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Short Communication

Thickness Calculation of Thin Transparent Conductive Membrane on the Border with a Magnetic Fluid

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The determination method of the membrane thickness of ITO ($InSnO_2$). The magnetite nanoparticles in the electric field migrate, forming the thin layer near conductive ITO membrane with varying thickness. Lighting this structure by monochromatic plane polarized light the interference of light in the thin membrane was observed. The experimental values of the intensity of the reflected light from the surface of «ITO – layer of magnetite particles" for samples with different thickness of the conductive coating.

Keywords: Thin membrane, Interference, Electric field, Magnetic fluid.

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1. INTRODUCTION

In [1] the membrane thickness of magnetite nanoparticles on the surface of the transparent conductive electrode in the electric field was calculated.

The purpose of this study – the calculation of the thickness of the conductive ITO coating and investigate the dynamics of the formation of the near-electrode layer (two-layer thin membrane) optical methods, including a description of a new phenomenon – the electrically interference from thin transparent two-layer membrane, one layer of which – conductive coating (ITO), and the second layer – magnetite particles. Practically, this phenomenon may be applied to determine the thickness ITO- membranes used as a transparent electric-coating layers for displays, solar cells, etc. if it is impossible to measure the thickness of traditional (such as inaccessibility), the measurement of the thickness of electrochromic glass coatings for aircraft windows, the design of multi-use sensors [2, 3], that determines the relevance of this work

2. THE EXPERIMENTAL DEVICE AND TECHNIQUE OF THE EXPERIMENT

Apparatus for observing the reflected light intensity change in the electric field is a parallel cell (Figure 1) Consisting of two electrodes, one of which – the glass coated with transparent conductive (ITO). In order to eliminate glare from the surface of the cell a glass prism is installed on it. Between the electrodes is a colloidal solution - magnetic fluid type "magnetite in kerosene." Magnetite concentration - 3.2% vol. The dielectric constant $\varepsilon = 2{,}7$, conductivity $\sigma = 5 \cdot 10^{-7}\,(\Omega \cdot m^{-1})$ (measured at a frequency of 100 Hz). The average size of the magnetite particles ~ 10 nm, the thickness of the protective envelope consisting of molecules HOl ~ 1,5 nm.

In the face of the prism, glued to the glass by immersion liquid (Figbre 1) falls a beam diameter of 2 mm from the laser pointer ($\lambda = 650$ nm) so that the angle θ of falling on the glass surface is 45 degrees. The beam is reflected from the surface of the "glass-conductive coating" and "conductive coating - magnetic fluid" and interferes. Reflected beam falls through the diaphragm – 6, and polaroid – 7 on a photodiode FD-256. The photodiode is connected to the input of a two-beam oscilloscope GDS-71022, which allows us to observe the dependence of the voltage on the photodiode from time on the screen and memorize the results in tabular form (4000 points). The rays reflected from the boundaries of the "prism-glass" and the layer "conductive coating – magnetic fluid" spatially separated ~ 5 mm. In order to avoid glare of a photodiodes a diaphragm with orifice about 1 mm was placed in front polaroid 7. Laser and polaroid can be rotated over the beam. The plane of polarization of the polaroid 10 coincides with the plane of polarization of the laser beam. Polaroid serve to reduce the depolarized component of the laser light. Rotating the laser with a polaroid we try to achieve the s-component (TE-wave) to be perpendicular to the plane of falling. Rotating the polaroid 7 we weakened the light so that photodiode operated in the linear mode. The area of the electrode surface $S = 36 \times 30$ mm², thickness of the magnetic layer of liquid l – 250 mcm. In the experiments we used two samples of coated glass (manufactured by LLC «Polytech», St.-Petersburg). Glass thickness for two samples –

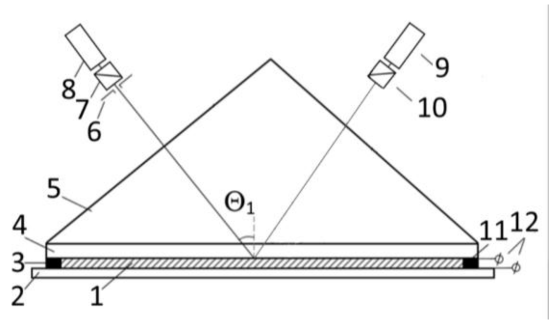

Fig. 1 – Schematic of the experimental device to observe the

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changes in the reflected light intensity. 1 – magnetic fluid; 2 – plate of Micarta foil; 3,11 – isolation pads made of polystyrene; 4 – a transparent conductive coated glass (ITO); 5 – isosceles rectangular prism; 6 – diaphragm; 7, 10 – Polaroids; 8 – a photodiode; 9 – Laser Pointer; 12 – electrodes

