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Electromagnetic resonances in YBaCuO bicrystal grain boundary Josephson junctions.

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Electromagnetic resonances in large YBaCuO grain boundary Josephson junctions are studied as a function of the magnetic field. These electromagnetic resonances appear as bumps in the I(V) characteristics at low temperatures. From the study of these bumps it is possible to obtain information on the stuctural parameters of the junction and on the YBaCuO magnetic field penetration depth.

1. INTRODUCTION

From measurements of the periodicity in the magnetic field dependence of the critical current $I_c(B)$ of YBaCuO grain boundary Josephson junctions (GBJJ), it is possible to obtain information on the ab plane magnetic penetration depth λ_{ab} (B applied perpendicular to the c-axis YBaCuO film) [1,2]. The behavior of $\lambda_{ab}(T)$ is important for the problem of d-wave superconductivity invoked for the cuprates. However the periodicity in the Fraunhofer pattern can be seen only in the case of narrow junctions when the length W of the junction is smaller than the Josephson penetration length $\lambda_J = (\Phi_0/(2\pi\mu_0 dJ_m))^{1/2}$ where J_m is the maximum critical current density and $d = 2\lambda_{ab}+t \approx 2\lambda_{ab}$. At low temperatures, λ_J decreases and no simple periodicity can be seen. However, these large GBJJ can exhibit electromagnetic resonances which appear as bumps on the I(V) curves at low temperatures. From the study of these bumps (positions, amplitude, width) it is possible to obtain information on the stuctural parameters of the junction (thickness t and dielectric constant ε of the barrier) and on λ_{ab} at low temperatures.

2. RESULTS

Details of the fabrication of the GBJJ can be found elsewhere [1]. YBaCuO epitaxial thin films were deposited on a bicrystal $SrTiO_3$ (100) substrate using an excimer laser ablation process. The tilt angle of the bicrystals is 38.6°. The critical temperature and the normal resistance of the GBJJ are T_c= 84 K and R = 0.98 Ohm.

Fig. 1 shows two typical Fraunhofer patterns at 12 K and at 65 K. At 65 K it exhibits a rather good magnetic field periodicity. This means that the successive extrema vary linearly versus the magnetic field positions as shown in the insert. It means also that, at 65 K, the length W = 21 μm of the junction is smaller or of the order of $2\lambda_J$. As the temperature decreases, the Fraunhofer pattern degrades and at 12 K, the same junction shows no well defined periodicity. This means that $W > 2\lambda_J$. At these low temperatures, it is not possible to obtain information on λ_{ab} from the $I_c(B)$ curve as it was obtained on short GBJJ [1].

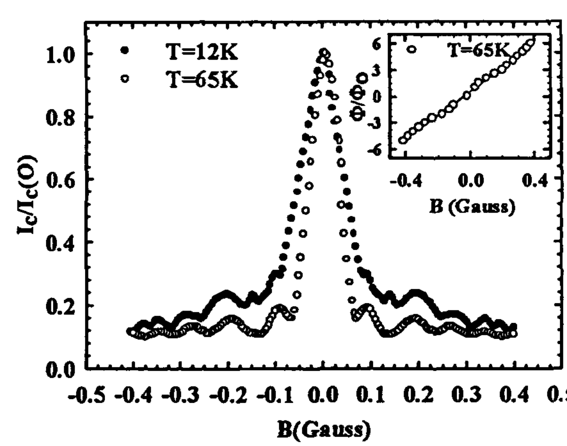

Fig.1 Fraunhofer patterns at 12 K and 65 K of a large GBJJ (length 21 μm). In the insert are shown the successive magnetic field positions of the extrema for T = 65 K.

Fig.2 shows a typical I(V) characteristic of this GBJJ at 12 K. We observe a well defined bump in the I(V) curve. The insert shows the bump obtained when we substract the background obtained by a linear extrapolation at low and high voltages. Other authors [3,4] usually determine I - V/R. The amplitude of the bumps oscillates with B and the voltage position V_m varies linearly versus B (fig.3), indicating that these structures are electromagnetic or Fiske resonances [1,5,6].

