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Characterization of micro-bridges in SQUIDs YBCO thin film

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Here, it is studied a fabrication of Superconducting Quantum Interference Devices (SQUIDs) on the grain boundaries (GB) Josephson Junctions in High Critical Temperature Superconductors (HTS) thin films produced by pulsed laser deposition. $YBa_2Cu_3O_{7-\delta}$ thin films (YBCO) are formed on $SrTiO_3$ bicrystal substrates with various grain boundary misorientation angles, and different micro-bridges, as well. The growth conditions of the YBCO thin film, in addition their influence on the properties of the different angles, are investigated. Furthermore, the angles influence the critical current I_c in the region of the grain boundary. As well as the properties of the varying patterned micro-bridges width of Josephson junctions are presented. In some cases, it is even found an increase in the resulting I_cR_N-product. X-ray diffraction and EDX measurements suggest a preferred orientation of the (110) lattice plane parallel to the substrate surface.

Keywords: Superconductivity; SQUIDs; Grain boundary; Josephson junctions.

1. INTRODUCTION

Josephson junctions are key elements in superconducting quantum interference devices (SQUIDs) [1–7], enabling extremely sensitive detection of magnetic fields through quantum interference effects. The fabrication of these junctions at the nanoscale—such as using bicrystal substrates and precision lithography—reflects major advancements in nanotechnology, which allows for improved device performance, scalability, and integration into quantum circuits. Nanotechnology not only enhances the control over junction dimensions and material interfaces but also plays a vital role in developing compact, high-speed, and low-power superconducting electronics for quantum computing and sensing applications.

The quantum mechanical tunneling of electrons between weakly linked two superconducting regions is the basis of the Josephson junctions. Because of its unusual qualities, it could be used as a component in future superconducting electronic circuits. The Josephson junction is used to create superconducting qubits, which are a key component of quantum information processing devices [8,9]. The fact that superconducting devices must be cooled to extremely low temperatures to become superconducting limits their real application. Thus, the discovery of high-Tc superconductors has broadened the scope of superconductors' potential applications [10]. YBCO is the most widely utilized electrical gadgets with superconducting material among the numerous high-Tc superconductors, such as Josephson junctions, quantum interference devices, single flux quantum circuits, THz detectors, and bolometers [11–17]. Several methods are used to create high-Tc superconducting $YBa_2Cu_3O_{7-\delta}$ (YBCO) thin films. YBCO thin films prepared on a bicrystal sapphire substrate are patterned with Josephson junctions. These YBCO-based devices are made on single-crystal SrTiO3 (STO), $LaAlO_3$ (LAO), and MgO substrates with good superconducting characteristics, the Si-wafer, as well [18]. These substrates have possible matched lattice constants and coefficient of thermal expansion that is excellent candidates for YBCO thin films [19]. The characteristics of grain boundaries are essential for a variety of applications [20–24], including the development of Josephson junctions for superconducting electronics and basic investigations into the symmetry of the pair wave function in HTS's [7]. Aside from crystalline Josephson junctions, grain boundary Josephson junctions include biepitaxial and step edge junctions [8,25,26]. Constrictions, ion irradiation, and ramp-edge junctions are examples of other types of junctions [27]. Up to date, the researchers revolve about improving the electrical properties in YBa2Cu3O7 thin films. That is achieved of construct JJs which formed by high-Tc grain boundary in YBa2Cu3O7.

In this paper, an attempt has been made to highlight the wide range of applications of Josephson junctions, including grain boundary junctions based on YBCO material. The bicrystal approach is the most straightforward method for establishing a grain boundary. The bicrystal approaches have been the most widely employed, owing to their ease of usage and adaptability to various high-temperature superconductor compounds and deposition procedures [1]. As a result, many research groups have found this to be an interesting topic to investigate.

