JETI Journal of Experimental Techniques and Instrumentation

Original Paper

I-V characteristic behavior of BSCCO-2223 superconductor under low intensity DC magnetic fields

DOI: 10.30609/JETI.2018-2.5682

Guilherme T. Botega[1]*, Gustavo Q. Freitas[2], Claudio L. Carvalho[3]

[1] IFMS – Instituto Federal de Mato Grosso do Sul, Naviraí, MS – Brasil.
[2] IFGoiano – Instituto Federal Goiano, Rio Verde, GO – Brasil.
[3] UNESP - Universidade Estadual Paulista, Ilha Solteira, SP – Brasil.

Resumo

Electrical characterization of superconductor materials exposed to external magnetic field play an important role for many technological applications. In this paper, the electrical characterization of Bi-2223 pellet prepared by conventional route was performed. The electrical resistance temperature dependence (RxT), showed a superconductor transition at around 105 K. The current-voltage (I-V) behavior under magnetic field and temperature has been investigated, the results point to a power-law dependence between the electrical current (I) and applied voltage (V), at different conditions, as described by the literature. The external DC magnetic field, was produced by a simple home-made apparatus, where a simple copper coil was used to produce an external DC magnetic field between 2,0 mT and 8,0 mT. Then, the dependence of the critical current (Ic) on magnetic field and temperature has been studied, revealing a double step behavior.

Key words: Bi-2223 superconductors, current-voltage characteristics curves, electrical properties, DC magnetic field.

1.- Introduction

High temperature superconductor materials have been extensively investigated in the literature [1-2]. Many studies are devoted to new routes of processing, able to produce fibers, tapes, wires, bulks, thin films, and others, by several techniques [1-7]. Studies regarding the superconductor characteristics, such as, electrical, magnetic and structural properties are the most common.

The $Bi_2Sr_2Ca_2Cu_3O_x$ (Bi-2223) can be cited as the most interesting system, exhibiting critical temperature at around 110 K [8], many studies are devoted to improve the understanding of the dominant mechanism that limit the Ic in applications under external magnetic fields.

The oxide superconductors are commonly called Type 2. The critical temperatures (Tc) associated with them are much higher than those of superconductors based on metallic alloys [1,9]. The oxide superconductors were discovered in 1986 by Georg Bednorz and Alex Mueller. They realized that the league had distinct characteristics of conventional superconductors, Type 1. The transition to the superconducting state was gradual, with the presence of an intermediate state. Moreover, the Meissner effect was not perfect: the material allowed the penetration of a magnetic field, hence contrary to the type-1 superconductors.

The Type 1 presents the complete Meissner effect for values of applied magnetic field (H_a) below of H_c (critical magnetic field). For H_a over H_c the sample behaves like a normal material allowing the penetration of the field. While, type 2 presents the complete effect until the lower critical field H_{c1}. From H_{c1} the penetration of the field into the sample begins and the fluxoids appear [2].

The density of the fluxoids increases when approaching the upper critical field H_{c2}, at which, the superconductivity disappears completely from the material. Between H_{c1} and H_{c2}, the superconductor is in a "mixed state", where the nucleus of the fluxoids is in the normal state, and the rest of the material remains in a superconducting state. In this field range, it is possible to say that an incomplete Meissner effect is observed [9,10].

In this paper, a study is performed based on the effect discovered by physicists Walter Meissner and Robert Ochsenfeld, better known as the Meissner effect [9]. The superconductors are not only perfect conductors, but also exhibit perfect diamagnetism.

2.- Experimental

2.1- Sample preparation.

Superconducting ceramics of the $Bi_{1.6}Pb_{0.4}Sr_{2.0}Ca_{2.0}Cu_{3.0}O_x$ system were prepared, by chemical process [11]. The precursor polymeric resin was dried in an electric furnace at 100°C for 24 hours, the resulting powder was submitted to a several thermal treatments at 600°C/24hs, intercalated by milling steps in an agate mortar.

Finally, 6.0 g of the obtained powder was used to produce pellets with 1,0 mm thick and 20 mm of diameter, by uniaxial pressing applying 9 Tons at room temperature. Finally, the pellets were sintered at 840°C for 100 hours, in air atmosphere, by using a heating hate of 120°C/h and a cooling rate of 300°C/h.

