

AlF₃ thin films deposited by reactive magnetron sputtering with Al target

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Abstract: Aluminum fluoride thin films have been deposited by magnetron sputtering of an aluminum target with CF₄, and CF₄ mixed O₂ as the working gas onto a room temperature substrate. The quality of the coated AlF₃ film applied with 25W sputtering power using CF₄ mixed 5% O₂ was better than for films deposited using conventional methods. The extinction coefficient of AlF₃ was smaller than 6.0×10^{-4} in the wavelength range of 190nm to 250nm. Single layer antireflection coatings on both sides of a fused silica substrate increased the transmittance from less than 91% for a bare substrate to higher than 96% in the wavelength range between 190nm to 250nm.

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OCIS codes: (310.1860) Deposition and Fabrication, (310.1620) Coatings.

References and links

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1. Introduction

In order to achieve higher resolution in lithography, shorter exposure wavelength UV and DUV light sources are necessary. Fluoride materials have less optical loss in the UV and DUV, therefore, high quality fluoride thin film coating is an important technology for the current optical industry. AlF₃ is one of the important low-index materials used for UV and DUV coatings. The fluoride films are usually deposited by conventional thermal evaporation and sputtering [1-5]. The AlF₃ starting material can be decomposed, causing absorption in the films. Besides, AlF₃ coating material is very expensive. In this research we used a simple process to fabricate AlF₃ thin films by DC magnetron sputtering and used inexpensive but pure (4N) Al metal as the sputtering target. CF₄ gas, and CF₄ mixed with O₂ were introduced as working gases.

2. Experiment

2.1 Film Preparation

AlF₃ thin films were coated on quartz substrates and silicon wafers by magnetron sputtering with various DC powers by using a 4N Al target. The target was 6 inches in diameter set about 8cm below the substrate. Before coating, the substrates were cleaned with a UV photocleaner to remove organic contaminants. The deposition chamber was pumped down to a base pressure of less than 8×10^{-6} torr by a cryopump. Then CF₄ (total flow 110sccm), or CF₄ mixed 5% O₂ (total flow 65sccm) was injected as the working gas to sputter the Al target onto a room temperature substrate.

2.2 Film Characterization

The transmittance of thin films on quartz substrates was measured with a Hitachi U4100 spectrometer. The refractive index and extinction coefficient of AlF₃ thin films coated onto a silicon wafer were measured by a SOPRA GES5 Variable Angle Spectroscopy Ellipsometer and analyzed by the Forouhi-Bloomer model [6]. The surface roughness was measured by atomic force microscopy (AFM).

3. Results and Discussion

3.1 Transmittance

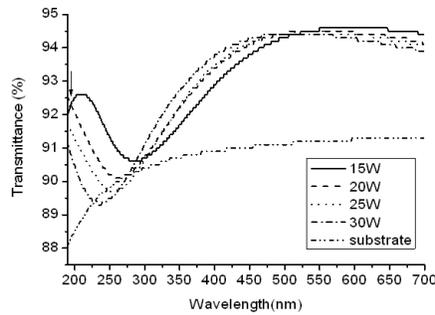


Fig. 1. Transmittance spectra of AlF₃ thin films prepared with 110sccm CF₄ at different sputtering DC powers.

Figure 1 shows the transmittance spectra of films produced by different sputtering DC powers with 110 sccm of CF₄ gas. The transmittance increased as DC power decreased. The higher absorption with higher power might be due to the higher sputtering power decomposing the CF₄ gas such that the carbon atoms contaminated the AlF₃ film. Furthermore, higher sputtering power also sputtered too many aluminum particles and a few of them might not be fully fluorinated. Also, there was a negative inhomogeneous refractive index at low DC power (15W) due to the low mobility of the sputtered atoms [7]. In order to reduce carbon atoms produced by higher sputtering power, O₂ was mixed in with the CF₄ gas. We found that 5% of O₂ was enough to solve the absorption problem. The results are shown in Fig. 2(a) and Fig. 2(b) with 25W and 30W DC power, respectively. The arrows in the figures indicate the difference in transmittance of the films deposited at the two different powers. The transmittance increased obviously when 5% O₂ gas was added in the working gas. This was because O₂ gas reacted with the carbon atoms which decomposed from the CF₄ gas to form

CO₂, so that the optical loss decreased and transmittance increased, as we will discuss in the next section.

