Transmittance optical characteristics of columnar nanoscale niobia arrays formed via anodizing of Al/Nb layers on glass

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Abstract: Anisotropic columnar nanoscale niobia arrays formed via anodizing Al/Nb bilayers on glass showed the sensitivity of transmittance characteristics to the light polarization, which can serve as a basis for applications in photonics and integrated optics.

Keywords: Niobium-oxide, column-like array, planar Al/Nb film, anodizing, nanoscale

1. Introduction

Anodic oxides of valve metals are amorphous materials[1,2], which are known to be characterized by isotropy. But the presence of mesoporous structure of porous anodic alumina (PAA) causes its anisotropy, including optical[3]. Morphological parameters of porous and tubular valve metal anode oxides can be varied in a wide range directly in the process of formation, which allows creating optically active materials[4]. The optical properties of nanostructures based on columns of anodic niobia and tantala free-standing and encapsulated in PAA have been previously reported[5,6]. Due to the periodically changing refractive index, such structures exhibit the properties of 2D photonic crystals, showing pronounced maxima on the optical reflection curves.

In the proposed work, the authors investigated optical transmission properties of the unpolarized and linear (s- and p-) polarized light of columnar nanoscale niobia arrays (CNNA) formed via anodizing of Al/Nb layers on glass substrate.

2. Experimental

CNNA for optical research was formed from bilayer system Al/Nb (1000/50 nm) by magnetron sputter-deposited on polished glass substrate. Species with Al/Nb were anodized in specially designed cylindrical two electrode cell first in 0.2 mol·dm^{-3} oxalic acid aqueous solution at 53 V and then were re-anodized in the mixed solution of 0.5 mol·dm^{-3} boric acid and 0.05 mol·dm^{-3} sodium tetraborate in potentiodynamic mode at increase of potential until 200 V. Re-anodizing current was maintained in 300 µA per 1 cm^2 region. A Keysight N5751A programmable power supply controlled by LabVIEW software via PC and a general-purpose interface bus cable was used as the anodizing unit. CNNA was obtained by a complete removal of PAA in the hot mixture of phosphoric and chromic acids with maintaining a temperature of 50 °C.

CNNA morphology was investigated by scanning electron microscopy (SEM) in a Hitachi S-4800 operated at 10–15 kV. A gold layer, about 4 nm in thickness, was evaporated over the specimens to reduce the charging effects.

Optical characteristics were measured on Spectrophotometer MC–121 (UV–VIS–NIR) with single-beam optical design and dual monochromator and P1 polarizer based on the Glan–Taylor prism by SOL instruments Ltd. The spectral slit width of the monochromator was fixed and amounted to 2 nm. The spectral scanning step was 2 nm in the range from 250 to 800 nm at an incident angle of 0, 10, 30 and 60° when examining the transmission of CNNA of unpolarized and linear (s- and p-) polarized light, and at an incident angle of 10° when examining the transmission of unpolarized light with a glass substrate.

3. Results and Discussion

Fig. 1a shows the cross-section SEM-image of CNNA. The figure shows that all anodic niobium-oxide nanocolumns are free-standing and no PAA residues are observed, which may indicate correctly selected etching regimes. As it can be seen, the NbO_2 sublayer thickness is 121 nm, CNNA height is 327 nm, and the column diameter is 75.4 nm.

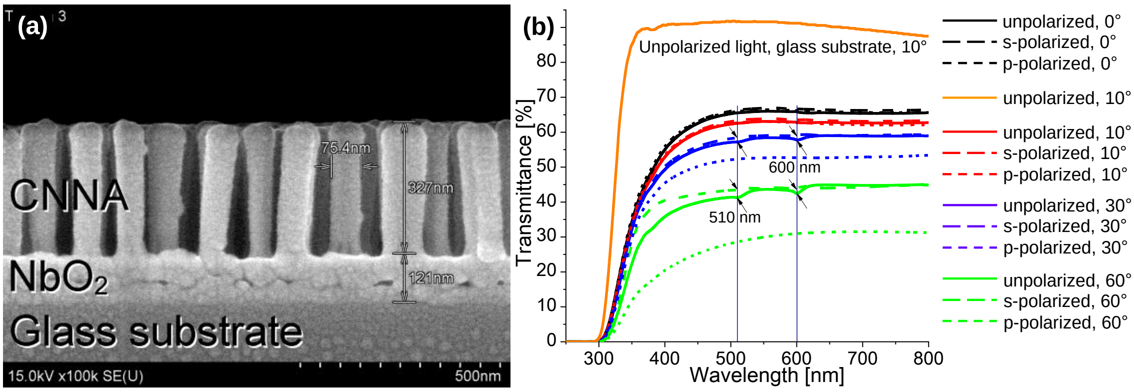

Figure 1 Columnar nanoscale niobia array SEM-image (a) and transmittance optical characteristics (b) of glass substrate (incident angle 10°) and columnar nanoscale niobia arrays (incident angles 0, 10. 30 and 60°) formed via anodizing Al/Nb layers on glass.

Fig. 1b shows the transmittance characteristics of CNNA and glass substrate. The polarization of light is naturally irrelevant to CNNA transmittance at an incidence angle of 0° and the differences for different cases of polarization are minimal at an incidence angle of 10°. By increasing the incidence angle to 30 and then to 60° the transmission curves of unpolarized light and s-polarized light have a similar character and show minima at 510 and 600 nm, but the transmission of p-polarized light decreases. This character of the dependences is explained by the polarization sensitivity due to CNNA anisotropy.

4. Conclusions

This paper demonstrates the sensitivity of an anisotropic columnar nanoscale niobia arrays formed via anodizing of a Al/Nb bilayers on glass substrate to the nature of light polarization. This will form the base for the development of photonics and integrated optics devices.

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