Physica C 491 (2013) 59–62

Contents lists available at SciVerse ScienceDirect

Physica C

journal homepage: www.elsevier.com/locate/physc

An investigation of the effect of grain size on some properties of intrinsic Josephson junction

Özden Aslan Çataltepe [a,*], Zeynep Güven Özdemir [b], Ülker Onbaşli [c]

[a] Gedik University, Faculty of Engineering, Yakacık/Kartal, 34876, İstanbul, Turkey
[b] Yıldız Technical University, Physics Department, Faculty of Science and Arts, Davutpaşa Campus, Esenler 34210, İstanbul, Turkey
[c] University of Marmara, Physics Department, Faculty of Science and Arts, Rıdvanpaşa cad.3.sok., 85/12, 34730, Göztepe, İstanbul, Turkey

ARTICLE INFO

Article history:
Available online 8 February 2013

Keywords:
Intrinsic Josephson junction
Hg-based high temperature superconductor
Plasma frequency
Effect of oxygen annealing
Effect of grain size

ABSTRACT

Some superconducting parameters of the high temperature superconductors, such as the plasma frequency and the critical transition temperature, depend on the oxygen content of the material. Since the oxygen content is effective on the grain size of the system, the under, optimally and over oxygen doped Hg-based copper oxide layered superconductors, which have the hole type superconductivity, have been investigated in this study. As is known that the concentration of hole type carriers is increased via optimally oxygen annealing. In other words, relatively higher values for the various critical parameters are achieved by the optimally oxygen doping procedure. In this work, the grain sizes of the oxygen annealed samples have been investigated by Scanning Electron Microscopy (SEM). Moreover, the magnetization data obtained via Superconducting Interference Quantum Device (SQUID) has been utilized for calculation of critical current density, which is essential parameter for determining Josephson penetration depth. The Josephson penetration depths of the systems have been calculated by Lawrence–Doniach Model for high temperature superconductors. Since plasma frequency of the system is inversely proportional to Josephson penetration depth, the plasma frequencies of the various doping profiles have also been calculated for the high temperature superconductor investigated.

1. Introduction

Hg-based cuprate superconductors [1–3], which exhibit the highest superconducting Meissner transition temperature, T_c at normal atmospheric pressure, posses the hole type conductivity. As is known, the optimum oxygen doping provides the highest transition temperature via increasing hole carriers for the mercury cuprate superconductors [3]. Also, the procedure of the oxygen doping is profoundly effective on the grain size and the electrodynamics parameters such as the Josephson penetration depth and plasma frequency of the superconducting system. In this context, effects of the oxygen doping process on the grain size, plasma frequency and the critical transition temperature have been investigated.

The dependence of superconducting properties of Hg-based superconducting family on the hole concentration i.e. the oxygen content has been studied by some researchers. The effect of heat treatment with oxygen on the critical parameters of mercury-based superconductors such as the Meissner transition temperature, T_c, the critical supercurrent density, J_c, and the lower and upper critical magnetic fields, B_{c1} and B_{c2} had been previously investigated by Onbaşlı. It had been determined that the over oxygen annealing has a negative effect on the critical parameters of the Hg-based superconducting sample [4]. Moreover, Fukuoka et al. have studied the relationship between T_c and the excess oxygen content by neutron diffraction experiments. Also, Fukuoka et al., had confirmed that the highest T_c value for the Hg-based superconductors is only achieved by the optimum oxygen doping. In addition to these results, the *a*-axis and *c*-axis lattice parameters of Hg-based superconducting samples had been found to decrease monotonically with the increase of the oxygen level [5]. Moreover, the variation of cell parameters, grain size and the critical transition temperature as the function of oxygen concentration for Hg-based superconductor had been studied by Passos et al., and it had been also determined that these parameters are sensitive to oxygen doping procedure [6,7]. Tidrow et al. had demonstrated the relationship between the grain size and oxygen diffusion for high T_c superconductors [8]. The temperature dependence of magnetic susceptibility for $HgBa_2Ca_2Cu_3O_{8+x}$ (Hg-1223) samples had been investigated by Fujinamia et al., who have found that the

* Corresponding author. Tel.: +90 216 5912199; fax: +90 216 5952155.
E-mail address: ozdenaslan@yahoo.com (Ö. Aslan Çataltepe).

0921-4534/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.physc.2013.01.011

oxygen content which is less than or more than the optimal doping level decreases the Meissner critical temperature, T_c [9].

