

Structural properties and epitaxial growth mechanisms of nanoscale $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_y$ thin films

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$\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_y$ (Bi:2212) nanoscale films were deposited on LaAlO_3 substrate by d.c. magnetron sputtering. The growth conditions for the deposition have been optimized. X-ray diffraction shows that the films are single Bi:2212 phase, epitaxial and oriented with their c-axis perpendicular to the substrate surface. The growth mechanisms of Bi:2212 have been studied by atomic force microscopy (AFM) on various nanoscale thin films.

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1. Introduction

High quality high temperature superconductors (HTS) thin films fabrication and multilayers are indispensable for the fabrication of integrated junction circuits. $\text{Bi}_2\text{Sr}_2\text{Ca}_{n-1}\text{Cu}_n\text{O}_y$ (Bi-based) superconductors have a high critical temperature (T_c around 85 K for $n=2$, and 110 K for $n=3$, respectively), high stability for humidity and strong anisotropy due to a layered crystal structure [1].

Superconducting Bi-2212 material suitable for applications at 77 K should have high critical current densities. The films with c-axis aligned to the film plane appear to be preferably suited for the fabrication of sandwich type SNS and SIS Josephson and quasiparticle tunnel junctions [2]. In order to fabricate superconducting devices, it is necessary to get a high quality of Bi-based films. Thin films of Bi:2212 grow epitaxially depending on the substrate material, thermodynamic and kinetic growth conditions. The epitaxial growth of thin films of Bi:2212 has been realized on substrates like SrTiO_3 , LaAlO_3 and MgO [3-6]. The importance of $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+d}$ HTSC is being reinvented in the light of its potential use in Terahertz nanotechnology and as a natural SQUID. Bi-2212 has a layered structure, which allows the propagation of EM waves (called Josephson plasma oscillator) [7-9] if transverse magnetic field H_{ab} and longitudinal electric field E_c is applied. Bi-2212 is also used as natural SQUID because there are non-superconducting layers sandwiched between superconducting CuO layers [10]

The modification of the 2212 sequence by deep reduction of the bismuth deposition time leads to intergrowth nanostructures. As a main feature, these structures appear to be governed by the sequential nucleation of $(\text{BiO})_2$ bilayers: when the Bi amount, which is deposited at each sequence, is smaller than the half of a full bilayer, then the nucleated $(\text{BiO})_2$ aggregates do not percolate for transport properties and thus their structure is not coherent [11].

Usually these films were grown with their c-axis perpendicular to the substrate surface, since c-axis growth

is thermodynamically favored growth direction. Sputtering is one of the most common vacuum techniques currently applied for superconducting oxide thin film growth. The sputter deposition technique can tolerate quite high gas pressure while still giving controllable growth rates, as long as the targets surface is insensitive to oxidation.

Here we present the growth mechanisms of Bi:2212 by using atomic force microscopy (AFM) on various nanoscale epitaxial Bi:2212 thin films.

2. Experimental

Bi:2212 thin films were deposited in situ onto (100) LaAlO_3 heated single crystal substrate by using DC magnetron sputtering system [5]. In order to compensate the Bi loss, a bismuth enriched target with chemical composition $\text{Bi}_{2.6}\text{Sr}_{1.97}\text{Ca}_{0.97}\text{Cu}_{2.4}\text{O}_y$ has been synthesized. The optimal parameters used for fabrication of epitaxial quality Bi:2212 thin films were: sputtering gas pressure of 0.9 mbar (with a ratio 1/1 between the argon and oxygen partial pressures), the substrate temperature 790 °C and d.c. plasma power between 20 W and 30 W. The substrate temperature is one of the most important parameter for obtained high quality films, because of the influence on the stability of Bi:2212 phase and on the Bi losses.

The increase of T_c for Bi:2212 thin films arise by optimizing the oxygenation of BiO bilayers. The oxygen content of our thin films was adjusted by an oxygenation treatment after the high temperature annealing. The oxygen pressure was of 0.15 mbar, the temperature of thin film of 500 °C and the oxygenation time of 40 minute.

X-ray diffraction pattern shows only (001) reflexions observed for thin films and the reflexions (i00) for LaAlO_3 substrate. The FWHM (full width for high maximum) of rocking curve is equal to 0.40° , and confirmed the high orientational quality of sample.

In order to give an insight into the growth mechanisms of Bi:2212 films, a series of thin films with different thicknesses have been grown.

The AFM study was carried out in air at room temperature in constant force mode.

3. Results and discussion

Prior the deposition, the quality of substrates surfaces was checked. AFM investigations shows that the surface is smooth, clean and defect free planar surface.

