SPM investigations of the morphology features and local electric properties of HTS YBaCuO thin films

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Abstract: The results of SPM investigations of the morphology features and local electric properties of the YBaCuO thin films, prepared by dc magnetron sputtering are presented. Two different cation composition of the magnetron single target were used. It is shown that using stoichiometric and Cu-rich targets at optimal deposition temperature facilitates island film growth. The films have a well-defined grain structure which is formed by coalescence of 1-2-3 YBCO phase crystallites. It is established that YBCO thin films with high superconductive properties and not containing CuO-particles can be obtained in the *90° off-axis* magnetron sputtering system.

Introduction

It has been established to date that YBaCuO (YBCO) thin films with superior superconductive properties have a non-stoichiometric integral cation composition. The superconductivity optimum of YBCO thin film is located in the Cu- and Y-rich composition area [1-3]. Such composition deviations from the 1-2-3 stoichiometry generally lead to secondary phase particle formation, for example, BaO, Y_2O_3, CuO, etc. CuO-particles have the characteristic sizes of 0.5 μm and surface density to 10^8 cm^{-2}. Therefore, they pose a serious problem in fabrication of multilayered structures and devices on multilayers base. Some time ago [4] we developed a *90° off-axis* magnetron sputtering system, which enables fabrication of high quality YBCO films without secondary phase particles. In the present work comparative SPM investigations of the morphology features and local electric properties of the YBCO films, obtained in the *90° off-axis* and in the widely used inverted cylindrical magnetron sputtering (ICMS) systems have been carried out.

Experiment

The films to be investigated were fabricated *in-situ* on $NdGaO_3$ substrates by dc magnetron sputtering from ceramic YBCO single targets. Stoichiometric (1-2-3) and Cu-rich (1-2-3.3) targets were used. The substrate temperature and deposition rate have been optimized experimentally. The temperature of the superconductive transition was measured by the non-conductive third-order local nonlinear microwave response method [5]. The critical current density was estimated by the Bean's model from the value of the remanent magnetic field [6]. SPM investigations of the films were carried out with the scanning probe microscopes "Solver" facility (production of NT-MDT company, Zelenograd).

Results and discussion

The study has revealed that YBCO films obtained in ICMS under optimal deposition conditions comprise well-defined Cu-rich precipitates on their surface. These particles have a semi-spherical shape and a characteristic lateral size of 1 μm and height of up to 400 nm. A typical AFM surface image of such films is given in fig.1. In the area between the precipitates the film revealed a distinct block structure. The STM volt-ampere characteristics from the CuO surface were of the metal – wide gap semiconductor type. As the STM investigations have shown, the film areas between the precipitates had the metal conductivity type, which would be expected from the 1-2-3 YBCO phase.

The YBCO films fabricated by the *90° off-axis* sputtering technique have a different surface morphology. Fig. 2 presents the AFM image of the film obtained in the *90° off-axis* system at an optimal (720 °C) deposition temperature, when the stoichiometric (1-2-3) target was used.

The film has a clear block structure, which is the outcome of the *c*-oriented YBCO crystallites coalescence, resulting in formation of low angle grain boundaries. The important characteristic of this film is the absence of CuO particles on its surface.

Fig. 1. AFM images of the YBCO films obtained by inverted cylindrical magnetron sputtering system.

Fig. 2. AFM images of the YBCO films obtained by a *90° off-axis* sputtering technique.

Therefore, this film does not practically have the non-stoichiometric outgrowths and, moreover, has rather high superconductive properties: $T_{c0} \geq 88$ K и $J_c \geq 1\times10^6$ A/cm^2 at 77 K.

In order to study the cation composition influence on the YBCO film properties the experiments for film deposition in the *90° off-axis* system from 1-2-3.3 composition targets were carried out. It is known that an increase of Cu-atom concentration in the composition of deposition material depresses the cation disorder processes in an YBCO unit cell [8].

Fig. 3. AFM image of the M2.19 film surface.

The morphology features and the electrical properties of films made from 1-2-3.3 targets are substantially influenced by the deposition temperature. The AFM image of M2.19 film fabricated at optimal (for this cation composition) temperature (750 °C) is shown on Fig. 3. The critical temperature of this film is $T_{c0} \geq 88$ K. X-ray analysis has shown that the film consists of *c*-oriented YBCO crystallites. According to the AFM data, the film has a very rough surface relief. One can distinguish two layers on the AFM images of the film tentativly. The lower layer corresponds to the coalescenced crystallites. The top layer consists of separate microblocks. The crystallites of this film have more of a rectangular shape as compared to the films from stoichiometric targets (fig. 1,2) and equiprobable *a* and *b* orientations. According to the AFM profile, the actual height of the top layer microblocks is 50-70 nm. These morphology features are the consequence of film recrystallization during the tetragonal-orthorhombic transition. The film has a high critical current: $J_c \geq 4\times10^6$ A/cм^2 at 77 K. The X-ray analysis data have revealed a relatively high epitaxial Y_2O_3 nanoparticles concentration in the film. These nanoparticles can be the pinning centers [7] and stipulate high critical currents in these films. STM investigations have shown that this film has a uniform metallic type conductivity. Thus, despite the Cu-rich target employment, the film does not contain CuO particles or any other big size (~1 μm) insulating inclusions.

Fig. 4 presents the AFM image of film (M2.18) obtained at a low deposition temperature (735 °C) than M2.19.

Fig. 4. AFM image of the M2.18 film surface.

This film is characterized by sharp crystal grain boundaries and porosity. Such surface morphology of M2.18 sample correlates with the decrease of the depinning current which is about 0.5×10^6 A/cм^2 at 77 K for this film, and with the reduction of Y_2O_3 particles also. The critical temperature of this film is 87 K. Thus, the minor changes in the deposition temperature (15 °C) produce an appreciable influence on the surface morphology and transport film properties, but much less affect the critical temperature.

Conclusion

Using the dc magnetron sputtering technique we have fabricated and tested a series of YBaCuO thin films. SPM investigations of the morphology features and local electric properties of the films made from different cation composition targets were carried out. It is shown that the use of stoichiometric and Cu-rich targets at optimized deposition temperature results in island film growth. The films have a well defined block structure which is formed by coalescence of *c*-oriented 1-2-3 YBCO phase crystallites. It is established that YBCO thin films with high superconductive properties and, at the same time having no CuO-particles can be fabricated in the

90° off-axis magnetron sputtering system. YBCO films produced from Cu-rich targets have higher superconductive transport properties than the films from stoichiometric targets.

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