Optical constants of aluminum films prepared by electron beam evaporation

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The metal aluminum (Al) is widely used because it has high reflectivity from the ultraviolet to the infrared band. But the new deposited Al films is exposed to the atmosphere, it forms transparent Al_2O_3 films on its surface at once. In this letter, the Al films is deposited on the quartz substrate by electron beam evaporation. The effect of Al films oxidation on refractive index and extinction coefficient is investigated by spectroscopic ellipsometry (SE). The optical constants of Al films change with the increase of oxidation time. The two parameters become stable when these films are exposed in air more than 2 days.

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The metal films have been broad applied due to their unique optical properties, such as high reflectivity, wide stop band, and neutral and small polarization effect. Compared with other metal films, the aluminum (Al) films is widely used because it is the only one which has high reflectivity from the ultraviolet to the infrared band in all materials[1,2]. However the new deposited Al films when is exposed to in air will form transparent Al_2O_3 films on its surface at once. The transparent Al_2O_3 films could effect reflectivity. The optical constants of Al bulk has been extensively studied, and optical constants of Al films in the ultraviolet band also have been studied[3,4]. However the optical constants of Al films and thickness with oxidation time are few studied.

In this letter, the optical constants and thickness of Al films deposited on ZS-1 glass substrates by electron beam evaporation are studied. The spectroscopic ellipsometry (SE) is an outstanding way to analyze optical constant and thickness of films, due to its nondestructive character and high sensitivity. So we choose SE to measeure samples.

Al films were deposited by electron beam evaporation with a plane target made of high purity (99.99 at.-%) Al. The pressure was $\leqslant 1.6\times10^{-3}$ in the chamber. The voltage and current of electron gun were 400 V and 150 mA, respectively. Al films were deposited with 3–9 A/S. The ZS-1 glass with polished one side was chose as the materials of substrates and its size was 40 mm in diameter and 6 mm in thickness. After being coated, Al films were placed in the thousand-grade purification room and were measured at different oxidation times.

In order to study the effects of optical constants of Al films and thickness with oxidation time, Al films were placed in a quartz culture dish air for 1–30 days. For example, the time of 1 day means that the sample was placed in air for 0 h. After 24 h, the sample was measured for 2 days. 3 days mean that the sample was placed in air for 48 h, and so on. SE is in general more accurate in determining optical constant because of the sensitivity of the phase difference for small variations in the optical thickness. In order to study oxidation time effect on optical properties of Al films, we have recorded the ellipsometry spectra of these samples at different oxidation times. SE measurements were made with a two-channel spectroscopic polarization modulation ellipsometer in the spectral range from 300 to 2 000 nm with an interval of 10 nm at angle of incidence 55° and 65° by Woollam SE. In ellipsometric experiments it is common to use the so-called p- and s-polarized directions as the two orthogonal basis vectors used to express beam polarization states. The p-polarized direction is defined as lying in the plane of incidence. The plane of incidence contains the incident and reflected beams and the vector normal to the sample surface. The s-polarized direction lies perpendicular to the p-polarized direction.

Ellipsometer measures the change in polarization state of light reflected from the surface of a sample. The measured values are expressed as Psi (ψ) and Delta (Δ).

These values are related to the ratio of Fresnel reflection coefficients $\widetilde{R}_p$ and $\widetilde{R}_s$ for p-polarized and s-polarized light, respectively[5]

$$\rho = \frac{R_p}{R_s} = \tan(\psi)e^{\mathrm{i}\Delta}, \tag{1}$$

where $\tan(\psi)$ represpents the ratio of amplitude for p- and s-polarized light, and $\Delta=\delta_p-\delta_s$, it represpents variation with phase of reflection for p–and s–polarized light.

The Lorentz oscillator model for optical constant dispersion is very useful for metal films and metal substrates. The Lorentz oscillator formula is as[5]

$$\widetilde{\varepsilon}(E) = \varepsilon_1(\infty) + \sum_i^N \frac{A_i}{E_k^2 - E^2 - i\Gamma_i E}, \tag{2}$$

where $\widetilde{\varepsilon}$ is the dimensionless complex dielectric function as a function of photon energy, $\varepsilon_1(\infty)$ describes the value of the real part of the dielectric function at very large photon energies, and N is the total number of oscillator. In order to fix the total number of oscillator in the Lorentz oscillator model, we demonstrate the impact of numbers of oscillator on the fitting mean-squared error (MSE), and the resulted curves are shown in Fig. 1. It can be seen that MSE descended with the increase of numbers of oscillator. When the selected numbers of oscillator was 7, the values of MSE was smallest, so 7 oscillators were all chosen in the calculation of optical constants of Al films in our experiments. Figure 2 is the experimental data and fitting results using Lorentz oscillator model. It can be seen that the theoretical fitting results match well with the measured data through Lorentz oscillator model with 7 oscillators.

