Laser damage properties of Al_2O_3/MgF_2 antireflection coatings on large, curved substrates at 248 nm

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ABSTRACT

As 248nm DUV lithography tools pursue resolution of smaller features, the transition towards higher numerical aperture optics in these tools is pushing the development of high-performance anti-reflection coatings on large-area, highly curved transmitting optics present in these systems. We present the results of one such effort to coat multi-layered Al_2O_3 and MgF_2 antireflection coatings on substrates of planar, spherical, and aspherical geometries. The spectral, surface quality, and pulsed laser damage performance of these coatings are presented.

Keywords: anti-reflection coatings, laser damage threshold, 248nm, high NA

1. INTRODUCTION

Modern high-throughput optical lithographic systems frequently use krypton fluoride (KrF) excimer laser as an illumination source operating at a central wavelength of 248 nm [1]. Within these lithographic systems exists a series of transmitting and reflective optics working to enable high-volume chip manufacturing. As the need for more complex circuit designs arises, these systems are shifting towards achieving higher numerical aperture. To accomplish this, the optical systems within these tools are becoming dramatically more complex by increasing the number of optical elements present. Each optic has also increased in size and curvature with the requirements for surface quality and wavefront errors becoming ever more stringent. Modern systems often have 20 or more unique elements with surface steepness approaching 60 degrees from the normal and clear aperture sizes far exceeding 100mm [2].

The transmissive optical components present in these lithography systems require anti-reflective (AR) coatings to reduce their reflectivity, improve transmission, prevent ghost imaging and damage to the source laser cavity. Requirements for low reflectance over wide angular acceptance, low absorption, high-surface quality, low wavefront errors, and high laser damage threshold (LDT) dictates the coating design, processes, and materials for these anti-reflection coatings. In this article we present spectral and laser damage performance of Al_2O_3/MgF_2 AR coatings optimized for use in a 248nm excimer laser system. The multi-layered AR coatings were deposited on UV grade fused silica substrates of planar, spherical, and aspherical geometries with a radius of curvature ranging from -900 mm to 300 mm and diameters exceeding 300 mm. Single layer uniformities of <0.5% were achieved over 20 inches. Coating performance was measured at angles of incidence from near normal to 59 degrees. Laser damage threshold testing was measured using 10Hz, 20nsec pulses at 248nm.

2. EXPERIMENTAL

Al_2O_3 and MgF_2 were deposited via e-beam evaporation in a Vacuum Process Technologies optical coating system. The deposition chamber is capable of coating substrates with diameters <30” in a dual rotation planetary system and <43” in a simple rotation configuration. A Telemark electron beam evaporation source was used. Film thickness was controlled using an Inficon quartz crystal monitor. All spectral and LDT measurements were performed on representative witness samples measuring 1” in diameter and 5 mm thick, placed alongside the optics during deposition. The reflectance and transmission spectra were measured with an Agilent Cary 7000 spectrophotometer.

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LDT was measured at Spica Technologies Inc. [3] at 10Hz, with a 248nm laser set to emit 20ns flat-top pulses and imaged/inspected for damage using a 150x Nomarski brightfield microscope. The physical durability of coated optics was tested per MIL-C-48497. Film stress was measured by a ZYGO Verifire interferometer. Surface roughness was measured on a Veeco atomic force microscope (AFM). Before deposition, substrates were cleaned per a ZYGO proprietary cleaning process. Acetone and methanol were used for a final cleaning before loading the substrates into the chamber.

3. RESULTS AND DISCUSSION

Materials used to manufacture optical coatings in the DUV region are limited [4]. Oxides generally offer excellent physical durability, index contrast, ease of process and methods as well as high LDT. In recent studies, Al_2O_3 based multi-layered stacks have shown better LIDT and lower absorption than HfO_2 based coatings [5] at wavelengths below 266 nm. In this work, single layers of Al_2O_3 (high-index material) and MgF_2 (low-index material) were optimized for low losses.

