ALUMINUM NANOSTRUCTURED COATINGS AS ALIGNMENT LAYERS FOR LIQUID CRYSTAL MIXTURES

Prof. Dr. Alexander G. SMIRNOV[1], Dr. Andrey A. STSIAPANAU[1], Prof. Dr. Victor V. Belyaev[2], Dr. Denis N. Chausov[2]
Belarusian State University of Informatics and Radioelectronics, Minsk, Belarus[1]
Moscow Region State University, Moscow, Russia[2]

smirnov@bsuir.by

Abstract: *Aluminum nanostructured coatings are the promising alternatives to transparent semiconductors or metals. In this paper we describe the fabrication of these coatings by electrochemical anodization of aluminum deposited by magnetron sputtering on a glass substrate. The process of anodization is strictly controlled by process parameters followed by selective chemical etching of aluminum oxide. Optical transmittance and surface resistance depend on the mesh dimensions of Al nanostructured coatings and have been investigated theoretically and experimentally.*

Keywords: INDUSTRY 4.0, NANOSTRUCTURED COATINGS, ALIGNMENT, LIQUID CRYSTALS

1. Introduction

Main requirements for transparent conductive electrodes (TCEs) are good transparency in a limited and well-defined range as well as suitable conductivity. E.g., the wavelength interval constitutes 300nm-2500 nm for photovoltaic and 400-700 nm for displays. Nowadays the best material to reach this goal is indium tin oxide (ITO). It is commonly used in many kinds of displays, light-emission diodes, solar cells and other devices. The average transmission for ITO is approximately 80-90% depending on thickness variation. For smaller thickness, ITO has better transmission and resistance and vice versa. The range of ITO sheet resistance is 10-100 Ω/□ [1]. Assuming ITO is “ideal”, novel TCEs should have the same properties or even better.

The metal-based thin transparent films are attractive due to their plasmonic properties and better flexibility. Planar metal films have poor optical performances, however a special nanostructuring can increase the transmission. The cross-linked Cu layer with average 61 and 75% transmittance and sheet resistance 10 and 15 Ω/□ for 120 and 200 nm grating line width were demonstrated correspondently [2]. Another nanostructuring shape is a nanoholey structure. The main feature of these structures is the independence on the light polarization at defined holes arrangement. In [3–5] data on transmission, reflection and absorption *vs* different hole size, inter hole distance and thickness are shown. Besides, development of other types of conductive films on the base of organic materials is an important task for flexible displays. In this paper, two simple methods of transparent conductive metal electrodes fabrication were proposed and realized. There optimal optical and electrical parameters were found and systematized. In addition, some organosilicon materials have been studied from the point of view of their application as transparent electrodes.

2. Experimental results

Anodized aluminum transparent conductive films: A glass substrate with 200 nm aluminum (Al) is used for the first method of the TCEs fabrication [6]. The full process is illustrated on Fig. 1, where, for simplicity, the holey alumina (Al_2O_3) is not included. When the electrochemical anodization of Al starts the holes grow with sphere shape. At time t_0 (step ***a***) the holes (sphere) contact with the substrate and an aluminum electrode is forming. At this position the transparency is small and a further anodization is required (step ***b***). At time $t_1>t_0$ the transmission increases and at time $t_2>t_1$ has the biggest values. The conductance has opposite behaviour and has the smallest value at time t_2. Thus trade-off between transparency and conductivity is necessary.

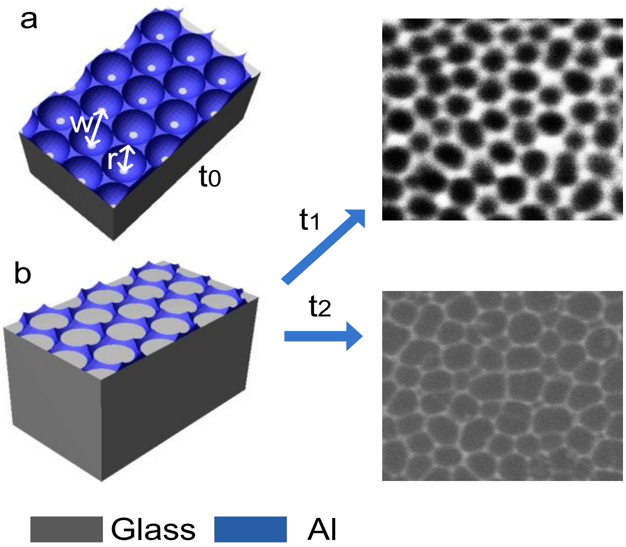

Fig.1. *First method of TCEs fabrication*
a) The beginning of Al TCE formation (time t_0*); b) The end of Al TCE formation (time* t_1 *or* t_2*);*