4 mm, thickness of the conducting coating sample No 1 $h_{01} = (280 \pm 5)$ nm, sample No 2 $h_{02} = (215 \pm 5)$ nm. Measurements were made at five different points on the surface, and then averaged.

Fig. 2 a, b are graphs showing the change in voltage in the photodiode (optical response) with time dependence for two samples of glass, c – view of voltage applied to the cell electrodes.

The shape of curves is explained as follows: at the beginning of the period of zero voltage (points A_1 and A_2 in Figures 2a, b) the optical response is fixed. Then, with increasing voltage, the reflectance changes (A_1B_1 and A_2B_2 plots on the curves of Figures 2a, b). Optical signal responses have distinct peak (Figure 2a) and minimum (Figure 2b), which is characteristic of interference in thin membranes. At a certain critical voltage (~ 12 V) the intensity of the reflected light begins to change periodically (B_1C_1 areas and B_2C_2), indicating a periodic variation (fluctuation) of the layer thickness.

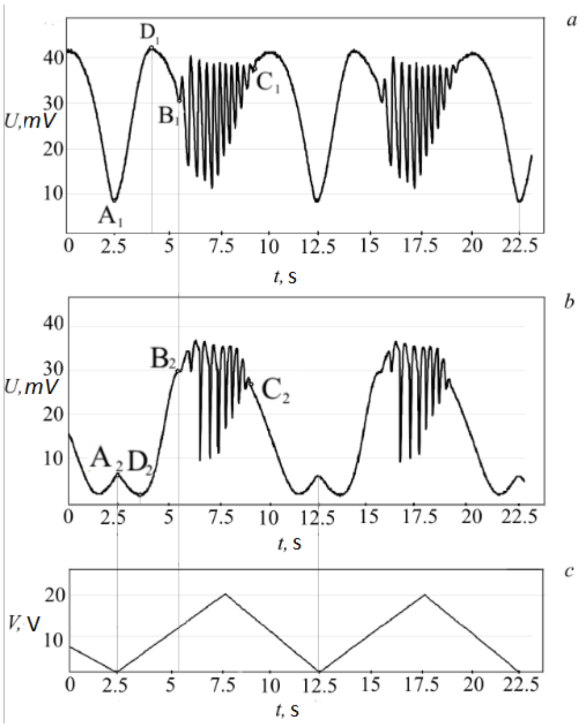

Fig. 2 – The time dependence of the intensity of reflected light from the surface "conductive coating – a layer of densely packed particles of magnetite" (clarifications in the text)

In the absence of an electric field magnetic liquid in a cell is homogeneous, however, when the field exists – solid phase particles under the influence of electrodypolophoresis and begin to migrate to the electrodes at the electrode surface and the conductive coating concentration of magnetite particles apparently increases to a maximum value (25-27 vol.%) in which it has not lost fluidity. This concentration corresponds to the dense packing of spheres with a diameter ~ 12 nm.

Complex refractive index and thickness of the conductive coating were measured with a spectroscopic ellipsometer SE 800 SENTECH. Refractive index of glass $n_1 = 1{,}52$, the refractive index of the conductive coating $\hat{n}_2 = 1{,}76\ (1 + 0{,}04\ i)$. The refractive indexes of the magnetic fluid concentration 3,2 vol.% – $\hat{n}_3 = 1{,}45\ (1 + 0{,}01\ i)$, concentration 26 vol.% – $\hat{n}_4 = 1{,}75\ (1 + 0{,}03i)$. Note that $\hat{n}_2 \approx \hat{n}_4$, ie the growth of concentrated magnetic fluid layer by the optical properties is equivalent to an increase in the thickness of the conductive coating of ITO. Thus R – reflectance of the conductive coating with a layer of densely packed particles of magnetite, is a function of [4]:

$$R = R(h, n_1, \hat{n}_2, \hat{n}_3, \theta, \lambda)\,, \qquad (1)$$

where $h = h_0 + \Delta h$, $\theta = 45°$– angle of light falling on the glass, $\lambda = 650$ nm – wavelength, Δh – the thickness of the sheath , h_0 – thickness of the conductive coating.

