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Short Communication

Piezoelectric Properties of Barium Titanate Langmuir Films

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Langmuir films from stabilized barium titanate nanoparticles have been produced. The processes of polarization and polarization reversal of ferroelectric coatings obtained were studied. The inverse piezoelectric effect has been recorded and its quantitative characteristics have been determined.

Keywords: Langmuir-Blodgett films, Ferroelectric, Piezoelectric modulus, Scanning probe microscopy.

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1. INTRODUCTION

Ferroelectric (FE) materials on the basis of barium titanate (BTO) have been well studied and have found wide use in engineering. The elevated interest in them can be explained with theoretically predicted abnormal increase in the module of elasticity [1], enhancement of dielectric properties, emergence of new nonlinear effects and the phenomena with a transition to nanodimensional area, which is related to the outlook in the development of transistors [2], elements of energy-independent memory on quantum tunnel transitions [3]. Of special interest are ferroelectrics with nanodimensional structure. However, their practical application involves high requirements for purity and faultlessness, which are met by the choice of the relevant technologies [4]. In the present work, the piezoelectric (PE) properties of BTO films have been investigated, for the first time obtained by the Langmuir-Blodgett (LB) method on the KSV-NIMA 2002 [5] setup.

Material for the production of SE LB films was the stabilized nanoparticles of BTO with a form close to spherical produced by peroxide synthesis. As a substrate for sedimentation, cover glasses were served whose surface was specially prepared with the deposition of a magnetron platinum film. This made it possible to accomplish the best quality of LB according to [5], as it is shown by the image of its surface obtained with the atomic force microscope (AFM) SmartSPM AIST-NT (Fig. 1).

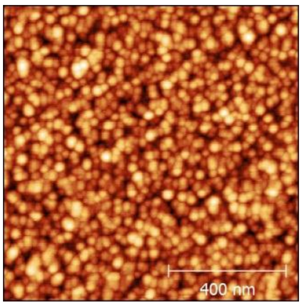

Fig. 1 – AFM image of a WTO film on a platinum sublayer

Investigations of PE properties of LB films were conducted by the method of contact and semi-contact microscopy of piezoresponse (MPR), AFM and Kelvin probe microscopy (KPM) by means of the carrying Ti-Pt cantilevers (30 nm, 5 N/m). Polarization of SE LB coating in the form of a square (5 × 5 μm) was carried out by method of contact MPR under a constant voltage (– 7 V) with a speed of 5 μm/s line-by-line with a frequency of 1 Hz. On the center of this square, a square (2×2 μm) with a voltage of + 10 V underwent polarization reversal by MPR method for visualization of the created areas, KPM method was used (Fig. 2a).

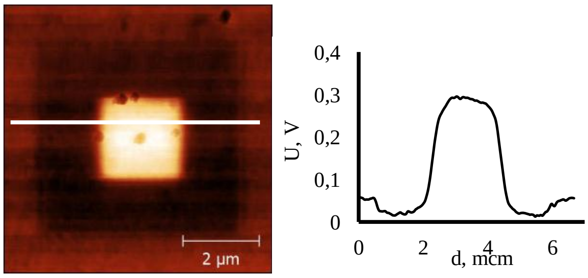

Fig. 2 – Polarization of LB film: left – distribution of surface potential according to KPM; right– a profile of surface potential

In Fig. 2a the direction is marked, along which the distribution of surface potential, according to KPM, is given in Fig. 2b. Comparison of surface potential distributions in two opposite polarized areas indicated high degree of their contrast (for $U = -7$ V reached 50 : 1, and for $U = +10\ V - 600 : 1$) with respect to the area without electric influence.

The piezoelectric properties of LB films were studied at polarization by voltages of + 10 *V* and – 10 by the areas the size 2 × 2 μm, in whose center polarization reversal of their fragment in areas 1 × 1 of micron was made (Fig. 3).

According to Fig. 3, at polarization deformation perpendicular to the surface of LB film was found, which was sign-variable: it either rose, or fell by 6 nm with respect to the initial level. Such a change perhaps corresponded to the origin in LB film of the inverse piezoelectric effect, whose main characteristic is piezoelectric modulus [1], which connects the intensity of the electric field applied to a piezoelectric material with its elongation. The change of BTO film thickness due to

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the inverse piezoelectric effect in the uniform electric field directed perpendicularly to the sample surface is described by only d_{33} component of the piezoelectric constant tensor [6].