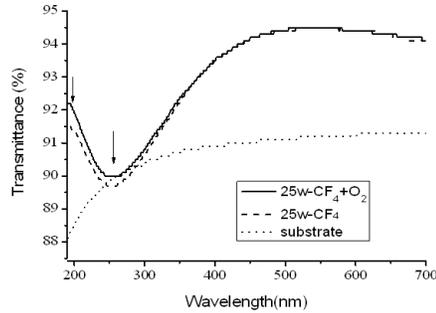


Fig. 2(a). Transmittance spectra of AlF₃ thin films prepared with CF₄ (110sccm) and CF₄ with 5% O₂

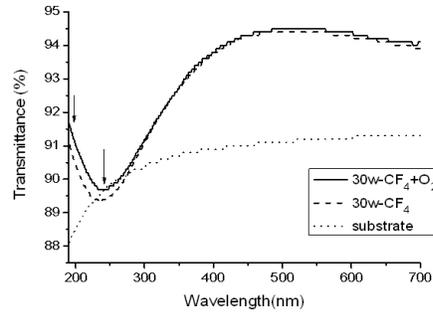


Fig. 2(b). Transmittance spectra of AlF₃ thin films prepared with CF₄ (110sccm) and CF₄ with 5% O₂ (65sccm) at 30W sputtering DC power.

3.2 Extinction coefficient and refractive index

Figure 3 shows the extinction coefficient, k , of AlF₃ coated at different sputtering powers. The increase in k with increasing sputtering power might be due to fewer F ions or excited F* atoms reacting with aluminum particles to form AlF₃. The lower sputtering power sputtered fewer aluminum particles such that the sputtered aluminum particles reacted fully with F ions or excited F* atoms, so that k was lower. In addition, higher sputtering power could decompose CF₄ gas to create carbon atoms to contaminate the AlF₃ thin films and make k increase. In order to decrease k caused by carbon atoms, O₂ gas was introduced and the results are shown in Fig. 4(a) and Fig. 4(b). Obviously, k decreased after O₂ gas was introduced into the chamber and the experimental results are consistent with Fig. 2. The corresponding refractive index, n , is shown in Fig. 5. The refractive index at 193nm was about 1.43 for both 25W and 30W when O₂ was introduced. This value is similar to the result obtained using ion beam sputtering with an AlF₃ target [8]. 25W power is better than 30W power from an absorption loss point of view as we can see from Fig. 2, Fig. 4 and Fig. 5.

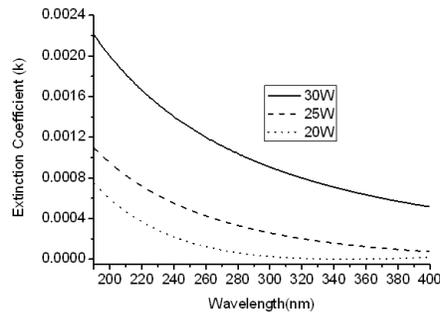


Fig. 3. Extinction coefficient of aluminum fluoride films prepared at different sputtering powers with 110 sccm CF₄ gas.

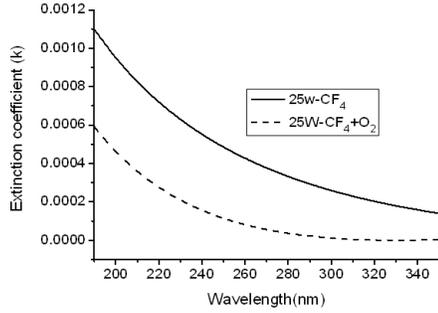


Fig. 4(a). Extinction coefficient of AlF₃ thin films deposited with CF₄ (110 sccm) and CF₄ mixed with 5% O₂ (65 sccm) at 25W sputtering DC power.

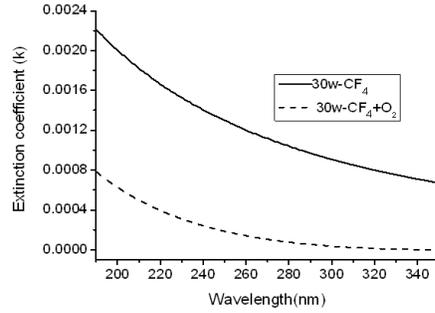


Fig. 4(b). Extinction coefficient of AlF₃ thin films deposited with CF₄ (110 sccm) and CF₄ mixed with 5% O₂ (65 sccm) at 30W sputtering DC power.