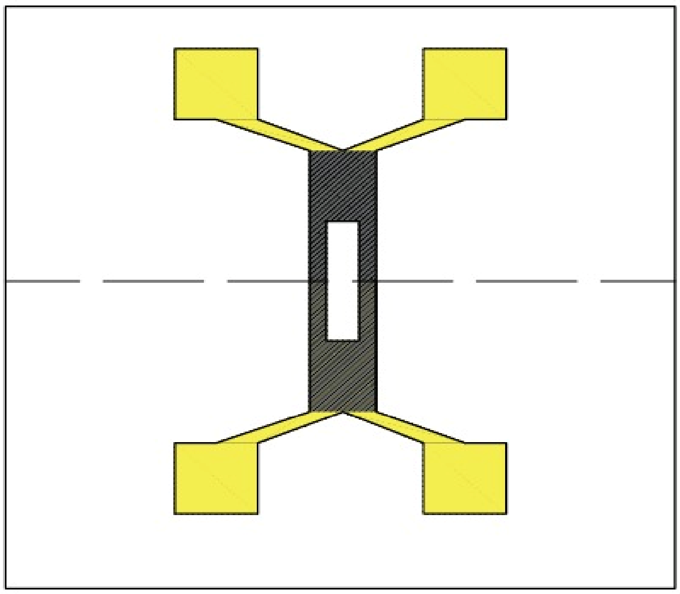

Figure 1 Schematic of junction’s design, the yellow region is covered by gold works as electrodes, the gray region represents YBCO film, and dashed line is grain boundary between bicrystal substrates. The junctions are located where the grain boundary.

2. METHOD

To create samples of grain boundary YBCO JJs, we first have manufactured YBCO-bulk samples and then used them as a target to deposit YBCO thin films. Thus, Y2O3, BaCO3, and CuO served as the experiment's initial components. The methods for producing this synthesis product are available in refs. [28–31]. Liquid nitrogen is used to measure the electrical characteristics of YBCO pellets; its Tc is 83K. The calculated critical current density (Jc) of 23 A.cm-2can be detected.

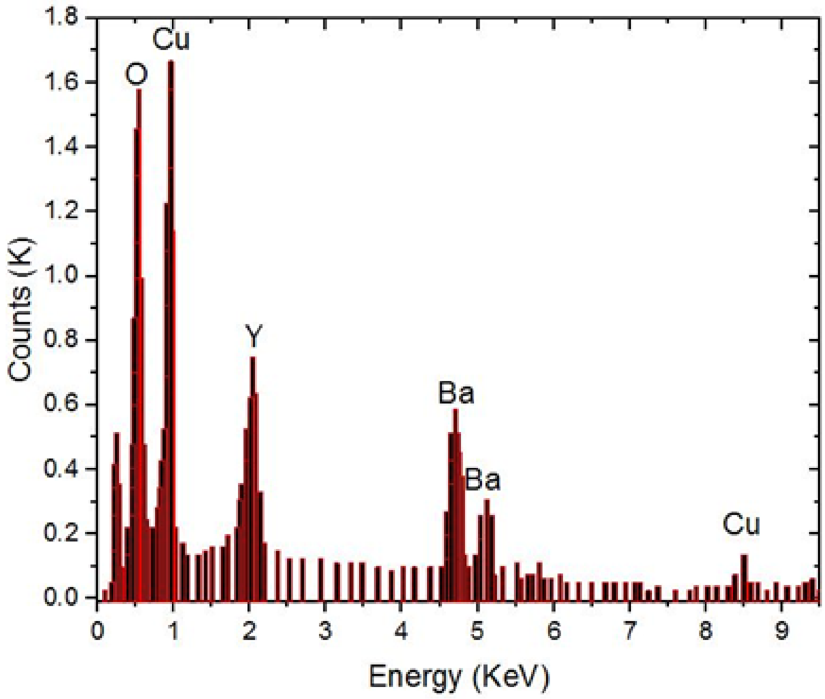

Figure 2 EDX measurements of deposited YBCO thin films. The graph is obtained by counting the respectively emitted photons from individual atoms versus illumination energy.

Thin films of YBa2Cu3O7-δ are deposited on SrTiO3 bicrystal substrates (STO-sub) with varying grain boundary angles. When commercial substrate with 10x10x0.5mm3 is used, promising characteristics can be achieved. The bicrystals are made with two twisted directions [100] and (110)-tilt grain boundary junctions. These had 24° and 30° twist boundaries in the bicrystals, about the common crystallographic axis perpendicular to the grain boundary. The thin films we employed in this investigation are produced on two distinct bicrystalline substrates having misorientation angles of 24 and 30 degrees.