2.2- Sample Characterization.

The temperature dependence of electrical resistance (RxT) and current density (IxV) measurements were performed by using the DC four probes method. First, the electrodes were painted with conductor silver ink over the BSCCO pellet surface, then the RxT measurements were carried out from room to liquid nitrogen temperature (300K – 77K), by using an automatic home-made system which employs a temperature sensor DT470 SD from Lake Shore Cryotronics and a Dewar with liquid nitrogen to temperature control.

The electrical measurements were carried out by using a programmable voltage/current source model 228A, a nanovoltimeter model 2182, and a high performance multimeter DMM model 2000, all of them from Keithley Instruments. The external magnetic fields were applied perpendicular pellet surface direction, Figure 1, by using a small home-made copper coil, which was previously characterized by using a gauss meter model MG 2000-20, the final dimensions of the coil were of around 8,75 mm in thickness and 2,24 in diameter.

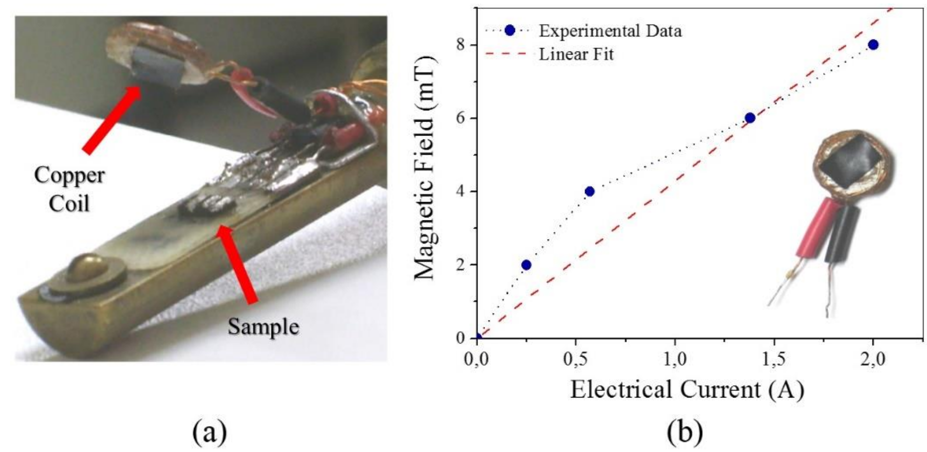

Figure 1: Plot of the magnetic field generated by the coil according to the applied electric current.

3.- Results and Discussion

The temperature dependence of DC electrical resistance (RxT) for the BSCCO ceramic pellet is shown at Figure 2. By decreasing of the temperature a one step drop of the resistance value was observed at 105 K (as evidenced by the inset RxT derivative curve), this critical temperature can be attributed to Bi-2223 superconductor transition.