2. Theoretical

As is known, copper oxide planes in cuprate superconductors form common structural layers that are responsible for almost all superconducting properties. According to Lawrence-Doniach (L-D) Model proposed in 1971, which is valid for the high temperature superconductors, the copper oxide layered superconductors are viewed as a stacked array of two-dimensional superconductor, that is coupled together by Josephson tunneling between adjacent layers [10,11]. According to L–D model [10], a two dimensional form of Ginzburg–Landau equations are used to describe superconductivity which occurs between superconducting layers with Josephson coupling. Since $HgBa_2Ca_2Cu_3O_{8+x}$ (Hg-1223) system exhibits Josephson effect via the copper oxide layers within the superconducting material, the superconductor is considered as a stack of nearly ideal, intrinsic Josephson junctions. In this context, L–D model is appropriate for the Hg-1223 superconductor for calculation of some electrodynamics parameters such as Josephson penetration depth, and plasma frequency. In order to determine the electrodynamics parameters, critical current density is a key parameter which is determined by dynamic magnetization versus magnetic field hysteresis curves. The dynamic hysteresis measurements of Hg-1223 samples have been performed by the Quantum Design superconducting Susceptometer, model MPMS-5S. The magnetic field of 1 Gauss has been applied parallel to the c-axis and the critical current flows in the ab-plane of the sample. Obviously, using Bean Critical State Model [12] for the calculation of the critical current density, J_c is appropriate, since all calculations have been made below the lower critical magnetic field, B_{c1} where the whole magnetic flux has been totally expelled from the sample. The critical current density, J_c values have been calculated by the equation:

$$J_C = 30\frac{4\pi\Delta M}{t} \tag{1}$$

where ΔM is the magnetization difference between the increasing and decreasing field branches and t is the average grain size of Hg-1223 samples [13,14].

According to the scientific literature, Josephson penetration depth, λ_j, is considered as a measure of the magnetic penetration depth of the field induced by supercurrent [15–17]. Furthermore, the maximum current is essentially limited to J_c over a surface layer of thickness λ_j [11,13]. The λ_j quantity is defined by the formula:

$$\lambda_J = \sqrt{\frac{c\Phi_0}{8\pi^2 J_C s}} \tag{2}$$

where Φ_0 is the flux quantum, c is the speed of the light and s is the average spacing of copper oxide bilayers [13,15]. The other crucial electrodynamics quantity is c-axis plasma frequency, f_p, which is equivalent measure of the electromagnetic coupling [18]. f_p is given by the equation

$$f_p = \frac{c}{2\pi\lambda_j} \tag{3}$$

The main Josephson plasma excitation modes in weakly Josephson coupled layered superconductors are the longitudinal mode along the c-axis and transversal mode in the ab-plane. Whereas the transverse-mode plasma oscillations can be converted into electromagnetic waves at the boundary of the junctions [19], the longitudinal plasma propagation modes in an array of intrinsic Josephson junction (IJJ) do not lead the electromagnetic wave radiation. Since the electromagnetic wave has only transverse mode [20,21]. It has been proved that the electromagnetic coupling energy along the c-axis, which couples the CuO_2 planes, is responsible for the pairing mechanism in the Hg-1223 superconductor. The two-dimensional Bose Einstein Condensation (BEC), carried out by the electron pairs in the ab-plane of superconducting copper oxide layers, has been extended to all layers along the c-axis via quasi-particle tunneling at the Josephson plasma resonance frequency [13,21].

3. Effect of oxygen content in the high temperature superconductors

Primitive cells of all oxide high temperature superconductors contain one or more superconducting copper oxide layers and insulating layers. There are three types copper oxide layers in high temperature superconductors; (1) CuO_6 octahedron, (2) CuO_5 triangle pyramid, (3) CuO_4 square.

The schematic representation of copper oxide layers are given in Fig. 1. The distinguished property of copper oxide layers in Fig. 1 is that the oxygen atoms connect to the copper atoms in-plane or out off-plane (apical).

In octahedron construction, oxygen atoms settle not only under the copper oxide layers but also above the layer (Fig. 1a). In triangle pyramid structure, the oxygen atoms are only found above layer (Fig. 1b). In square type, there is no apical oxygen in the structure by means of all oxygen atoms join to the copper atoms in the plane (Fig. 1c). The superconductors, which posses copper oxide layers with the shape of octahedron and triangle pyramid,

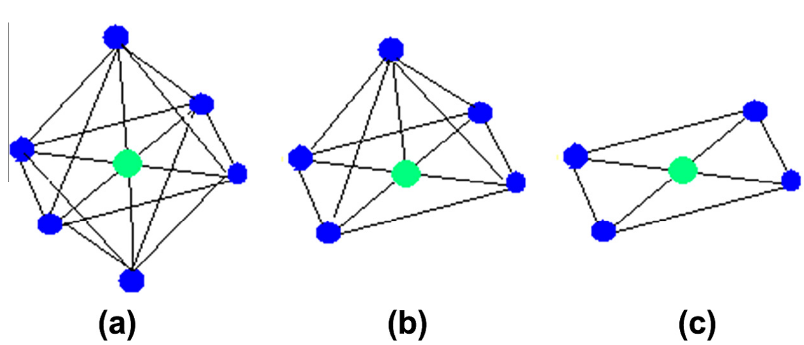

Fig. 1. In high temperature superconductors, the schematic representation of copper oxide layers (a) Octahedron (b) Triangle pyramid and (c) Square. In figure, green and blue atoms show copper and oxygen atoms, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)