1. INTRODUCTION

Thin layers of the La$_{x}$A$_{1-x}$MnO$_3$ perovskite-like manganites, where $A$ = Ba, Ca, Sr,..., show considerable promise as materials for sensors of magnetoresistive and IR radiation detectors [1, 2]. These compounds exhibit a strong dependence of the electrical resistivity on the magnetic field strength and a fairly high bolometric response near the Curie temperature $T_C$. The La$_{x}$A$_{1-x}$MnO$_3$ films whose $T_C$ is close to room temperature appear particularly attractive for applications. The ferromagnetic phase transition in the La$_{x}$A$_{1-x}$MnO$_3$ (LBMO) solid solution takes place at $T_C = 340$ K [3].

The electrical resistivity and magnetotransport properties of heteroepitaxial La$_{0.67}$Ba$_{0.33}$MnO$_3$ films are strongly affected by the mechanical stresses [4] and defects formed in the course of structural relaxation. The level of biaxial mechanical stresses in La$_{0.67}$Ba$_{0.33}$MnO$_3$ films were found to correlate unambiguously with the position of the maximum in the temperature dependence of their resistivity and the magnetoresistance [5].

We report on a study of the structure and electronic properties of La$_{0.67}$Ba$_{0.33}$MnO$_3$ films stressed mechanically asymmetrically (i.e., differently along the $a$ and $b$ axes) in the course of formation. The thickness $d = 40$ nm of the grown layers did not exceed the critical level at which the relaxation of mechanical parameters would be accompanied by a change in the unit cell parameters in the substrate plane.
Fig. 1. X-ray diffraction pattern (CuK$_{\alpha1}$, $\omega/20$) of the La$_{0.67}$Ba$_{0.33}$MnO$_3$/NdGaO$_3$ (40 nm) film in the case where the incident and reflected x-ray beams lie in the plane perpendicular to NdGaO$_3$ (001). The asterisk indicates the (001) peak of La$_{0.67}$Ba$_{0.33}$MnO$_3$. The inset shows a fragment of the same x-ray scan in the vicinity of the (002) peak of La$_{0.67}$Ba$_{0.33}$MnO$_3$ on an enlarged scale. Arrows indicate the Laue satellite peaks.

The resistance $R$ of the manganite films was measured in van der Pauw geometry both in the magnetic field $H$ and without it. The magnetic field ($\mu_0H$ up to 5 T) was oriented parallel to the substrate plane along the Mn–O–Mn chains in the La$_{0.67}$Ba$_{0.33}$MnO$_3$ film, and the measuring current $I$ was parallel or normal to $H$. The electrical resistivity $\rho$ of the films was calculated from the relation $\rho = \pi dR/ln2$ [6]. Four silver contact pads were thermally evaporated at the corners of a square on the free surface of the films.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Neodymium gallate belongs to perovskite-like oxides with the following parameters of its orthorhombic unit cell: $a/\sqrt{2} = 3.837$ Å, $b/\sqrt{2} = 3.891$ Å, $c/2 = 3.853$ Å (the parameter of the corresponding pseudocubic unit cell $a = 3.851$ Å) [7]. The orthorhombic distortion $(b-a)/a$ of the stress-free unit cell of NdGaO$_3$ crystals is about 1.4%. The parameter of the La$_{0.67}$Ba$_{0.33}$MnO$_3$ pseudocubic unit cell is $a = 3.910$ Å [3]. The positive lattice mismatch $m = 1.5\%$ favors generation of biaxial compressive mechanical stresses in the La$_{0.67}$Ba$_{0.33}$MnO$_3$/NdGaO$_3$ film [$m = (a_i-a)/a_i$]. Note also that the orthorhombic distortion of the neodymium gallate unit cell introduced nonuniformity into biaxial stresses in the La$_{0.67}$Ba$_{0.33}$MnO$_3$/NdGaO$_3$ films (one of the Mn–O–Mn chain groups was compressed stronger than the other, which is turned in the substrate plane by 90° relative to the first one). The temperature coefficients of linear expansion of La$_{0.67}$Ba$_{0.33}$MnO$_3$ and NdGaO$_3$ are close in magnitude [8, 9].

3.1. Structure of Grown
La$_{0.67}$Ba$_{0.33}$MnO$_3$/NdGaO$_3$ Films

The x-ray diffraction patterns featured only peaks due to the substrate and the manganite film (Fig. 1). This implies the absence of macroinclusions of secondary crystalline phases in the bulk of the layers. We have not succeeded in revealing any complex structure in x-ray diffraction peaks that could be traced to relaxation of mechanical stresses in the bulk of the manganite films. The presence of distinct Laue peaks in the x-ray patterns (see the inset in Fig. 1) suggests that the grown layers are uniform in thickness and homogeneous in composition. The unit cell parameter $a_0 = 3.969 \pm 0.005$ Å in the La$_{0.67}$Ba$_{0.33}$MnO$_3$/NdGaO$_3$ films was substantially larger than the parameter $a_0 = 3.849 \pm 0.005$ Å, which implies that the manganite films were subjected to compressive mechanical stresses in the substrate plane. The $a_0$ parameter practically coincided with the pseudocubic unit cell parameter $a_{\text{NGO}} = 3.853 \pm 0.005$ Å calculated from the x-ray diffraction data (20 for the (004) NdGaO$_3$ peak). The effective volume $V_{\text{eff}} = a _{\parallel}^2 \times a _{\perp} = 58.80$ Å$^3$ of the La$_{0.67}$Ba$_{0.33}$MnO$_3$/NdGaO$_3$ unit cell was noticeably smaller than that of the corresponding unit cell of the La$_{0.67}$Ba$_{0.33}$MnO$_3$ single crystal (~59.78 Å$^3$ [3]). The mechanisms responsible for the change in the unit cell volume of the manganite films, which were elastically stressed by the substrate during their formation (nucleation and growth), were discussed elsewhere [10].

The x-ray $\phi$ scans of the (111) reflection of La$_{0.67}$Ba$_{0.33}$MnO$_3$ from La$_{0.67}$Ba$_{0.33}$MnO$_3$/NdGaO$_3$ films exhibited four equidistantly (90°) spaced peaks each. The peak half-width in the $\phi$ scan of the La$_{0.67}$Ba$_{0.33}$MnO$_3$ film was 0.08°, which is only twice that in the corresponding scan of the (111) reflection from a single-crystal neodymium gallate substrate. The full width at half-maximum of the rocking curve (~0.07°) of the (002) x-ray peak obtained from a La$_{0.67}$Ba$_{0.33}$MnO$_3$/NdGaO$_3$ film practically coincided with that of the corresponding curve for the (200 nm) La$_{0.67}$Ba$_{0.33}$MnO$_3$ films grown [11] on the substrate with a small $m$. Figure 2 displays the x-ray reciprocal space map visualized for the (103) reflection of La$_{0.67}$Ba$_{0.33}$MnO$_3$. The data presented in the map, as well as the insignificant difference between the $a_0$ and $a_{\text{NGO}}$ parameters, suggest that the La$_{0.67}$Ba$_{0.33}$MnO$_3$ films were grown quasi-coherently on the NdGaO$_3$ (001) surface. The rigid bonding to the substrate accounts for the orthorhombic unit cell distortion in the La$_{0.67}$Ba$_{0.33}$MnO$_3$ film; it was, however, somewhat smaller than the corresponding distortion of the