The large range for angles of acceptance, steep sag, and low reflectance made the design sensitive to the errors in thickness uniformity and variability. Unique geometries of planar, spherical, and aspherical optics compounded by shadow effects for optics with large sag were addressed by developing uniformity shadow masks for different geometries. The uniformities were optimized by depositing multi-layered mirror stacks $(HL)^n$ mimicking the number of layers, thicknesses in the stack, and curved profile of the optics. Coating stresses were limited to <100 MPa tensile stresses.

Figure 1 shows the spectral performance of a multi-layered AR deposited on one of the representative witnesses. Reflectance values of ~0.1%, ~0.2%, and ~1.0% were achieved at near normal, 26 degrees, and 49 degrees angle of incidence. Total losses <0.5% were achieved for these multilayer AR designs.

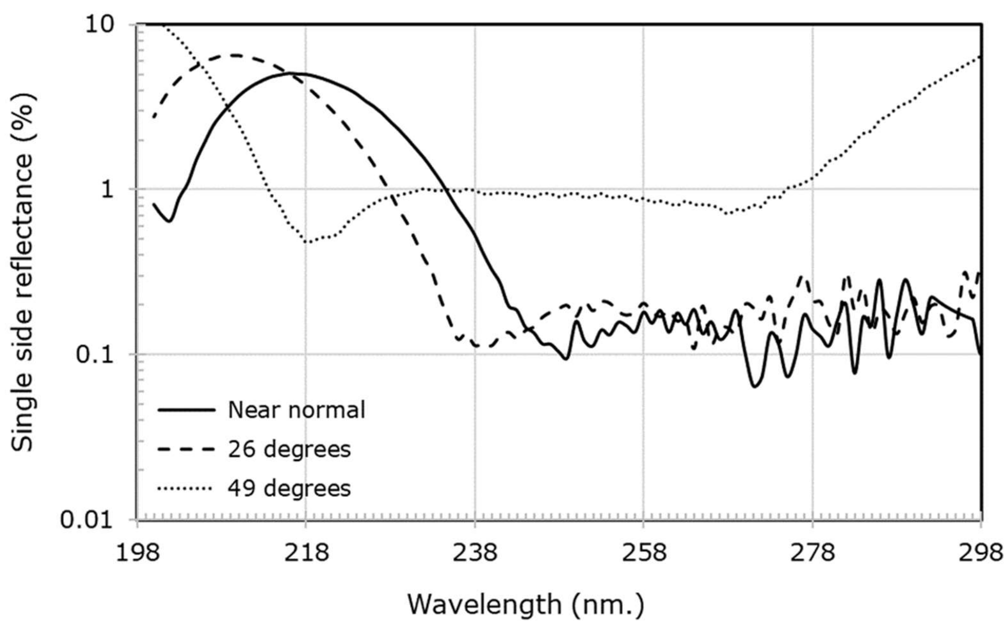

Fig. 1. Spectral performance of a multilayer Al_2O_3/MgF_2 AR coating optimized for a wide angle of incidence.

Surface roughness plays a key role in achieving low absorption and a high laser damage threshold for coatings. Surface preparation of the substrates is more critical in achieving a high laser damage threshold for AR coatings [6] as compared to high reflectors. Consequently, a larger variation in LIDT values is typically seen for AR coatings.

nm

A surface image of our 6-layer AR coating deposited on a commercially polished substrate, captured via AFM, is shown in Figure 2. Surface roughness of 6.98A was measured for the coating over a 10 µm x10 µm area on the coated substrate.