Pulsed laser deposition is used to grow epitaxial c-axis YBCO films with thicknesses ranging from 50 to 250 nm on these 10 by 10 mm substrates under conventional deposition circumstances, followed by a 20 nm Au film. As well, it deposited a gold layer on surface of the YBCO thin-film by DC sputtering to act as electrodes for both shunting resistor and ohmic contact formation. On the STO-sub., the SQUIDs design is constructed using photolithography, D.C. sputtering, and Ar-ion beam etching procedures. The grain boundaries are linked consecutively. By employing a mask and ion beam etching, mask aligner photolithography makes it easy to define the required sample processes. Using this technique, Josephson junctions with a junction width of between 2µm and 12µm across the grain boundaries are prepared. The scheme in Fig. 1 illustrates the SQUIDs design of two JJs. Depending on the fabrication concept; the junctions are systematically characterized in terms of device performance and optimization procedure. The first critical point on the path to the optimal high-Tc Josephson junction is the quality of the base epitaxial YBa2Cu3O7-δ thin-film electrode with diverse c-axis orientations. It can measure independent IVC with four linked electrodes.

3. MEASUREMENTS

3.1 Energy dispersive X-ray diffraction

The structural characterizations are carried out after the deposition of YBCO thin films. The energy dispersive x-ray diffraction (EDX) is utilized to figure out what's in the YBCO thin films that are produced. The EDX result indicates (see fig.2) that the concentration of materials shows 7.62%, 17.16%, and 23.11%) for Y, Ba, and Cu, respectively. That is calculated by counting the photons released by individual atoms as a function of illumination energy. The correct stoichiometry can be considered to have been acquired.

3.2 XRD

The crystal structure of the films is determined by using X-ray diffraction (XRD) patterns, a useful technique for identifying crystalline phases in epitaxial growth YBCO-films on (110) bicrystal STO substrate and assessing structural parameters like stress, grain size, crystal orientation, and defects of various phases. A Philips X-ray diffractometer with CuK=1.5418A° is used to make the XRD measurements. At angles ranging from 10 to 70 degrees are applied to the sample. In the film crystalline structure, the curves of the YBCO (002), (003), (004), (005), (006), and (007) peaks reveal a strong c-axis orientation. Fig. 3 shows the XRD patterns measurements of the YBCO thin film sample produced at optimal growth conditions. In addition, it is performed X-ray diffraction on the produced samples. The analysis of the material is to show the orthorhombic YBCO film crystal structure.

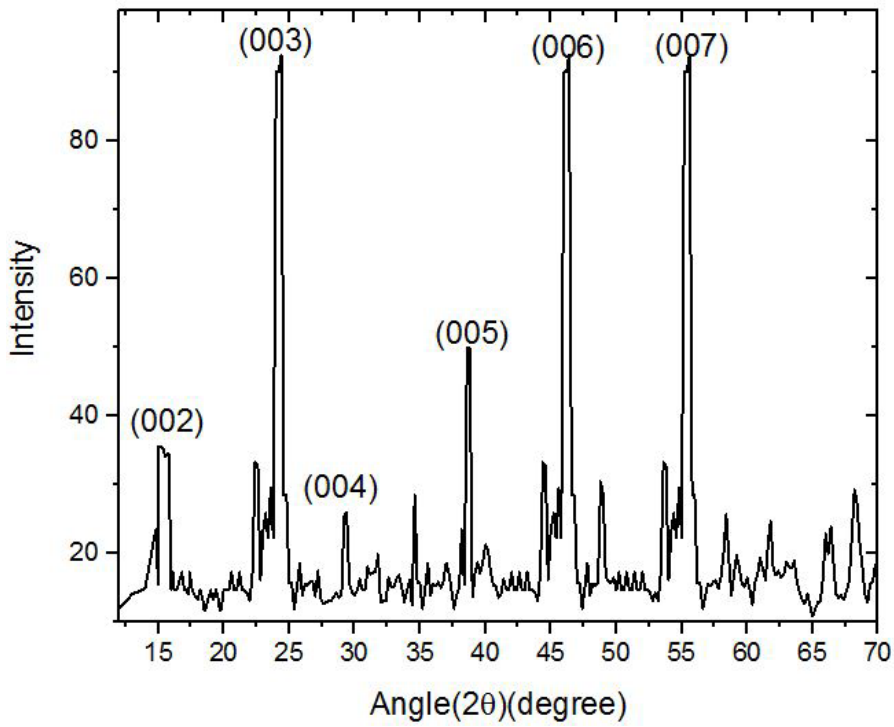

Figure 3 X-ray diffraction pattern for YBCO thin films.

