Characterization of curved multilayer optics for an extreme ultraviolet lithography projection system

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INTRODUCTION

Extreme Ultraviolet Lithography (EUVL) is currently the leading candidate technology for patterning semiconductor devices with features as small as 30 nm. The success of this technology has been demonstrated through the development of the engineering test stand (ETS), a laboratory tool designed to produce full-field imaging and provide data to equipment manufacturers to support commercial development. The ETS, which has been described in detail in our Abstract in the1999 ALS Compendium [1], incorporates an all-reflective condenser and imaging system using multilayer-coated mirrors. One of the most critical tasks in the development of EUVL is the accurate deposition and characterization of these reflectors. The present abstract describes the characterization of the second set (Set 2) of four Mo/Si-coated projection optics for the ETS, aiming in producing 70-nm resolution images. Each of these elements consists of a stack of 40 Mo/Si bilayers deposited on a polished Zerodur substrate, designed to reflect around 13.4 nm at near-normal incidence angles. Several ALS beamlines (built and operated by CXRO) are involved in metrology for EUVL, including the Calibration and Standards beamline 6.3.2. [2], where the present work was performed.

MULTILAYER COATINGS FOR THE ETS PROJECTION SYSTEM

A new, production-scale DC-magnetron sputtering system was used at LLNL in order to coat the four curved optics (M1, M2, M3, M4) of the ETS camera [3]. All optics were Mo/Si-coated during a single deposition run, assuring best wavelength matching between the four coatings. Ideally, the multilayer coatings should not degrade the residual wavefront error of the imaging system design and should effectively become “invisible” to the optical performance. For the present set of optics, this requirement is equivalent to depositing multilayer coatings with uniform thickness to within ±0.2% peak-to-valley (P-V), adding a figure error of less than 0.1 nm rms [4]. In addition, all mirrors should be matched in centroid wavelength in order to insure maximum throughput of the EUVL tool. In order to meet such strict tolerances, the multilayer deposition process needs to be controlled to atomic precision.

MIRROR MEASUREMENTS AND DISCUSSION OF RESULTS

Bragg reflectance curves vs. wavelength were measured for all mirrors at the beamline 6.3.2. reflectometer [2]. The sample stage allows to move the optic in 3 dimensions, tilt it in 2 dimensions and rotate the sample holder around its center. The detector arm can be rotated 360° around the axis of the reflectometer chamber. Curved optics of up to 200 mm in diameter can be mapped in this facility. Advanced hardware and software capabilities allow to pre-calculate for each surface point a table of all coordinates of the sample stage, and program wavelength scans on multiple locations on the mirror surface without any manual input needed in-between scans. The centroid wavelength was determined for each reflectance curve and the thickness profile for each optic was produced using values of centroid wavelength normalized at an arbitrary point on the optic surface. The P-V thickness uniformity specification of ±0.2% was met for all four coatings. As an example, Figure 1 shows the measurement results for the M2 optic, using data points obtained every 5 mm in the radial direction. In summary, the added figure errors due to the multilayer coatings were determined to be 0.032 nm rms (M1), 0.037 nm rms (M2), 0.040 nm rms (M3) and 0.015 nm rms (M4), well within the aforementioned requirement of 0.1 nm rms. The centroid wavelength of each optic, weighted across the clear aperture area, was found to be 13.355 nm (M1), 13.347 nm (M2), 13.363 nm (M3) and 13.342 nm (M4), resulting in an average wavelength of 13.352 nm for the projection optics system, with an excellent optic-to-optic matching of $1\sigma=0.010$ nm. This level of wavelength matching produces 99.3% of the throughput of an ideally matched four-mirror system. Peak reflectances were determined at 63.8% (M1), 65.2% (M2), 63.8% (M3) and 66.7% (M4) at the center of the clear aperture of each optic. All wavelength and reflectance measurements were obtained with a 0.002 nm and 0.2% (absolute) precision, respectively. The variation in reflectance values among the four optics is consistent with their high frequency substrate roughness and was verified through atomic force microscopy characterization of the substrates prior to coating and scattering measurements of the coated optics.