The AFM image of Fig. 1 shows such a pattern for the film with approximately 4 nm thickness. This figure evidence a random distribution of particles with the maximum height around 10 nm, and their mean size around 50 nm. These dimensions of particles are similarly to the results reported in reference [12], but contrasts with published results on films with similar thickness [13]. Such type of particles were detected in small proportions on laser ablated thin films [14]. For thinner films than 4 nm, the particles are disk shaped, and for films of thicknesses between 4 nm and 20 nm, an increasing number of particles are rectangular shaped, indicating that these are indeed nucleates of the Bi:2212 material.

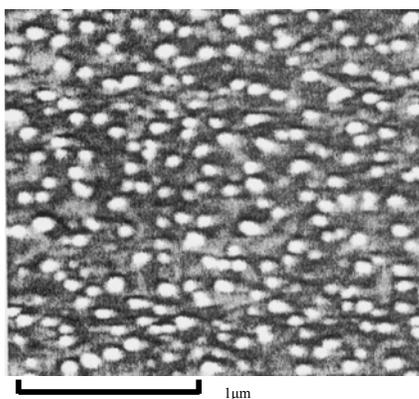


Fig. 1. AFM image of Bi:2212 thin film with 4nm thickness.

The 50 nm thin film shows a rectangular pattern and a highly oriented structure. The line scans indicate the presence of Bi:2212 with some intergrowth of Bi:2201. By increasing film thickness, the surface structure gradually changes to much more ordered pattern. The 90 nm film (Fig. 2) shows also a rectangular pattern with terrace-like structures. The height of these structures is lower than 10 nm and their average width is smaller than in the 150 nm film, indicating that the film is indeed at an earlier stage of its formation. No grain can be put in evidence and the surface represents more an intricate lattice of interconnected layers.

For the film with thickness around 150 nm, Fig. 3 shows a regular structure composed of large rectangular grains around 500 nm, oriented parallel and perpendicular to each other, suggesting an a-b twinned structure. The lines scans across the grains indicate that their height ranges from 14 nm to 60 nm.



Fig. 2. AFM image of Bi:2212 thin film with 90 nm thickness.

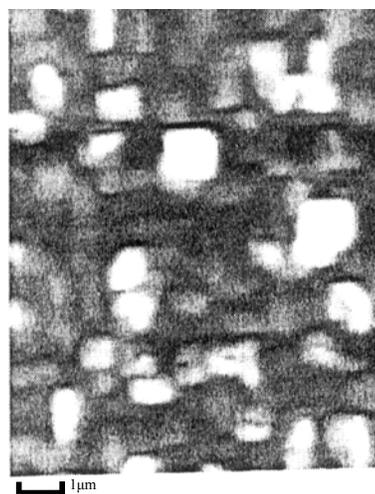


Fig. 3. AFM image of Bi:2212 thin film with 150 nm thickness.

The growth phenomenon can be established on the basis of thickness dependence function of mean particles size (Fig. 4). For films consisting only of few layers, the mean size of particles is very low (Fig. 1) and density very large. At this level, most of the particles are nucleates of Bi:2212 layers and the growth mechanisms are preferably of the island type. For intermediate thickness, the mean particle size increases and their density decreases, and the background begin to acquire a rectangular step structure (Fig. 2). At the same time, appear needle-like defects caused by high temperature annealing.

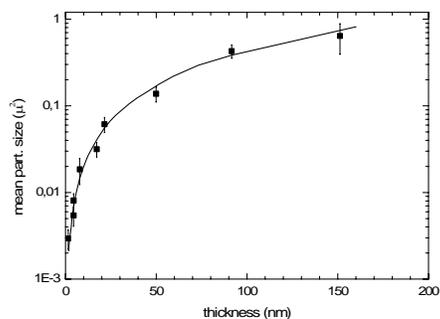


Fig. 4. Mean particles size dependence function of film thickness.

The background rectangular pattern, containing terraces, suggest that the starting island have joined and that a two-dimensional growth mode has started. This growth mechanism continues up to largest thin films thickness, where a granular structure appears. In this stage, the particle densities still decrease and their size increases.

In the first stage the growth mechanism is influenced by the film substrate interactions, while for the following layers the growth evolve to a more intrinsic mode (the adhesion of Bi:2212 to Bi:2212). This growth can be associated by Volmer-Weber mechanism [15].

4. Conclusions

The Bi:2212 thin films deposited by DC magnetron sputtering were found to be epitaxial and oriented with their c-axis perpendicular to the substrate surface.

The growth mechanisms of Bi:2212 deposited on LaAlO₃ polished single crystal have been studied by atomic force microscopy on films with different thickness.

At the nucleation stage the growth of films is of the island type. In the subsequent stage, the appearance of terrace like rectangular structures suggests the presence of an anisotropic mechanism. The final sequence shows a more rough topography for the thicknesses above approximately 150 nm, and can be associated with the Volmer-Weber growth mode.

Acknowledgments

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