Ion Beam Sputtering Deposition of Fluoride Thin Films for 193 nm Applications

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Abstract: Ion beam sputtering of AlF_3, LaF_3, and GdF_3 as single layers, AR and HR coatings for 193nm is presented. The low deposition temperature allows for both CaF_2 and fused silica substrates to be used.
OCIS codes: (310.1860) Deposition and fabrication; (310.6860); Thin films, optical properties

1. Introduction

Thin film coatings for deep UV wavelengths are predominately produced by evaporation methods (thermal and E-beam). Factors limiting the performance of evaporated films include surface roughness, porosity, absorption, and defect density. To enhance the films, they are typically deposited at high substrate temperatures (above 300° C.) The thermal stress created upon cooling down from the deposition temperature often restricts these films to be deposited on fluoride substrates.

Efforts to improve the quality and performance of deposited fluorides films includes the use of ion beam sputtering [1,2]. While the energy of ion beam sputtering removes some of the fluorine atoms during the sputtering process, this deficiency was compensated for by introducing a fluorine base gas in the deposition environment.

A method of ion beam sputtering fluoride films suitable for a production environment using a commercially available dual ion beam sputtering system is presented in this work. The resulting optical and material properties as well as suitable substrates are discussed for AlF_3, LaF_3, and GdF_3 films. Results for both single layer and multilayer coating designs are presented. Results are focused on the 193 nm wavelength of the ArF excimer laser.

2. Deposition system and parameters

A dual ion beam sputtering system was used to deposit films of AlF_3, LaF_3 and GdF_3. Only the main deposition ion beam was used in this work. The assisting ion source was not used. Xe sputtering gas was used with beam voltages and beam currents in the 700-900 V and 175-225 mA range, respectively. Sputtering with ion beam results in a fluorine deficient film, which contributes to absorption losses in the coating. To compensate for the fluorine depletion, NF_3 gas was added as a chamber background gas. Previously reported studies used fluorine [1,2] or CF_4 [3] gases. NF_3 was chosen here because it is relatively less hazardous and has a lower cost than F_2 or CF_4.

Two deposition systems were used interchangeably in this work. One was configured with a load locked single axis rotation 300 mm diameter substrate fixture. The other was not load locked and had a 4 × 200 mm diameter planetary fixture. No noticeable difference was observed between the films coated in the two systems.

No heat was added during the deposition process. Chamber temperatures during deposition remained low at below 30° C for a short antireflective coating and below 40° C for a longer high reflective coating.

3. Results

Single layers of AlF_3, LaF_3 and GdF_3 were coated on double-side polished UV grade fused silica and CaF_2 substrates, and on single side polished Si wafers. Deposition rate, index and film stress are shown in Table 1. Refractive index was measured from single layers deposited on fused silica and CaF_2 using an ellipsometer. Film stress of GdF_3 and AlF_3 was measured from single layers deposited on Si wafers.

Table 1. Single Layer Results

Film material	Target material	Deposition Rate (nm/s)	Refractive index	Film stress (MPa)
GdF_3	Gd	0.16	1.68	-118 (Compressive)
AlF_3	Al	0.30	1.44	101 (Tensile)
LaF_3	LaF_3	0.13	1.73	N/A

The transmittance of each single layer coating compared to uncoated substrate is shown in Figure 1. In the wavelength range studied, the loss of the GdF_3 film is low while AlF_3 and LaF_3 exhibit some loss.

