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Optical properties of Ag–Al_2O_3 nano-array composite structure

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Abstract

Ag/Al_2O_3 nano-array composite structures were obtained by alternating current (AC) electrodeposition of Ag into the pores of anodic alumina membrane (AAM). The ordered wire-grid structure of Ag nanowires formed along a preferential direction, typically 20 nm in diameter, was fabricated. XRD revealed that Ag_2O is also preserved in the pores of AAM. Optical properties of Ag/Al_2O_3 prepared at different annealing temperatures were measured by using spectrometer. Transmission spectra indicate that the transmittance of Ag/Al_2O_3 increases obviously with the increasing of annealing temperature. Polarization spectra indicate that Ag/Al_2O_3 has good polarization in the range of 900–2000 nm, and the extinction ratio increases with the increasing of the annealing temperature or incident angle.

Keywords: Film optics; Ag/Al_2O_3; AAM; Optical property; Micro-structure; Annealing time

1. Introduction

Recently, metal nanowires, especially Ag nanowires, have attracted an increasing interest for their potential application in microelectronics, optical and magnetic devices, and sensors [1–8]. Sun et al. [9] obtained the large-scale synthesis of uniform nanowires of bicrystalline silver whose lateral dimensions could be controlled via the reduction of $AgNO_3$ with ethylene glycol. Takano et al. [10] calculated the optical loss of Ag/Al_2O_3 and their results indicate that Ag/Al_2O_3 has good polarization in $0.7-1.0\,\mu m$. Pang et al. [11] measured the optical properties of the Ag nanowire array mocropolarizer within anodic alumina membrane (AAM), but it is difficult to measure optical properties of the samples because they are very thin and small. Zhang et al. [12] reported the numerical calculation of ordered silver nanowire arrays embedded in AAM which can provide the optimal parameters for the design of nanowire grid polarizers. In a word, the above reports mainly studied on the preparation and calculating optical properties of Ag nanowires.

In this work, Ag/Al_2O_3 nano-array composite structures were prepared by alternating current (AC) electrodeposition of Ag within the nanochannels of AAM. Their structure and morphology are measured by using X-ray diffractometer (BDX3200) and field-emission scanning electron microscope (JSM-6700). Transmission spectra in infrared wavelength and polarization spectra in near-IR wavelength are systematically investigated by using UV-3101 and IR-460 spectrometer.

2. Sample preparation and measurement

In this paper, optical properties of Ag/Al_2O_3 prepared at different annealing temperatures are systematically

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investigated. Firstly, high-purity (99.999%) aluminum foils were degreased in CH_3COCH_3 and C_2H_5OH solution for 10 minutes and then dried naturally and prepared for annealing. The annealing of the aluminum foils was carried out using EB500 film coating machine. In order to study the effect of the annealing temperature on the optical properties of Ag/Al_2O_3, four samples were prepared at not annealing, 350, 450 and 550 °C which were marked by A, B, C and D, respectively.

After annealing, the foils were electropolished in the solution of C_2H_5OH mixed with $HClO_4$ (4:1 in volume) for 10 min in order to obtain a high quality of flat surface. Then, anodization was performed at a constant voltage of 15 V in 15% H_2SO_4 solution for 5 h. And then, Ag was deposited into the pores of AAM by means of AC electrodeposition by using $AgNO_3$ electrolyte with power frequency of 200 Hz and voltage of 10 V at room temperature for 2 h.

After the electroplating process, the entrance of the pores was sealed in boiling water for 20 min, so that the Ag columns in the pores may not be eroded in the following etching process. Then the Ag/Al_2O_3 film was stripped from the aluminum substrate in a mixed solution of Br and methanol. Finally, the samples were eluted by ion water thoroughly for the two-fold purposes: (1) to clean electrolyte adsorbing both in the surface and in the inner part of the film, (2) to strengthen chemical stability of the film.

In order to measure the polarization spectra, the sample was fixed between two right-angled glass prisms with bromonaphthalene ($n = 1.65$) acting as glue and its structure is shown in Fig. 1. Two cross-sections and two inclined planes of the prism were polished excellently. In order to reduce optical loss in the interface between the prism and the sample as much as possible, the prism was made of LaK2 glass ($n = n_G = 1.67$), whose refractive index is close to that of anodic alumina ($n_1 = 1.6$) [13].

Dual-path equidirectional polarization method was adopted in the process of measuring the polarization spectra of the sample in order to erase influences of polarization effect on test results [14]. As shown in Fig. 2, Glan–Taylor polarizers were added in dual-path of the spectrometer with identical polarized direction. When the sample was rotated 90° around the incident light, the transmission curves of P and S polarization were obtained, respectively. Thus the extinction ratio of the anodic alumina with metal can be obtained by

$$\xi = 10 \times \log \frac{T_s}{T_p}, \quad (1)$$

where T_s and T_p denote transmittance of S and P polarization, respectively.

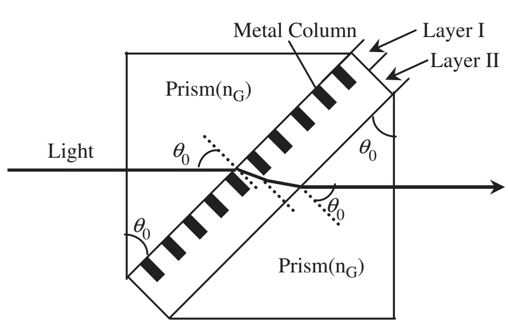

Fig. 1. The structure of the test sample.

3. Results and discussion

Fig. 3 shows the XRD spectrum of Ag/Al_2O_3. The peaks appearing in $2\theta = 38.35°$ and $2\theta = 64.63°$ correspond to face-centered cubic (fcc) Ag (1 1 1) and Ag (2 2 0) texture, respectively, and Ag (1 1 1) peak is relatively intensive. The phenomenon indicates that fcc structure of Ag is preserved in these wires and Ag nanowires are formed along a preferential direction. An obvious diffraction peak in $2\theta = 36.13°$ corresponds to hexagonal-close-packed (hcp) Ag_2O (0 0 2), indicating that the Ag_2O is also preserved in the pores of AAM. This is one of the reasons that the external appearance

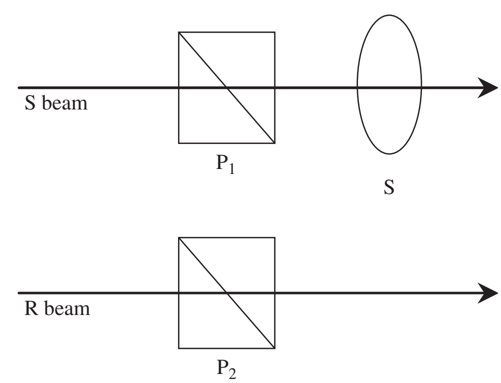

Fig. 2. The testing beam path. P_1, P_2: Glan–Tylor prism; S: the testing sample.

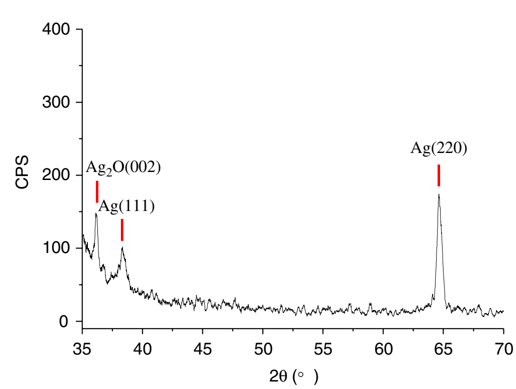

Fig. 3. XRD patterns of Ag/Al_2O_3.