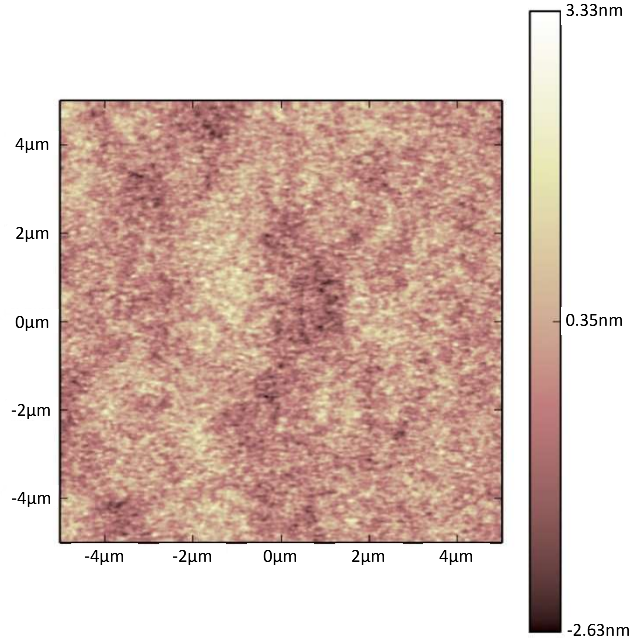

Fig. 2. AFM image of multilayered Al_2O_3/MgF_2 antireflection coating on a commercially polished substrate.

Figure 3 shows the laser damage threshold measured for our samples. The laser damage threshold for our coatings are 4 to 7 J/cm². These values remained consistent for both curved and plano surfaces. As seen in the literature, under the influence of irradiated laser, AR coatings typically damage at the substrate and coating interface [7]. Therefore, the substrate preparation methods used played a significant role for the laser damage resistance of AR coatings. The variation in LDT values for these AR coatings were most likely due to differences in the substrate preparation methods for witness samples.

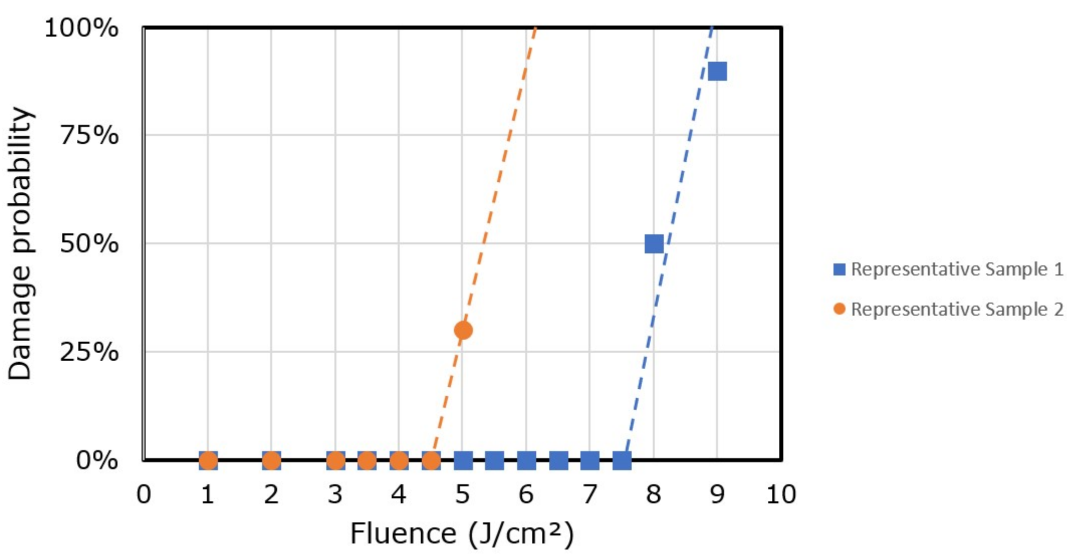

Fig. 3. LDT results for multilayered Al_2O_3/ MgF_2 coatings at 248 nm.

4. CONCLUSION

Al_2O_3/ MgF_2 antireflection coatings with single side reflection of 0.1% to 1.0% measured from 0 to 49 degrees angles of incidence were coated on fused silica substrates with curved and plano geometries. Uniformities of < 1% were optimized for each curved and plano surface. The surface roughness of the coatings was measured to 0.698 nm. rms. Laser damage threshold of these antireflection coatings measured at 248 nm with 20 ns pulsed laser were found to be in the range of 4-7 J/cm². These results were found to be consistent across several large substrate sizes and complex optical geometries.

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