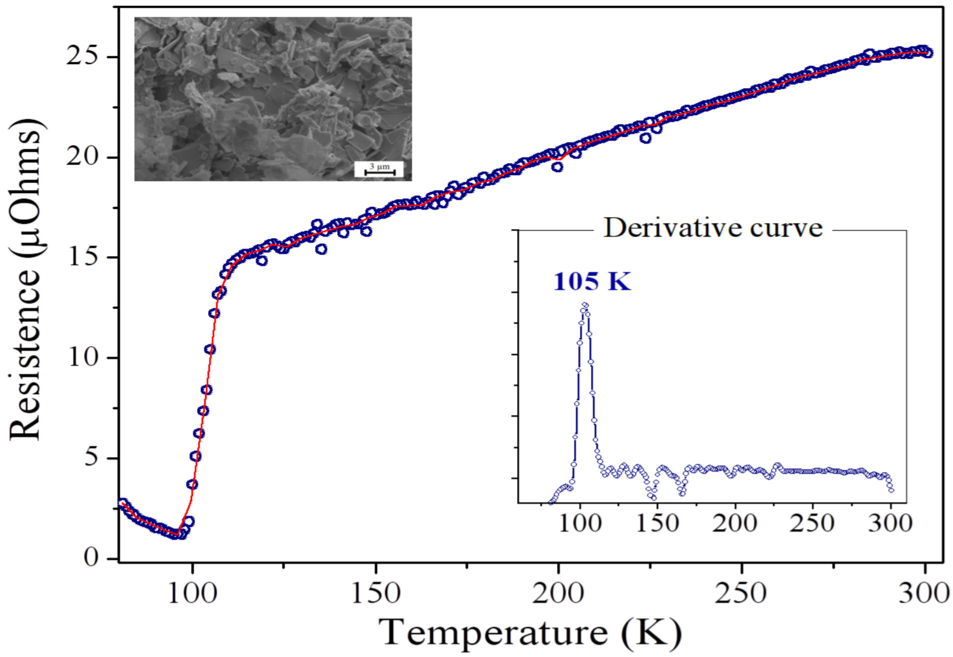

Figure 2: Resistance versus Temperature (RxT) measurement showing the superconductor transition (derivative curve inset). Sample surface image obtained by Scanning Electron Microscopy (SEM) showed inset.

The electrical characterization performed at 80K, Figure 3, revealed a loss of superconductivity occurs approximately 50 mA at zero magnetic field, and it is successively interrupt around 40 mA, 30 mA, 20 mA and 15 mA when external magnetic fields of 2,0 mT, 4,0 mT, 6,0 mT and 8,0 mT are applied, respectively. The critical current (Ic), showed to decreases considerably with increasing magnetic field, this result is in accordance with the behavior described theoretically, which describe a polynomial type dependency between the applied voltage and electrical current [9].

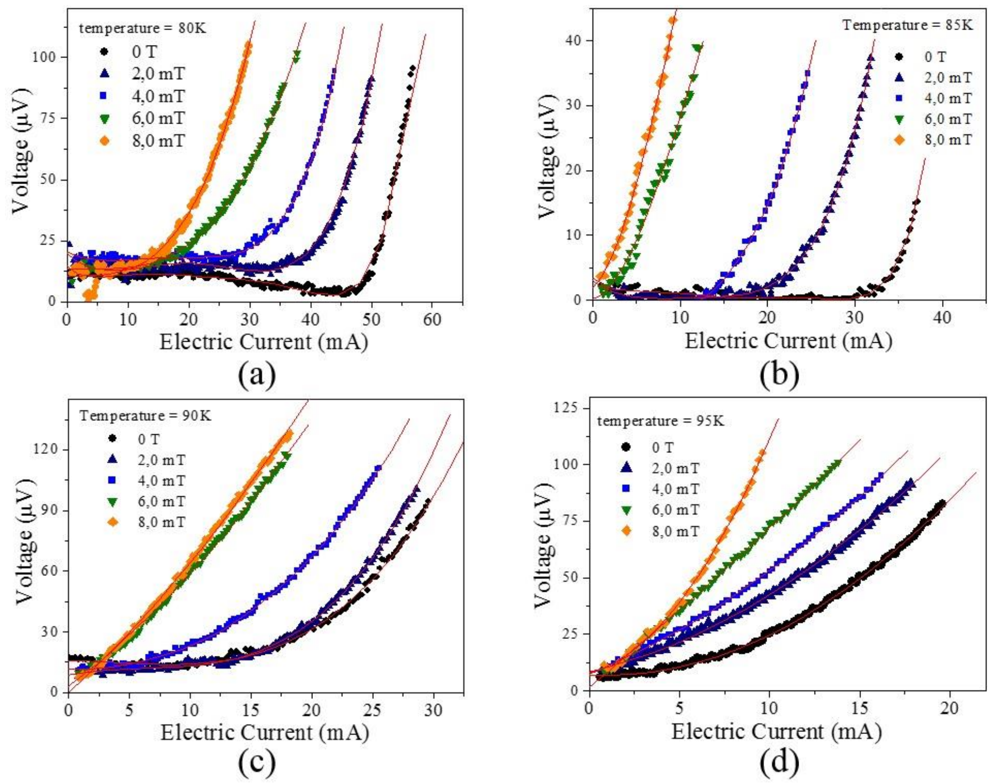

Figure 3: Characteristic curves of voltage versus electrical current for different external magnetic fields at 80K.