Due to cumbersome formulas given only the result of the calculation of $R(h)$, as shown in Fig. 3.

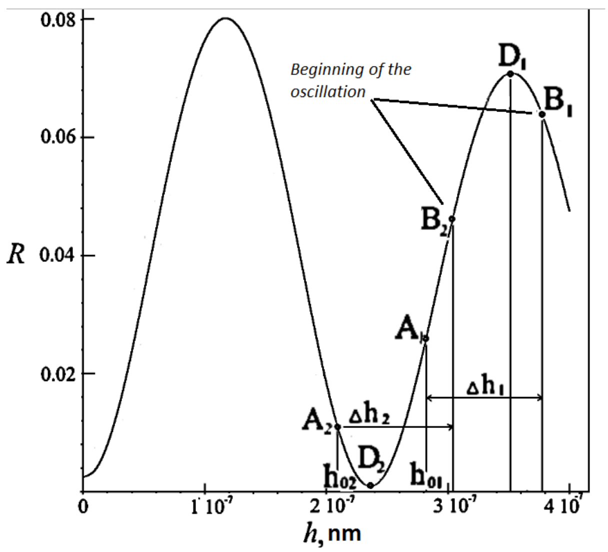

Fig. 3 – The dependence of the reflection coefficient R of a thin membrane of thickness h

Using the experimental results shown in Figure 2 and calculated dependence of $R(h)$, as shown in Figure 3, the method of determining the thickness of the conductive coating which varies depending on the applied electric field and the thickness of ITO sheath has been developed.

In the calculation of the curve $R(h)$ points A1 and A_2 corresponds to the thickness of the conductive coating samples No 1 and No 2 – h_{01} and h_{02} and the values of reflection coefficients $R_{01} = 0{,}01$ and $R_{02} = 0{,}026$.

Given that the photodiode operates in the linear mode, the voltage at the input resistor of the oscilloscope U' is proportional to the intensity of the reflected light and to the reflectance R. That is, knowing the dependence $U_1(t)$ and $U_2(t)$ reflection coefficients can be found for the samples No 1 and No 2 using the experimental data (Figure 2). The points B_1 and B_2 (Figure 2) corresponds to the beginning of periodic variation (oscillation) of the layer thickness, consisting of packed particles of magnetite, which is formed in the electric field at the surface of the conductive coating. Finding the values of the reflection coefficients which are relevant to B_1 and B_2 experimental points (Figure 2), we find the point B_1 and B_2 on the calculated dependence (Figure 3). The abscissas of the points B_1 and B_2 are the required thickness values h_1 and h_2. Found by this method the thickness of the sample No 1 and No 2: $h_1 = (365 \pm 5)$ nm, $h_2 = (301 \pm 5)$ nm, value Δh the thickness of the near-electrode layer of magnetite particles – $\Delta h_1 = \Delta h_2 = (98 \pm 5)$ nm and, respectively, ITO-coating thickness $h_{01} = (280 \pm 5)$ nm and $h_{02} = (215 \pm 5)$ nm. In view of the previously measured ellipsometer SE 800 SENTECH thickness values for conductive coatings and samples No 1 and No 2 appeared that the difference in results of these independent measurements of at least 10 %.

3. CONCLUSIONS

In this article has been developed a method of calculating the conductive thin membrane thickness, consisting of a located on glass transparent coating ITO, which is one of the electrodes in the electrochemical cell with a magnetic fluid. The optical properties of the structure «ITO nanoparticles of magnetite – layer membrane» in the electric field were discovered. It is found that by adjusting the voltage on the electrodes, it is possible to change the thickness of the layer of magnetite nanoparticles. By comparing the intensity of the reflected light from the time the results of mathematical modeling, it was possible to determine the thickness of the double-layered structure «ITO-magnetite» and magnetite nanoparticles sheath thickness, consequently, the thickness of the two samples conductive ITO membrane. Comparison with conductive coating thickness measurements for these samples using the spectroscopic ellipsometer 800 SE SENTECH showed that within the errors of the same to within 10 %.

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