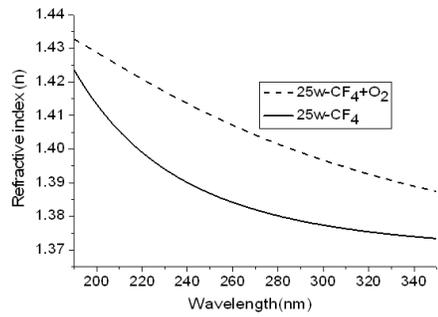


Fig. 5(a). Refractive index of AlF₃ thin films deposited with CF₄ (110 sccm) and CF₄ mixed with 5% O₂ (65 sccm) at 25W sputtering DC power.

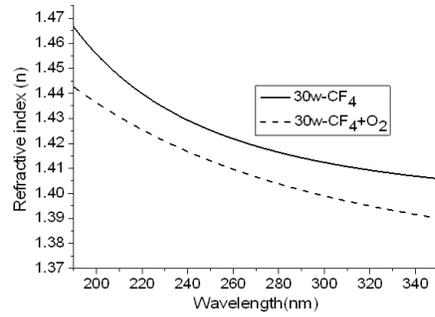


Fig. 5(b). Refractive index of AlF₃ thin films deposited with CF₄ (110 sccm) and CF₄ mixed with 5% O₂ (65 sccm) at 30W sputtering DC power.

C. Surface roughness and scattering loss

Surface roughness will cause scattering loss (S_T) according to Eq. (1), where T , n_f , σ and λ are the transmittance, refractive index, root-mean-square (rms) surface roughness and wavelength, respectively [9].

$$S_T = T(1 - \exp\{- [2\pi(1-n_f)\sigma/\lambda]^2\}) \quad (1)$$

Table1. Surface roughness of AlF₃ thin films with different sputtering powers

Power(W)	20	25	30
RMS surface roughness (nm)	9.22	4.42	1.46

Scattering is thus severe at short wavelengths if σ is not zero. Table 1 shows the surface roughness with different sputtering powers. σ decreased as sputtering power increased. Increasing sputtering power could strike or migrate the atoms or molecules to make the films smoother. Thus at the power of 30W, σ was the smallest. However the k value was too high, causing too much absorption, L_A , about 0.16% according to Eq. (2), where d is the film thickness. Absorption could cause laser damage at 193 nm, therefore the smaller the absorption the better. Thus we chose 25W to make the antireflection coating in the next section, although there was 0.37% scattering loss according to Eq. (1).

$$L_A = 1 - \exp(-4\pi kd/\lambda) \quad (2)$$

4. Application

According to the experimental results described above, 25W depositing power with CF_4 mixed 5% O_2 as the working gas enables us to deposit good AlF_3 thin films. An antireflection coating was then coated on both sides of a fused silica substrate using those parameters. The design was Air/L/ fused silica /L/Air, where L is a quarter wave AlF_3 film at 193nm.

Figure 6 shows the theoretical and experimental transmittance of the antireflection coatings on a fused silica substrate. The experimental transmittance was larger than 96%. That means the antireflection coating increased by more than 5% the transmittance in the wavelength range from 190nm to 250nm. As the scattering loss is about 0.37%, the experimental transmittance is consistent with the theoretical transmittance.

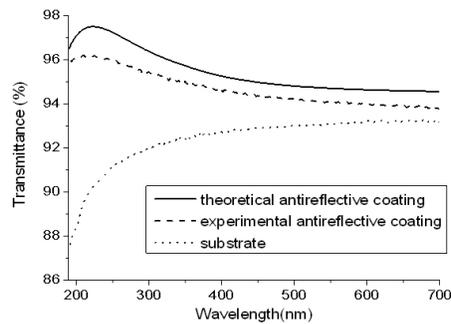


Fig. 6. The theoretical and experimental transmittance of the antireflection coating on fused silica substrate.

5. Conclusion

Aluminum fluoride thin films deposited by magnetron sputtering with an aluminum target by using CF_4 and CF_4 mixed O_2 as the working gas onto a room temperature substrate have been investigated. This new and simple process is better than conventional thermal evaporation and sputtering. By investigating the transmittance, refractive index, extinction coefficient, and surface roughness, we found that AlF_3 thin films deposited at 25W sputtering power with 65 sccm CF_4 mixed with 5% O_2 gas had the best quality. A good single layer antireflective film coated on both sides of a fused silica substrate to make the transmittance larger than 96% and increasing by more than 5% the transmittance in the wavelength range between 190nm to 250nm was demonstrated.

Acknowledgments

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