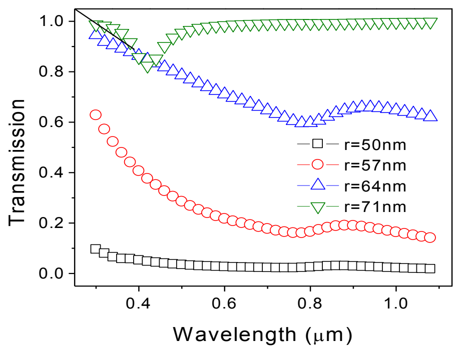

Fig.2. *Simulated optical properties for Al TCE with r=50, 57, 64, 71 nm and w=100 nm.*

In order to find the optimal parameters the FDTD Lumerical [7] and COMSOL Multiphysics [8] packages are used for optical and electrical properties simulation accordingly. The 10-20 Ω/□ sheet resistance for hole (sphere) radios *r*=60-70 nm and inter hole distance *w*=100 nm was obtained.

The simulated optical properties for hole (sphere) radii with r=50, 57, 64, 71 nm and inter hole distance w=100 nm is shown in Fig. 2. The r=50 nm and r=57 nm correspond to time t_0 and t_1 accordingly. The r=57 nm is an intermediate time value and r=71 nm (≈r0·√2) is value when conductance equals 0 Ω/□. In this case the trade-off between transparency and conductivity must satisfy condition 1.2-1.4r to obtain the average transmission 70-80% for range 300-1000 nm and 10-20 Ω/□ sheet resistance.

The second proposed TCE formation method includes three steps as illustrated on Fig. 3. The step ***a*** is aluminum deposition followed by anodization and holes widening in the solution containing phosphoric acid. Then the metal (gold Au in our case) is deposited by e-beam evaporation (step ***b***). The final step ***c*** is the transfer of obtained TCE to adhesive substrate.

Optical properties for Au TCE at different hole size r=100, 150, 200 nm, inter hole distances w=2r+25, 50, 75 nm and thickness d=25, 50 nm are simulated using commercial software FDTD Lumerical [7]. The larger holes size provides better average transmission, when larger inter hole distance and thickness have opposite dependence. The Au electrode only absorbs a part of light for the range of 300-600 nm due to localized plasmonic resonance. At λ>700 nm the reflection increases.

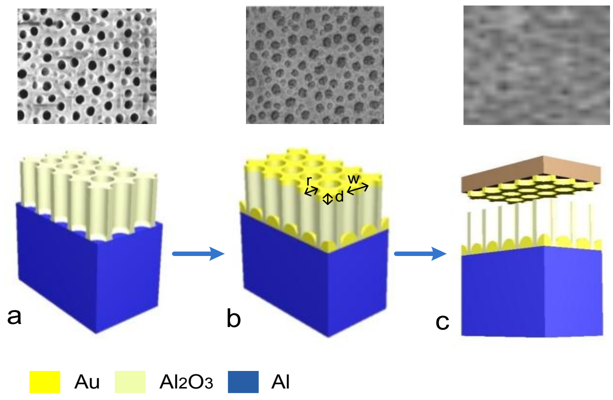

Fig.3. *Second method of TCEs fabrication*
a) aluminum deposition, anodizing and holes widening;
b) metal deposition;
c) metal TCE transferring.