A similar behavior were observed at 85K, Figure 4, the applied current of loss superconductivity was around of 34 mA at zero external magnetic field. The critical current (Ic) decreases considerably with increasing magnetic field. The observed Ic was around 20 mA, 17 mA, 3 mA and 1 mA when a external magnetic field of 2,0 mT, 4,0 mT, 6,0 mT and 8,0 mT was applied respectively. Complementary measurements taken at 90K, shown in Figure 5, show an Ic of loss superconductivity around 17mA at zero external magnetic field.

The critical current (Ic) also decreases considerably with increasing magnetic field. The estimated Ic value at 2,0 mT, 4,0 mT, 6,0mT and 8,0 mT was around of 15 mA, 11 mA, 2 mA and 1 mA, respectively. In the latter case, we observed that the material began to behave somewhat like a normal conductor, it can be understood as material is still partly in a superconducting state, but a small fraction is going to exhibit a normal conduction state.

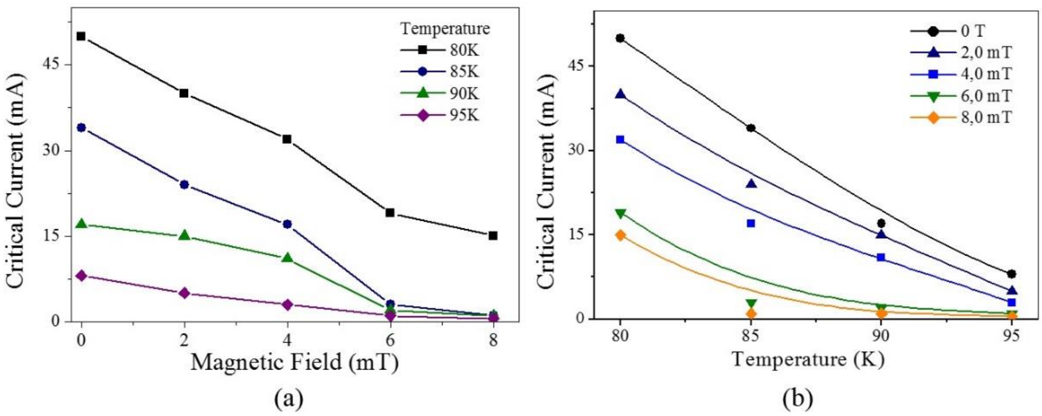

Figure 4: Characteristic curves of the critical current as function of (a) Applied external magnetic field at different temperatures, and (b) Temperature at different magnetic fields.

The Figure 5(a) shows that the decay of the critical current is almost linear from zero to 4,0 mT external magnetic fields at all temperatures investigated. This behavior is in accordance with the expression by Ginzburg-Landau5, equation B, considering that Ic is the maximum electrical current applied to the superconductor before it change to the normal state, and for the highest temperature the curve decline is smaller because it is closer to the critical temperature. It is possible that this decreasing effect of the Ic with the applied magnetic field is due to the increase of fluxoids, because with larger or more intense magnetic fields, the number of regions or islands in the sample in a normal state increases (the core of the fluxoids is in the normal state), given that the sample is in a mixed state.

This implies that a smaller amount of the sample is in a superconducting state, therefore, the critical current tends to further decrease. It can be noted in Figure 5(b) that when the temperature of the sample increases, the Ic has to decrease, similar to the Ginzburg-Landau equation that has a $I_C \propto \left(1 - \frac{T}{T_C}\right)^{3/2}$ behavior, because as the temperature increases, there is a greater vibration of the atoms, thus there is a greater loss of Cooper pairs limiting the amount of pairs in the material [12-16].

4.- Conclusions

Increasing the temperature of the material close to the critical temperature, the critical current significantly decreases, considering the null magnetic field applied. The temperature recommended for applications of superconducting materials must remain 30% below the critical temperature, in this case 77 K, therefore the critical temperature is at around 110 K. Based on the characterization performed, it can be stated that the oxide superconductor system BSCCO obtained in this work has a sensitizing characteristic with small magnetic fields, it can be cooled with liquid nitrogen, has a relatively low cost and, can be used as sensors, however, for not very intense magnetic fields. The medical area is among the areas of application, using of so-called SQUIDS (Superconducting Quantum Interference Devices) sensitive for extremely weak magnetic fields generated by electrical processes in the human body.

