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Superconducting, surface and anomalous electron transport properties of $BaNbO_{3-x}$ films

Vitaly A. Gasparov[a,*], S.N. Ermolov[a], S.S. Khassanov[a], G.K. Strukova[a], L.V. Gasparov[a], H.S. Wang[b], Qi Li[b], M. Schnider[c], Wo. Richter[c], E. Glaser[c], F. Schmidl[c], P. Seidel[c], B.L. Brandt[d]

[a]*Institute of Solid State Physics, Russian Academy of Sciences, 142432, Chernogolovka, Moscow district, Russian Federation*
[b]*Department of Physics, Pennsylvania State University, University Park, PA 16802, USA*
[c]*FSU-Jena, Institut für Festkörperphysik, Max-Wien-Platz 1, D-07743, Jena, Germany*
[d]*National High Magnetic Field Laboratory, 1800 E. Paul Dirac Drive, Tallahassee, FL 32310-3704, USA*

Abstract

Review of superconducting (T_c, $H_{c2}(T)$, J_c), electron transport $R_s(T)$, surface (XPS, UPS) and structural (XRD, RBS) properties of thin films of a novel superconductor $BaNbO_{3-x}$ on different substrates is presented. Superconducting films have been obtained when grown on the Al_2O_3 with $T_c = 14$ K, $J_c \approx 1 \times 10^4$ A cm^{-2} and large $H_{c2}(0) = 28$ T. At the same time, films on $NdGaO_3$ exhibit behavior typical to granular superconductors.

Keywords: BaNbO thin films; Upper critical field

Recently we have shown that $BaNbO_{3-x}$ ceramic compounds, with perovskite cubic structure and large oxygen nonstoichiometry ($0.6 < x < 1$), exhibit superconductivity with a T_c as high as 22 K, although stoichiometric $BaNbO_3$ is metallic but not superconducting [1,2]. It is known that removing of oxygen leads to appearance of superconductivity of dielectric $SrTiO_3$ [3]. Appearance of photoemission intensity in the band gap due to oxygen reduction was observed in a number of other parent niobates and titanates [4]. Thus, one of the interests currently is in electronic structure and superconducting properties in this class of reduced niobates.

The films were grown on heated (1 0 0) $SrTiO_3$, Al_2O_3, YSZ, MgO, $NdGaO_3$ substrates by ablating a single target with a pulsed Nd-YAG laser, in a UHV chamber. The preparation of ceramic superconducting targets starts with quick burning solid-state reaction described in Refs. [1,2], with additional regrinding, pressing and postannealing in argon.

XRD investigations shows that using of $SrTiO_3$ or $NdGaO_3$ substrates resulted in epitaxial films, while the same films on Al_2O_3, YSZ, MgO were highly textured. Assuming cubic perovskite structure, the lattice parameter of the films was determined in the range 0.412–0.414 nm, in comparison with 0.432–0.435 nm for ceramics [1,2]. No nitrogen and no other elements except for the original components were detected from the XPS spectra. The Nb3d spin–orbit doublet XPS peak for films on $SrTiO_3$ and $NdGaO_3$ were resolved by two peaks to Nb^{5+} and Nb^{4+}, while only single peaks were observed for superconducting films on Al_2O_3, indicating that Nb is present in different configurations. Careful analysis of the XPS and RBS indicates that the films on different substrates have the same composition $BaNbO_{3-x}$.

The angle-integrated valence-band UP spectra of films extend from about 3.5 to 9 eV. The Fermi level is pinned at the bottom of the conduction band and Fermi edge was clearly observed for films on $SrTiO_3$ and Al_2O_3

* Corresponding author.
E-mail address: vgasparo@issp.ac.ru (V.A. Gasparov)

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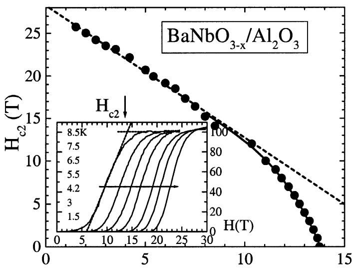

Fig. 1. Temperature dependence of $H_{c2}(T)$ for films on Al_2O_3. Inset shows the perpendicular fields resistive transition curves for the same film at different T.

consistent with their metallic character, while was rather weak for films on $NdGaO_3$ and YSZ which exhibit semiconducting-like electron transport behavior. This is observed in spite of the fact, that films on $SrTiO_3$ and $NdGaO_3$ have the same XRD structure and composition. Possibly, the electron structure of these films is affected by small variations in the oxygen composition.

While the films on Al_2O_3 substrate had superconducting transition at $T_c = 14$ K, similar films on $NdGaO_3$ demonstrated insulating behavior, i.e. a sharp increase of the resistance below the *same* temperature. This increase of the resistance could be suppressed by rising the measuring current or by magnetic field. Both, the current dependence and the negative magnetoresistance for films on $NdGaO_3$, can be explained in terms of granular superconductivity. The critical current density at 4.2 K for superconducting films on Al_2O_3 was rather low ($1\text{–}2 \times 10^4$ A/cm^2), because the substrates were polycrystalline. The sheet resistance of the same films on $SrTiO_3$ is ten times less then on Al_2O_3 and showed classical metallic behavior with high resistivity ratio ($e(300\ \text{K})/e(4.2\ \text{K}) \leqslant 1000$) and extremely low residual resistance (4 nΩ cm), due to formation of Nb-rich interface layer.

As we can see from Fig. 1, the resistive upper critical magnetic field $H_{c2}(T)$ are found to be extremely high for films on Al_2O_3. This field was derived from fluctuation conductivity ($T_c(H)$) at temperatures above and from linear extrapolation of $R_s(H)$ curves below 10 K. Contrary to conventional theory [5,6], we find that below 10 K the $H_{c2}(T)$ dependence is linear with $H_{c2}(0) = 28$ T ($\xi(0) = 34$ Å) and with no evidence of saturation down to 1.5 K. This linear $H_{c2}(T)$ dependence is characteristic for 2D superconductors [7], although the temperature dependence of fluctuation conductivity has a clear 3D form.

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