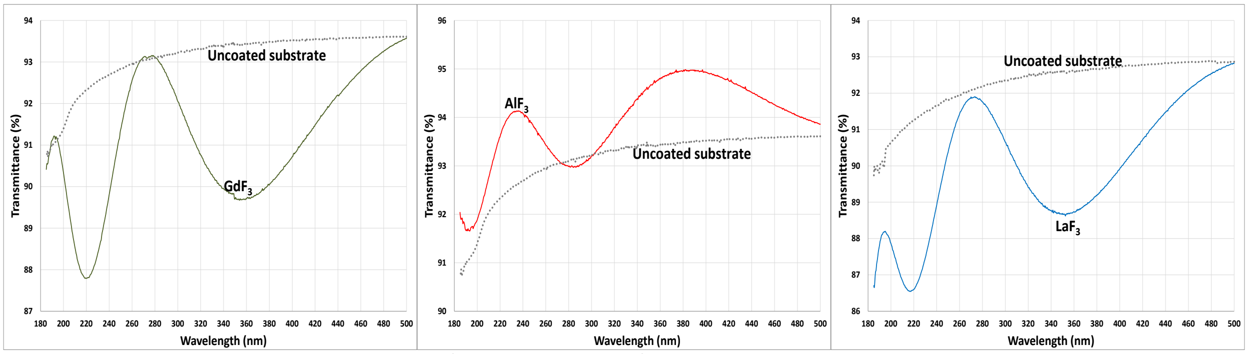

Figure 1. Transmittance data of single layer GdF_3 (left), AlF_3 (center), LaF_3 (right), and uncoated substrates.

3-layer antireflective (AR) coatings optimized for 193 nm at normal incidence were designed with LaF_3/AlF_3 and GdF_3/AlF_3 combinations. The AR coatings were deposited on both sides of double-side polished fused silica and CaF_2 substrates. The coatings were run on time-power, meaning that no in-situ layer endpoint monitoring was used. Figure 2 shows the measured transmittance data for the AR coated substrates. There was no measurable difference in the spectral performance of the AR coatings between the fused silica and CaF2 substrates. The transmittance of the LaF_3/AlF_3 AR coated substrates is 99.0%, and 99.1% for the GdF_3/AlF_3 AR coated substrates. The corresponding measured reflectance was 0.2% for LaF_3/AlF_3 and 0.06% for GdF_3/AlF_3. The 3 curves in each graph in Figure 2 show 3 sets of 2-side coated substrates for a total of 6 consecutive coating runs. This demonstrates stable and repeatable deposition without in-situ layer endpoint monitoring.

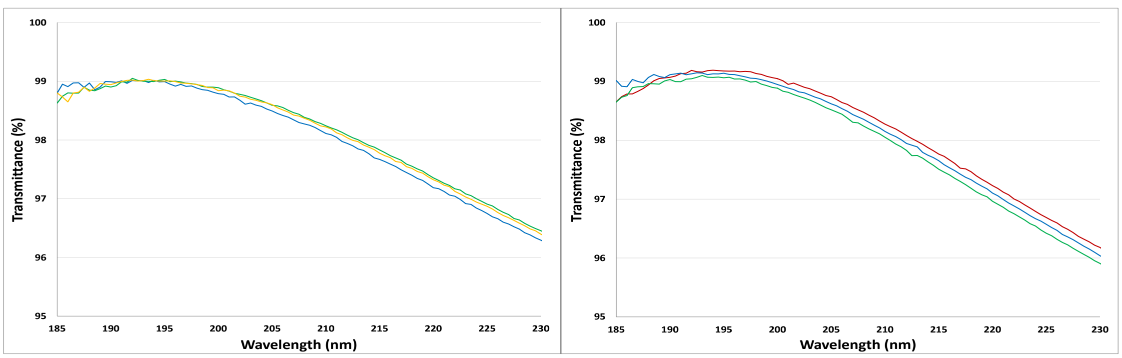

Figure 2. Transmittance data of AR coating on both side of fused silica, AlF_3-LaF_3 (left) and AlF_3-GdF_3 (right).
Each graph showing 6 consecutive coating runs without in-situ layer endpoint monitoring.

A high reflective (HR) coating centered at 193 nm for normal incidence, with total coating thickness of 1.25-1.4 µm, was coated on fused silica and CaF_2 substrates. Figure 3 shows the reflectance and transmittance data of the HR coating. Again, there was no measurable difference between the two different substrates. At 193 nm, the measured reflectance was in the range of 97.9-98.5% and transmittance was 0.44-0.51%. These values show that, although there is some loss in the film at 193 nm, they are comparable to commercially available E-beam deposited 193 nm HR coatings.