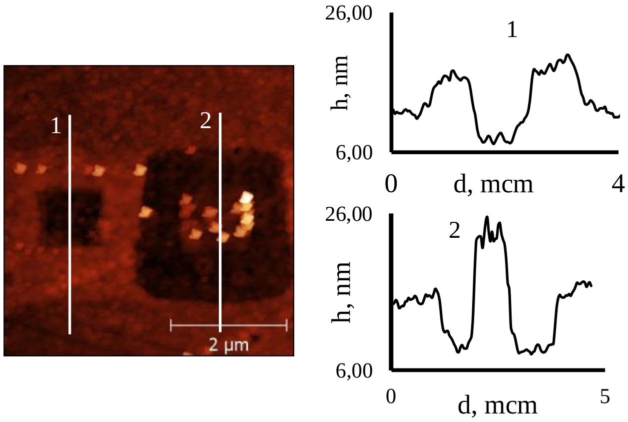

Fig. 3 – Atomic force microscopy of the polarized areas: left – surface topology; right – height profiles

At MPR measurements, changes of the SE LB film geometrical sizes are due to the applied alternating electric field. In doing so, the deformation of LB film throughout thickness causes normal fluctuations of a cantilever. All of this allows one, by using the map of distribution of its vibration amplitude (Fig. 4) to estimate the value of piezoelectric modulus:

$$d_{33} = \frac{A}{U}$$

where A is the average amplitude of cantilever normal vibrations on the polarized area, U is the amplitude of the applied alternating voltage when piezoelectric effect is measured. Calculated in this way, a component of the elasticity tensor amounted to: $d_{33} = 1{,}6$ pm/V, which is in accord with the values observed in other works [7] for thin-film BTO produced by other methods.

MPR made it possible as well to determine the direction of a polarization vector of areas after an electric field had an impact on them. When one analyzed the observed phase shift between cantilever normal vibrations and the voltage on a probe (Fig. 5), it was noted the appearance of zero and 180° shift for the SE areas of the film with various polarization.

For the area with the polarization directed downward, phase coincidence of an alternating voltage

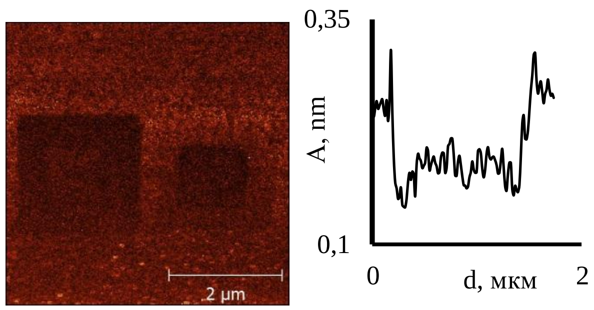

Fig. 4 – Distribution of cantilever normal vibration amplitude: left – map of distribution; right – profile of its change in the polarized area

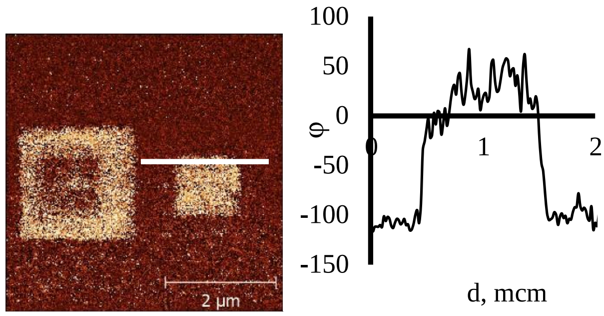

Fig. 5 – Phase shift of cantilever normal vibrations: left – topographical distribution; right– a profile of phase shift distribution in the polarized areas

(a phase – φ_U) was found on a probe with the cantilever forced vibrations caused by deformations of LB film (φ_C): $\varphi_U - \varphi_{With} = 0°$. Therefore, the areas polarized downward do not differ from the areas without polarization (Fig. 5). For the areas with the polarization directed upward, the origination of antiphase vibrations was observed: $\varphi_U - \varphi_C = 180°$ [8]. It may be concluded that high-contrast sign-variable dependence of the polarization vector of LB film on the sign of the applied voltage appeared.

Thus, LB method allows one to create qualitative ferroelectric films for the use in micro- and nanoelectronics.

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