Reflective optical characteristics of planar film with the nanoscale inner structure formed via anodizing of Al/Nb layers on glass

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Abstract: Planar film with nanoscale inner structure via anodizing Al/Nb layers on glass showed several distinct maxima on the reflection curve in the regions of 320, 380, and 850 nm corresponding to forbidden photonic bands.

Keywords: Niobium-oxide, porous anodic alumina, planar film, anodizing

1. Introduction

Aluminum- and niobium-oxides are promising materials for nanooptics and nanophotonics[1, 2]. One side band-gap energy of niobium-oxide is of 3.4 eV[3], a value close to that of TiO_2 (about 3.2 eV[4]) and is, therefore, suitable for use as a photocatalyst under UV light[5]. It can be noted that niobium-oxides are highly promising for the use in nanophotonic as photonic crystals. On the other hand, porous anodic alumina (PAA) whose optical properties have been studied repeatedly can be an excellent addition to niobium oxide in order to improve quality and optimize its morphological and optical properties.

In this work, composite planar films (PF) with the nanoscale inner structure were formed and their reflective optical characteristics UV–VIS–NIR ranges were investigated.

2. Experimental

PF for optical research was formed from bilayer system Al/Nb (1000/50 nm) by magnetron sputter-deposited on rectangular 6×9 cm^2 polished glass substrate thickness 1070 µm. Substrates with Al/Nb were cut into pieces with 6 cm^2 area and anodized in specially designed cylindrical two electrode cell made of polytetrafluoroethylene for taking account of the design features of spectrophotometric analysis and exception meniscus effect in the anodizing process. System Al/Nb was first anodized in 0.2 $mol \cdot dm^{-3}$ oxalic acid aqueous solution at 53 V and then was re-anodized in the mixed solution of 0.5 $mol \cdot dm^{-3}$ boric acid and 0.05 $mol \cdot dm^{-3}$ 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.

For planarization of the films, part of the PAA was removed. The chemical etching time was determined by the diameter of the oxide cell and was independent of the total thickness of the PAA. To slightly release the column tops from the PAA matrix with oxide cell size 119 nm, the alumina film may be etch-cleaned in the hot mixture of phosphoric and chromic acids for 476 s with maintaining a temperature of 50 °C.

PF 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) by SOL instruments Ltd. with single-beam optical design and dual monochromator. 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 190 to 1100 nm at an incident angle of 10°. Incidence scheme of an optical beam on the PF surface is shown in Fig. 1b. The measurements were carried out only in the reflection mode.

3. Results and Discussion

Fig. 1a shows the surface SEM-images of PF, a schematic 3D-view of PF displayed in Fig. 1b. The figure shows that all the tops of the anodic niobium-oxide nanowires uniformly protrude above the PAA surface. No PAA oxide residues are observed, which may indicate correctly selected planarizing etching regimes.

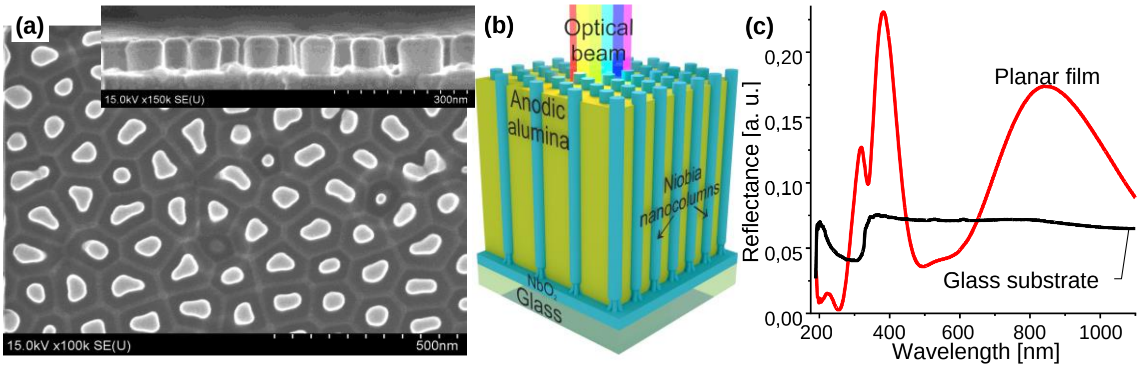

Figure 1 Surface SEM-images (a), schematic 3D-view (b) and reflective optical characteristics (c) of planar film with the nanoscale inner structure via anodizing Al/Nb layers on glass.

As it can be seen from Fig. 1b, the PF are two-layers of different thickness with a periodically varying refractive index. The first layer thickness 240 nm is a PAA with niobium-oxide nanowires located in the pores of 60 nm in diameter at a distance of 119 nm. The second layer is the protruding vertices of niobium oxide nanowires with a height of 90 nm.

Fig. 1c shows the reflective characteristics of PF and glass. The presence of such a two-layer structure led to the existence of several distinct maxima on the reflection curve in the regions of 320, 380, and 850 nm corresponding to forbidden photonic bands.

4. Conclusions

In the work, planar film with the nanoscale inner structure is formed by the method of via electrochemical anodizing Al/Nb layers on glass and chemical etching. The results of the research of the reflective characteristics of such films showed the presence of several distinct maxima on the reflection curve in the regions of 320, 380, and 850 nm corresponding to forbidden photonic bands. The presented research will expand the understanding of the reflective optical characteristics of nanostructured anodic aluminum- and niobium-oxide films, as well as planarized composite nanostructures and will allow to form a reserve for the development of photonic crystals and photovoltaic elements based on them.

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References

[1] M. R. Ok, R. Ghosh, M. K. Brennaman, R. Lopez, T. J. Meyer and E. T. Samulski, “Surface patterning of mesoporous niobium oxide films for solar energy conversion”, ACS Appl. Mater. Interfaces, **5** (8), pp. 3469–3474 (2013), doi: 10.1021/am400598u.

[2] M. Ashurov, V. Gorelik, K. Napolskii and S. Klimonsky, “Anodic alumina photonic crystals as refractive index sensors for controlling the composition of liquid mixtures”, Photonic Sensors, **10** (2), pp. 147–154 (2020), doi: 10.1007/s13320-019-0569-2.

[3] Y. Zhao, X. Zhou, L. Ye and S. Chi Edman Tsang, “Nanostructured Nb_2O_5 catalysts”, Nano Rev., **3** (1), p. 17631, (2012), doi: 10.3402/nano.v3i0.17631.

[4] H. Li, G. Li, J. Zhu and Y. Wan, “Preparation of an active SO_4^{2-}/TiO_2 photocatalyst for phenol degradation under supercritical conditions”, J. Mol. Catal. A: Chem., **226** (1), pp. 93–100 (2005), doi: 10.1016/j.molcata.2004.09.028.

[5] L. A. Morais, C. Adán, A. S. Araujo, A. P. M. A. Guedes, J. Marugán, “Synthesis, characterization, and photonic efficiency of novel photocatalytic niobium oxide materials“, Glob. Challenges, **1** (9), 1700066 (2017), doi: 10.1002/gch2.201700066.