5.- References

[1] HUANG, Y.; FUENTE, G. F.; SOTELO, A.; BADIA, A.; LERA, F.; NAVARRO, R.; RILLO, C.; IBANEZ, R.; BELTRAN, D.; SAPINA, F.; BELTRAN, A. $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10+\delta}$ superconductor composites: ceramics vs. fibers. Physica C, v. 185, n. 189, p. 2401-2402, 1991.

[2] GOTO, T.; SUGISHITA, T.; KOJIMA, K. A new fabrication process of $Y_1Ba_2Cu_4O_8$ superconducting filament by solution spinning method under ambiente pressure. Physica C, v. 171, n. 5-6, p. 441-443, 1990.

[3] G.Q. FREITAS, J.A. MORETO, C.R. CENA, G.B. TORSONI, C.L. CARVALHO. Estudo das propriedades elétricas e magnéticas de filmes finos supercondutores do sistema BSCCO tratados termicamente em um forno de microondas, Revista Brasileira de Física Tecnológica Aplicada, v.3, p.1-19, 2016.

[4] C.R. CENA, G.B. TORSONI, L. ZADOROSNY, L.F. MALMONGE, C.L. CARVALHO, J.A. MALMONGE. BSCCO superconductor micro/nanofibers produced by solution blow-spinning technique, Ceramics International, v. 43, p. 7663-7667, 2017

[5] G.Q. FREITAS, R. ZADOROSNY, C.R. CENA, J.B. SILVEIRA, J.A. MORETO, C.L. CARVALHO. Preparation and characterization of a homemade Josephson junction

prepared from a thin film sintered in a domestic microwave oven, Materials Research, v.19, p. 295- 299, 2016.

[6] G.B. TORSONI, C.R. CENA, G.Q. FREITAS, C.L. CARVALHO. Synthesis of (Bi,Pb)-2223 superconductor powder by Pechini method, Revista Brasileira de Física Tecnológica Aplicada, v.5, p. 42-53, 2018.

[7] G.Q. FREITAS, J.A. MORETO, C.R. CENA, C.L. CARVALHO. Construção de junções Josephson do tipo ponte obtidas manualmente em uma pastilha de Bi1.6Pb0. 4Sr2. 0Ca2. 0Cu3. 0Ox, Revista Brasileira de Física Tecnológica Aplicada, v.2, 2015.

[8] MAEDA, H.; TANAKA, Y.; FUKUTOMI, M.; ASANO, T. A new high-Tc oxide superconductor without a rare earth element. Japanese Journal of Applied Physics, v. 27, n. 2, p. 209-210, 1988.

[9] Cyrot, M.; Pavuna, D., Introduction to Superconductivity and High-Tc Materials, World Scientific Publishing Co. Pte. Ltd. , 1992.

[10] BRANÍCIO, P. S. Introdução à supercondutividade, suas aplicações e a mini-revolução provocada pela redescoberta do MGB2: uma abordagem didática, Revista Brasileira de Ensino de Física, v. 23, p. 381-390, 2001.

[11] SANTOS, D. I.; CARVALHO, C. L.; SILVA, R. R.; AEGERTER, M. A.; BALACHANDRAN, U.; POEPPEL, R. B. Superconducting films made by spin-coating with acetate solutions. Ceramic Transactions Superconducting, v. 18, n. 3, p. 263-269, 1990.

[12] SHAKED, N. et al. Effect of external magnetic field on the critical current in single and bifilar Bi-2223 tapes. Physica C, v. 354, n. 1-4, p. 237-241, May 2001. ISSN 0921-4534.

[13] CHADDAH, P. Critical current densities in superconducting materials: p. 273-282, 2003

[14] HORNG, L.; CHEN, K. Voltage criterion of transport critical current density for a Bi-based superconducting tape. Chinese Journal of Physics, v. 36, n. 2, p. 378-381, 1998

[15] S. VINU, P.M. SARUN, R. SHABNA, A. BIJU, U. SYAMOPRASAD, Materials Letters 62, p. 4421-4424, 2008.

[16] ZHANG, H.; WANG, Z. H. The superconducting properties of MTG-YBa1.8K0.2Cu3Oy. Materials Letters, v. 57, n. 16-17, p. 2519-2522, 2003.