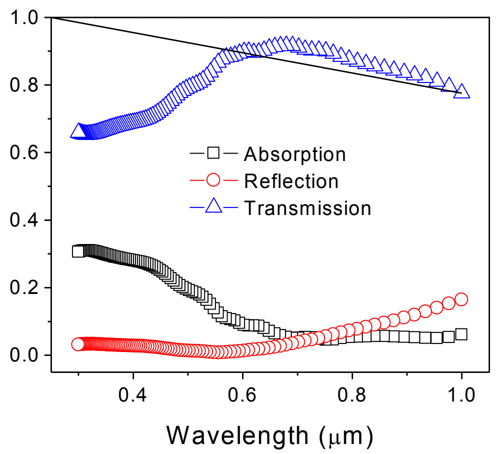

Fig.4. *Simulated optical properties for Au TCE with r=100, w=25 and d=25nm.*

The structure with r=100 nm, w=25 nm and d=25 nm has better average transmission for the range 300-1000 nm (Fig. 4) and equals to 82.5%. The 10-20 Ω/□ values were obtained for 25-50 nm TCEs thickness by four probe method.

Organosilicon transparent conductive films: Methods of synthesis of organosilicon substances (OS) and formation of dielectric films for liquid crystal alignment are described in [9,10].

Organosilicon substances with polar groups at the silicon atom have been synthesized to make transparent films with increased electroconductivity. There the OS comprising cyanoethyl and phenyl (2-hexoxy) substituents at the Si atom as well as functional ethoxy groups that interact with active substrate's centers and form a chemically bonded film.

To increase the film conductivity a toluene OS solution was mixed with a micellar solution of silver nanoparticles (produced by Nanomet Co., Moscow, Russia [11]). The solution is a triple system of reverse micelles: water solution of an Ag salt/a surface active substance/nonpolar solvent. The nanoparticle formation takes place in the water nucleus of the micelle formed by molecules of an anionic surface active substance (acid). The silver nanoparticles are as big as 5-20 nm.

The transparent film thickness is 100-150 nm. The films formed from the OS toluene solution are transparent and colorless. The films formed from the OS and Silvernano-1 solution have ~20% lower transparency, they are yellowish. Round nuclei are to watch in a microscope photo (Fig.5). However in this experiment the film resistance was too big for practical application in displays. Improvement of the film structure is in progress.

Fig.5. *A microphotograph of a transparent conductive film formed from the OS and Silvernano-1 solution.*

4. Conclusion

Two methods of transparent conductive metal electrodes fabrication by electrochemical anodization technology are presented. The obtained transmission in the range of 300-1000 nm and its sheet resistance are the same as at ITO reference electrodes. These electrodes can be applied in the various optoelectronic devices. The coatings made of organosilicon materials and silver nanoparticle solution should be improved for their application as transparent electrodes.

Acknowledgements

The work is partly supported by Belarusian Republican Foundation for Basic Researches (grant No T16P-200) and by Russian Foundation for Basic Researches, grant No 12-07-90006_Bel_a, 14-07-00574_a.

References

[1] A.L. Dawar and J.C. Joshi, J. Mater. Sci. Lett. **19,** 1-23 (1984)
[2] M.G. Kang and L.J. Guo, J. Vac. Sci. Technol. B, **25**, 2637-2641 (2007).
[3] W.A Murray and W.L. Barnes, Adv. Mater., **19**, 3771-3782 (2007).
[4] X. Shou, A. Agrawal and A. Nahata, Opt. Express, **13**, 9834-9840 (2005).
[5] Q. Wang, J. Li, C. Huang, C. Zhang and Y. Zhu. Appl. Phys. Lett., **87**, 091105-091107 (2005).
[6] A. Smirnov, A. Stsiapanau, A. Mohammed, E. Mukha, H.S. Kwok, A. Murauski, Proc. SID Symposium "Display Week-2011", Los-Angeles, 1385-1387 (2011).
[7] Trial Versions of FDTD Solutions http://www.lumerical.com
[8] COMSOL Multiphysics http://www.comsol.com
[9] V.V. Belyaev, and V.G. Mazaeva, *SID'11 Digest*, pp.1412-1415 (2011).
[10] M.V. Sobolevsky, et al., Mol. Crys. Liq. Crys., **329,** 293-304 (1999).
[11] http://www.nanomet.ru/chemical-elements/silver-nanoparticles/