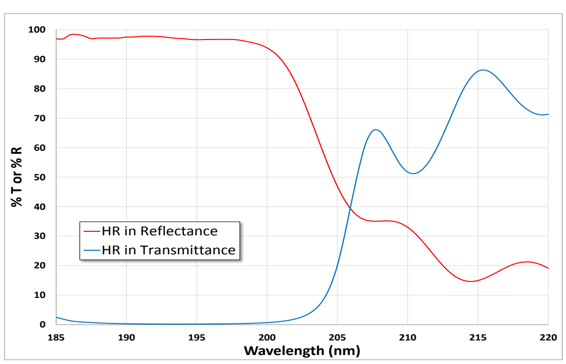

Figure 3. Transmittance and reflectance data of HR coating.

Atomic force microscopy (AFM) analyses of substrate surfaces were obtained before and after coating to measure the increase of surface roughness due to the coating. One 2 µm × 2 µm area was imaged near the center of each sample. Table 2 summarizes the AFM analysis results of the single layer, antireflective (AR), and high reflective (HR) coatings on super polished fused silica substrates. The single layer of GdF_3 coating and the AR coatings increase the surface roughness approximately 0.1 nm or less which is typical of ion beam sputtering of oxide films. Single layer of AlF_3 shows some increase in roughness of about 0.6nm. The combination of GdF_3/AlF_3 gives a significant increase in percentage roughness compared to LaF_3/AlF_3 coatings. Further studies are needed to understand the cause of this increase.

Table 2. Surface roughness, before and after coating

Film material	Coating type	Coating thickness (µm)	Surface roughness (nm RMS)		Roughness increase (nm RMS)
			Before coating	After coating	
GdF_3	Single layer	0.18	0.22	0.22	0.00
AlF_3	Single layer	0.21	0.21	0.77	0.56
LaF_3/AlF_3	AR	0.08	0.22	0.24	0.02
GdF_3/AlF_3	AR	0.09	0.24	0.36	0.12
LaF_3/AlF_3	HR	1.25	0.20	0.36	0.16
GdF_3/AlF_3	HR	1.41	0.29	0.96	0.67

To assess coating durability, the single layers, AR, and HR coating of AlF_3, LaF_3 and GdF_3 were tested for adhesion, analyzed before and after cleaning and subject to thermal cycling. The adhesion of all the single layers, AR, and HR coatings passed a tape test on fused silica, CaF_2 and Si substrates. Cleaning the coated surfaces with methanol soaked cleanroom grade wipes did not cause any observable physical degradation or changes to the optical performance. Single layers were subjected to a temperature ramp from room temperature to 75° C, followed by a dwell at 75° C for 2 hours, and then cooled down to room temperature. The films did not show any observable physical degradation when inspected under high intensity fiber light and no change was measured in the optical performance.

Additional coatings of up to 80 layers and total thickness of 3 µm have been deposited on both CaF_2 and fused silica with no optical or physical performance differences between the coatings on the two substrates.

4. Conclusion

Ion beam sputtered fluorides can be made with the expected low roughness and repeatability inherent to ion beam sputtering. The low temperature of the process allows for the use of standard fused silica substrates with equivalent optical and physical performance to CaF_2 substrates.

4. Acknowledgement

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5. References

[1] Yoshida, Toshiya, et al. "Fluoride antireflection coatings for deep ultraviolet optics deposited by ion-beam sputtering." Applied optics 45.7 (2006): 1375-1379.

[2] Ristau, Detlev, et al. "Ultraviolet Optical and Microstructural Properties of MgF2 and LaF3 Coatings Deposited by Ion-Beam Sputtering and Boat and Electron-Beam Evaporation." Applied optics 41.16 (2002): 3196-3204.

[3] Liao, Bo-Huei, et al. "Process for deposition of AlF3 thin films." Applied optics 47.13 (2008): C41-C45.