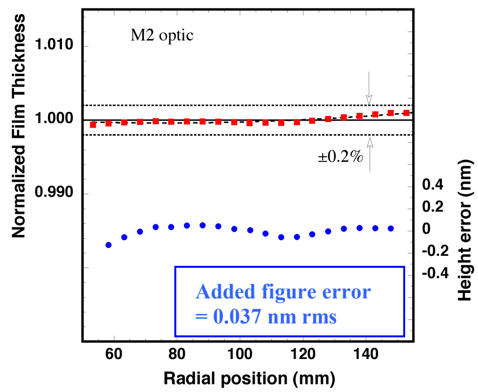

Figure 1. Measured multilayer profile vs. radial distance from the optic axis of the M2 mirror. The clear aperture area (i.e: the area that will be illuminated in the ETS camera) is shown. The top curve (left y-axis, unitless) is the normalized film thickness. A portion of the non-uniformity, corresponding to a best-fit 2nd order polynomial, can be compensated during alignment of the system. The bottom curve (right y-axis, in nm) is what remains after subtraction of the polynomial from the top curve. It represents the un-compensable figure error that the multilayer stack is adding to the system. The multilayer coating is well within specifications in terms of both P-V uniformity and rms added figure error.

In addition to the radial direction shown in Figure 1, data were also obtained in several other directions on each mirror surface in order to produce two-dimensional contour maps of centroid wavelength and mirror reflectance (see Figure 2). The wavelength information shown in Figure 2 can also be obtained from one-dimensional data such as in Figure 1, using the rotational symmetry of the coatings around the optical axis; the wavelength contour maps thus confirm this symmetry. The reflectivity values, on the other hand, are strongly influenced by the high frequency roughness of the Zerodur substrate and give therefore a map of the substrate topography of each mirror (see Figure 2). Reflectance variations across the surface of a given optic are undesirable since they cause intensity variations ("apodization") in the system exit pupil and may degrade the performance of the imaging system. Calculations using the measured reflectance maps of all four Set 2 projection optics demonstrated that the apodization in the ETS system will be small and can be compensated. In the future, specifications will be set for the substrate finish uniformity of beta-tool optics in order to prevent apodization-related problems in the lithographic performance of commercial systems.

CONCLUSIONS

The four ETS Set 2 projection optics have been successfully multilayer-coated at LLNL and characterized using the advanced capabilities of the beamline 6.3.2. reflectometer. Outstanding levels of wavelength matching and thickness uniformity were achieved for all four mirrors. Thus, the multilayer coatings will not introduce any aberrations in the ETS imaging performance.

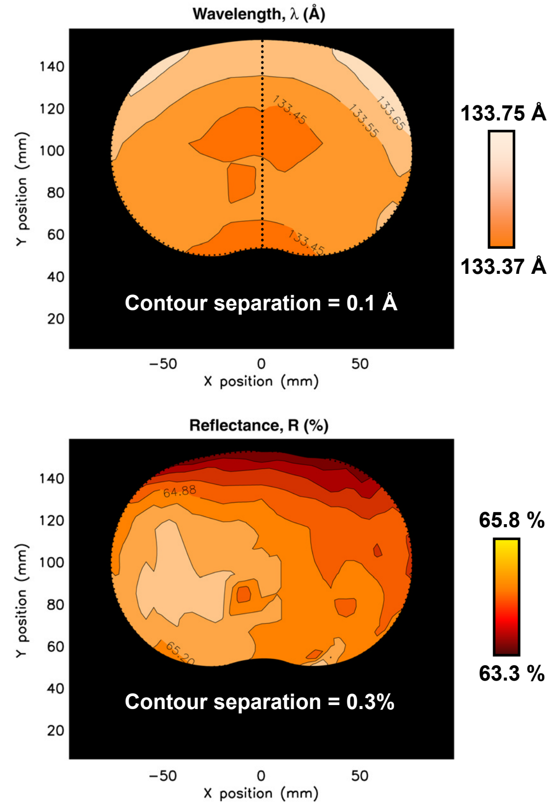

Figure 2. Two-dimensional contour maps of wavelength (top) and reflectance (bottom) in the clear aperture area of the M2 mirror. The wavelength map confirms the rotational symmetry of the coating process around the optic axis, located at (x,y)=(0,0) mm. The dotted line indicates the position of the normalized thickness results plotted in Figure 1. The reflectance map shows a 2.5% reflectance variation across the clear aperture, due to substrate roughness variations.

ACKNOWLEDGEMENTS

The authors would like to thank Paul Denham and Dave Richardson (LBNL) and Sherry Baker, Todd Decker, Gary Heaton, and Rick Levesque (LLNL) for their support of this work.

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This work was performed under the auspices of the U. S. Department of Energy by the Lawrence Livermore National Laboratory under Contract No. W-7405-ENG-48. Funding was provided by the Extreme Ultraviolet Limited Liability Company (EUV LLC) under a Cooperative Research and Development Agreement (CRADA). The work performed at Lawrence Berkeley National Laboratory is supported through a CRADA with the Extreme Ultraviolet Limited Liability Company (EUV LLC) and by the U.S. Department of Energy under contract No. DE-AC03-76F00098.

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