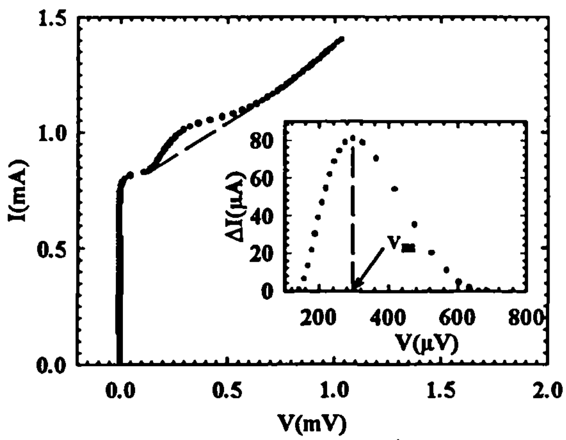

Fig.2 I(V) curve of a GBJJ at 12 K with the bump showed in the insert with substracted background.

3. DISCUSSION

The Josephson alternating current density j = $j_m \sin(\omega t - ky + \alpha)$ generates electromagnetic fields propagating in the barrier along its length y with a velocity c. At a given value of the external field, the maximum of the electromagnetic resonance occurs at a voltage such that $\omega/k = c$ when the phase velocity of the Josephson current density distribution ω/k matches the phase velocity c of the electromagnetic fields in the junction. The amplitude of the bump ΔI is given as a function of the voltage $V = (\Phi_0/2\pi)\,\omega$ and of the magnetic flux through the junction by [5]

$$\Delta I = [I_m/Q][c/2\lambda_J\,\omega]^2.\, f.\{[1 - k^2c^2/\omega^2]^2 + 1/Q^2\}^{-1}$$

where f is an oscillating function of the magnetic flux [1,5]. The Swihart velocity c is related to the light velocity in vacuum c_0, the thickness t of the barrier and its relative dielectric constant ε by $c = c_0(t/\varepsilon d)^{1/2}$. The amplitude ΔI which is field dependent has a maximum amplitude for B = 0.125 Gauss. In that case $f \approx 1.2$ and

$$\Delta I_{max} = 1.2\, I_m Q[c/2\lambda_J\omega]^2 = 0.3\, I_m\, Q[W/2\pi\lambda_J]^2$$

where the even mode (n=2) has been considered for this large junction for which $c = V_m.W/\Phi_0$. The quality factor $Q \approx 1.8$ can be estimated from the width ΔV at half of the maximum of the bump [6]. Taking the experimental values ΔI_{max} = 192 μA; I_m= 230 μA and W = 21 μm we find λ_J = 2.7 μm. From the expression of λ_J we can determine d = 320 nm at 12 K. This result is in good agreement with the value found from the Fraunhofer pattern for small junctions [1,2]. From the value of the Swihart velocity $c = 5.25.10^6$ m.s^{-1} corresponding to V_m = 0.5 mV, we can find t/ε = 0.1 nm which gives a thickness barrier of the order of the ab plane coherence length.

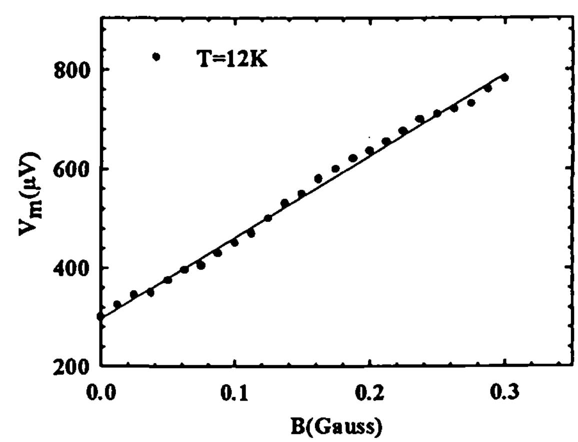

Fig.3 Magnetic field dependence of the voltage position of the maximum of the bump.

4 CONCLUSIONS

From the study of the electromagnetic resonances in large GBJJ, it is possible to obtain information on the structural parameters of the barrier and on the magnetic field penetration depth at low temperatures.

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