The calculated results on refractive index and extinction coefficient from Psi(ψ) and Delta (Δ) are shown in Fig. 3. It can be seen that the refractive index and extinction coefficient of Al films changes with the increase of oxidation time. The refractive index and extinction coefficient increased abruptly with oxidation time, especially the first 24 h. But the changes are not obvious when oxidation time more 2 days. In order to research the specific variation of refractive index of Al films, we chose the wavelengths of 500 and 1 000 nm for the studied objects. The refractive index and extinction coefficient

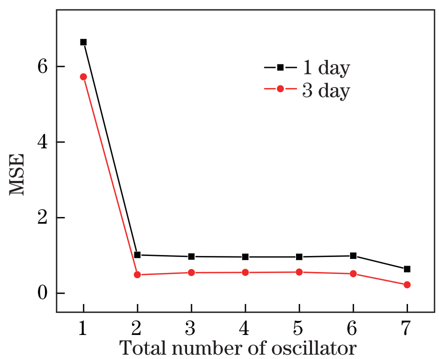

Fig. 1. (Color online) Relation curves of MSE with different numbers of oscillator.

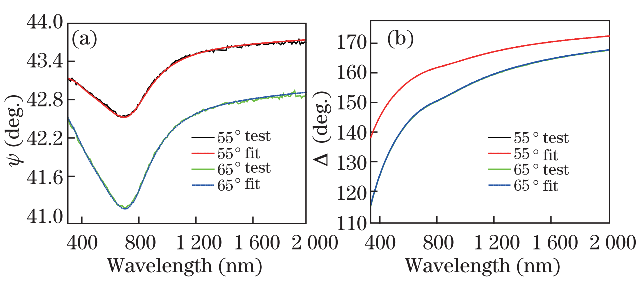

Fig. 2. (Color online) Experimental data and fitting results using Lorentz oscillator model: (a) Psi; (b) Delta.

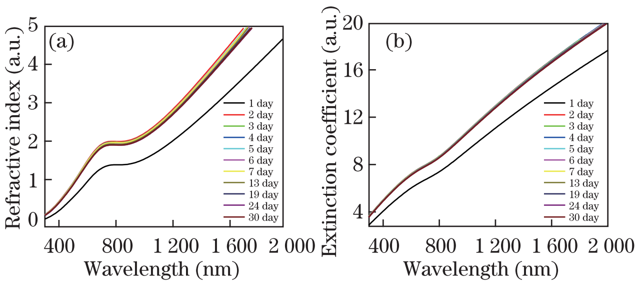

Fig. 3. (Color online) Variation of (a) refractive index and (b) extinction coefficient of Al films exposed in air for different days.

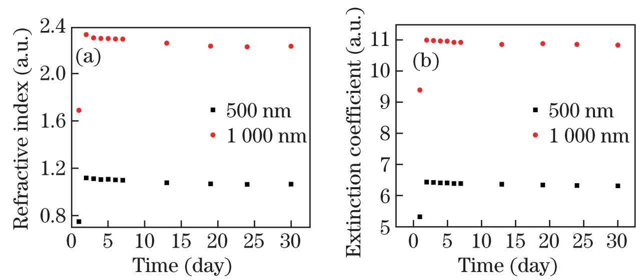

Fig. 4. (Color online) Variation of (a) refractive index and (b) extinction coefficient of Al films exposed in air at 500 and 1 000 nm.

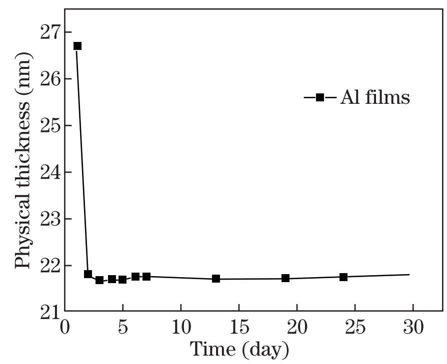

Fig. 5. Variation of physical thickness of Al layer exposed in air for different days.

of Al films exposed in air at 500 and 1 000 nm are shown in Fig. 4. It can be seen that the refractive index and extinction coefficient of Al films both change with the increase of oxidation time at the wavelength of 500 and 1 000 nm. When the Al film was exposed in air for 2 days, the values of optical constants increased more than 30% and 17%, respectivly. And then the values of optical constants decreased slowly with oxidation time increased. When the Al film was exposed in air more than 7 days, the values of refractive index and extinction coefficient tend to be constant. We guess it is probably due to the water vapour on the surface of sample.

The impacts of oxidation time in the air on physical thickness of Al layer on ZS-1 substrates are also demonstrated. Variation of physical thickness of Al films exposed in air for different days is shown in Fig. 5. It can be seen that the physical thickness of Al layer decreased sharply, and the corresponding variation rate is about 18%. When the oxidation time reached more than 2 days, the values of physical thicknesses of Al layer tend to be constant.

In conclusion, Al films on the quartz substrate are prepared by electron beam evaporation, and oxidation time effect in air on optical constants are investigated. SE is used to measure optical constants of Al films. The refractive index and extinction coefficient increase with oxidation time. When the samples are palced in air more than 7 days, the refractive index and extinction coefficient tend to be constant. And as the oxidation time increases, the thickness of Al layer reduces sharply. It is similar to the optical constants, the thickness of Al layer is tent to be constant when the samples are placed in air more than 2 days. The obtained results indicate that the change of optical constants appears mainly during the first day when the films are taken out from the vacuum chamber. The two parameters become stable when these films are exposed in air more than 2 days. As the same time, the Al_2O_3 layer is formed on the surface of Al films during the first 24 h. And after one day, the thickness of Al layer becomes stable.

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