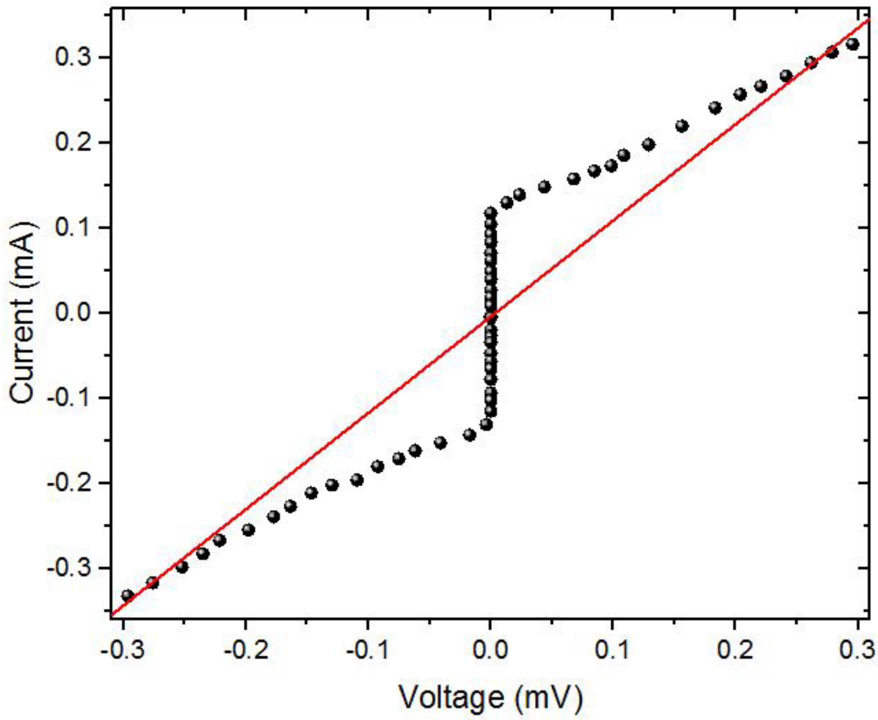

Figure 4 I-V characteristic measurements with higher accuracy showing the behavior of junction's 8μm width on 24-degree bicrystal STO substrate.

Concerning the current-voltage characteristics (I-VC), The I-VC of the junctions are defined in terms of bicrystal substrate orientations of 24 and 30 degrees and junction widths of (2-12) μm. The I–VC of YBCO-JJs is measured at 77 K. The temperature can be easily achieved with a low-cost system.

This IV measurement illustrates the current carrying characteristics of grain boundaries made with bicrystal technology. The junctions show a typical IVC, illustrated in Fig.4 and Fig.5 When compared to an ohmic line, the symmetric I V curves are evident. The RSJ model can be used to characterize Josephson's behavior. [32, 33]. Thus, the research revealed that the critical current (I_c) of JJs that determined by the misorientation angles for (24°), (30°), which equals (0.14mA), (0.66mA), respectively. When Ic determined, it has been considered within voltage criterion 2μV. The ohmic resistance can be derived from the I-V characteristics, which equals R_N (R_N is the normal-state resistance injunctions), (1.1311Ω) (0.674Ω), for (24°), (30°) respectively. To produce a significant higher junction characteristic voltage (V_c) equal I_cR_N, thus its most essitional parameters are I_c and I_cR_N-product. For the needs. It is in order to employ it for upcoming applications. The junction factors can be adjusted or improved to somewhat greater degree [16]. I_cR_N-products are equal to be (158.4μV), (445μV), (24°), (30°) respectively. There is a clear decrease in I_c with increasing angle. This decreasing of the electrical characteristics of the thin film is due to some reasons, including the influence of magnetic field during measurements, etching conditions, varying junction widths, and using the solvent materials (like water, and acetone) is the most common cause. The I-VC also is influenced by the homogeneity of thin films. However, that result is predictable in d-wave superconductor symmetry, where the superconducting coupling strength varies depending on the direction [34]. The results of I_c are in agreement with other works of literature [1-7]. The I-VC properties are influenced by the region of such interfaces, and, most likely, the grain boundary barrier as well as its micro-structure.

