2 are shown as squares with inset crosses. All other values were measured on beamline 6.3.2 before the experimental runs (gray points) and after experimental runs (black points).

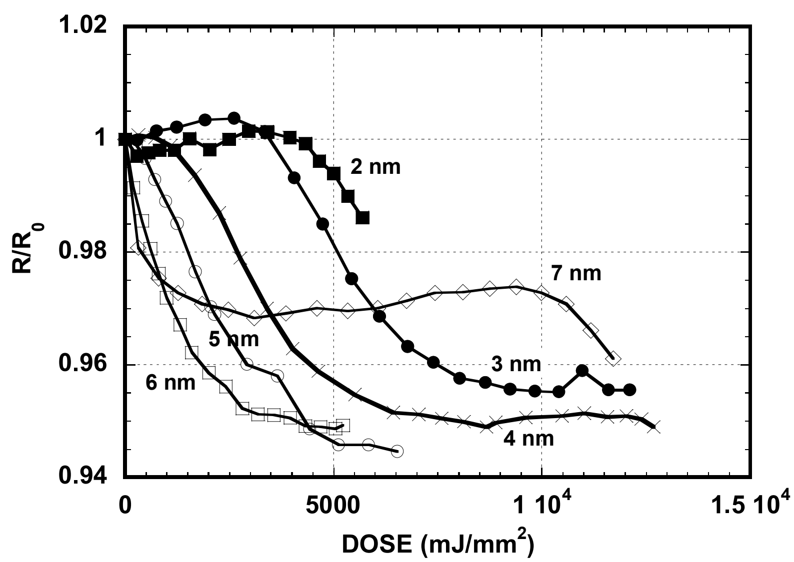

Figure 2. Relative reflectances) of samples with different capping layers exposed to EUV+HC as a function of photon dose.

In these samples, the doses where the relative reflectivities decreased most rapidly (e.g., at ~ 5000 mJ/mm^2 for the 3 nm capped sample) were also the doses where peaks in photocurrent emission occurred. These observations were consistent with the proposed correlation between photoemission (or near-surface electric field intensity) and carbon buildup. The results in both these figures also show that the use of a 3 nm capping layer on a Mo/Si MLM represents an improvement over the 4 nm layer since the 3 nm sample has both a higher absolute reflectivity and better initial resistance to carbon buildup. A typical Mo/Si MLM has a ~ 4.3 nm Si cap.

SUMMARY

The results of this work have shown that varying the silicon capping layer can change the characteristics of carbon buildup on a Mo/Si MLM optic. The data obtained indicated that a ~3 nm Si- capped Mo/Si MLM was the MLM which not only had the highest as-received reflectivity but also maintained that reflectivity the longest under EUV+HC vapor pressure exposure of the samples studied – those with Si capping layers from 2 nm to 7 nm. Using a 3 nm instead of 4 nm thick Si capping layer on Mo/Si MLMs should produce improved optic lifetimes and should likewise help reduce downtimes in EUVL tools using such optics. This work also showed that there is a strong correlation between the EUV-induced photocurrent from a MLM and its reflectivity, with maxima in the photocurrents occurring when relative reflectivity loss rates were the highest. This observation suggested that the carbon buildup was also correlated with photoemission, with higher carbon growth rates coincident with higher MLM photoemission. However, since the maxima in surface electric fields at the MLM are correlated with photoemission maxima, the current data did not allow a differentiation between the mechanisms of direct photon vs. photoelectron-caused hydrocarbon cracking. The current data were consistent with the existence of a standing wave electric field near the MLM surface and suggest that its form profoundly affected carbon contamination of MLMs. The results further suggested that the strategy of minimizing the near- surface electric field at the MLM/vacuum to reduce carbon buildup should be applicable to MLM systems other than conventional Mo/Si, including Mo/Si with other capping layers and MLMs using other material combinations

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