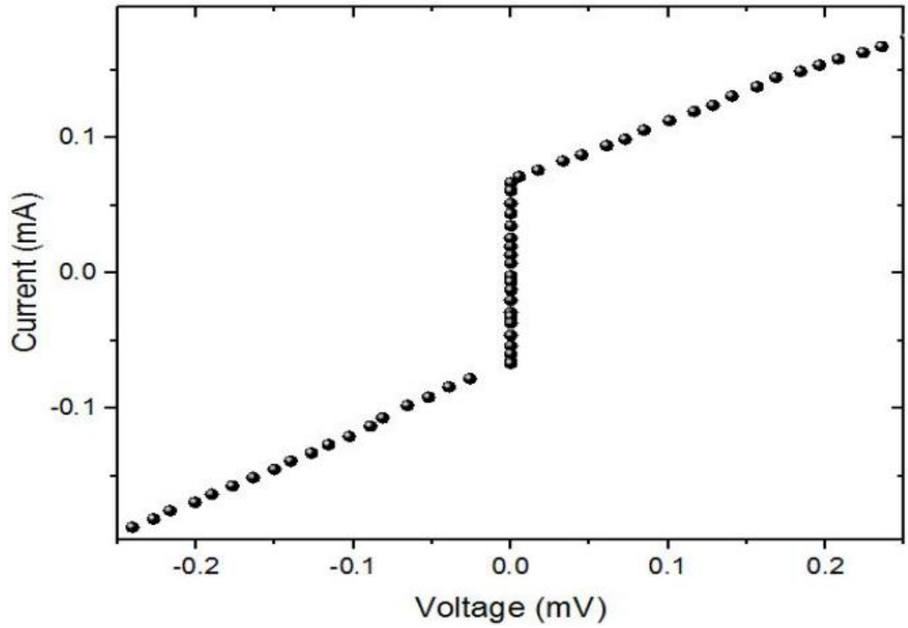

Figure 5 I-V characteristic measurements with higher accuracy showing the behavior of junctions 8µm width on 30-degree bicrystal STO substrate.

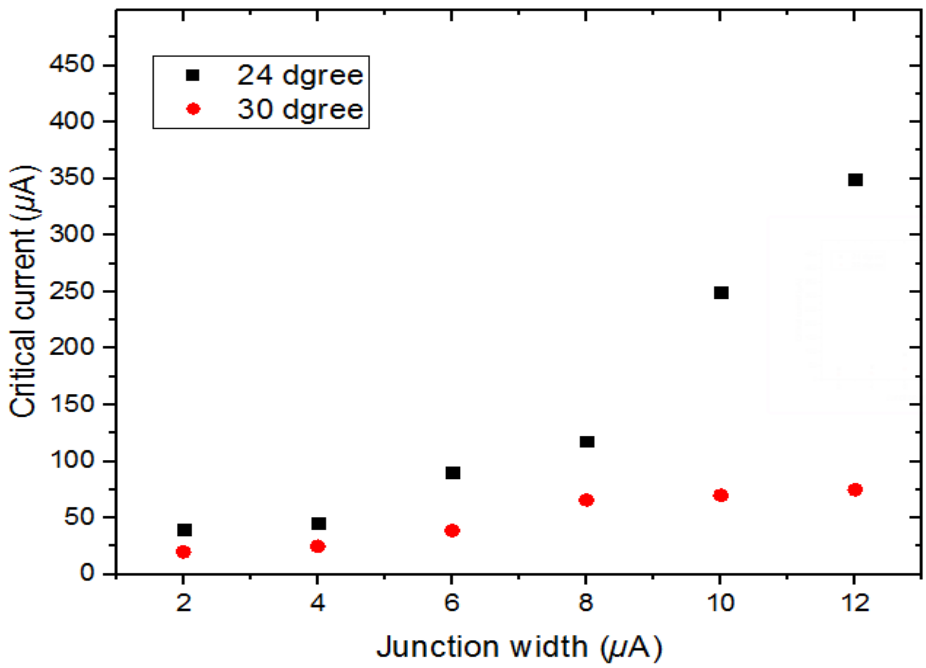

Figure 6 The extracted critical current (I_c) with different junction widths dependence (24, 30) degree crystal STO substrate.

4. CONCLUSIONS

In this study, it is fabricated SQUIDs GBJJs setup on YBCO with two altered tilt geometries: 24° [001] tilt, and 30° [001] tilt. SrTi03 (STO) bicrystalline substrates were used to build Josephson's junctions and thus formed SQUIDs. The deposited film on bicrystal substrates by PLD systems showed good results. The effect of a thin film of $YBa_2Cu_3O_{7-\delta}$ (YBCO) on the I-V characteristics of different angles in Josephson junctions with bicrystal grain boundaries (GBJJs) was investigated. This study focused on different junction widths, ranging between (2-12) μm. These widths have various dimensions and distributions and different impacts on electrical properties. I-V measurements in YBCO SQUIDs GBJJs propose that the decrease in current occurs in the narrow junction's width up to 6 μm.

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