MICROWAVE ABSORPTION AND MAGNETIC PENETRATION DEPTH IN NEW SUPERCONDUCTOR YBa2Cu3O7-δ

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MICROWAVE ABSORPTION AND MAGNETIC PENETRATION DEPTH IN NEW SUPERCONDUCTOR $YBa_2Cu_3O_{7-\delta}$

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Abstract. – The microwave signal upon excitation of $YBa_2Cu_3O_{7-\delta}$ by 9.2 GHz microwaves has been analysed. The critical exponent of the signal strength has been found to be $(T_c - T)^{2.7}$. The imaginary part of the complex susceptibility as a function of magnetic field is found to exhibit flux quantization.

We wish to report that the derivative $d\chi''/dH$ as a function of magnetic field is peaked at the Josephson frequency. We thus find that the low field microwave signal is a new manifestation of flux quantization. The compound $YBa_2Cu_3O_{7-\delta}$ ($\delta \simeq 0.2$) has a large superconducting transition temperature, $T_c \simeq 96$ K and shows a strong microwave signal at low magnetic fields [1]. It also shows a structural distortion upon going through the transition temperature.

The Josephson current is given by

$$J = J_0 \sin \left(\gamma_2 - \gamma_1 \quad \frac{2e}{h} \int \mathbf{A}.d\ell \right) \qquad (1)$$

where γ_2 and γ_1 are the phase factors, $\mathbf{A}$ is the vector potential of the electromagnetic wave and the integral is extended over the width of the Josephson junction. Since $A = B \times r$ and $\phi_0 = h/2e$, we can write,

$$J = J_0 \sin \left\{ \delta(0) + \frac{Bx(t+2\lambda)}{\phi_0} \right\}. \qquad (2)$$

The maximum current is given by

$$I_{\max} = 2I_0 \frac{\sin\ (\pi\phi_j/\phi_0)}{(\pi\phi_j/\phi_0)} \cos\ (\pi\phi_T/\phi_0) \qquad (3)$$

where $\phi_j = Bx(2\lambda + t)$ with λ as the London penetration depth, t the thickness of the normal barrier, x the width and $\phi_T = nh/2e$ where n is an integer. The amplitude of (1) is related to the gap Δ of the superconductor and to the normal state resistivity R_N of the insulating layer, the surface area of which is S, by the relation,

$$J_0 = \frac{\pi\Delta}{2SR_N}. \qquad (4)$$

The zeros of the current are located at

$$\delta(0) + \frac{2e}{h}Bx(t+2\lambda) = \pi \times \text{integer}. \qquad (5)$$

At these fields the Josephson supercurrent is zero for finite integers and the superconductivity vanishes but on both sides, less or more, of such fields, the system superconducts. The maximum of the spherical Bessel function $(\sin x)/x$, occurs at $x = 0$, so that the maximum current is found for a general solution of

$$\delta(0) + \frac{2e}{h}Bx(t+2\lambda) = 0. \qquad (6)$$

The difference $\delta(0)$ around a closed circuit which encompasses a total magnetic flux ϕ is given by $\delta(0) = (2e/hc)\,\phi$ so that the maximum current occurs for a field of,

$$Bx(t+2\lambda) = \frac{h}{2e} \qquad (7)$$

The Josephson frequency and voltage relationship is given by $\hbar\omega_J = 2$ eV. Therefore, the field at which the maximum current occurs is related to the voltage and the frequency by the relation

$$B = \frac{2\pi V}{x\omega_J(t+2\lambda)}. \qquad (8)$$

We use these relations to develop the understanding of new peaks in $d\chi''/dH$ as a function of field in high temperature superconductors. When a large number of Josephson junctions occur such as in an oxide material, we expect, to find Gaussian behaviour rather than that of the spherical Bessel function $(\sin x)/x$ as in (3). When a system is excited by microwaves of frequency, say 9.2 GHz, the response is given by

$$\chi'' = \frac{\delta\Omega}{(\omega - \omega_J)^2 - (\delta\Omega)^2} \qquad (9)$$

where ω_J is the Josephson frequency. Since the total current is given by the sum of normal and superconducting currents, $J = J_n + J_s$. The Meissner effect is given by

$$c \text{ curl } \Lambda\mathbf{J}_s + \mathbf{B} = 0 \qquad (10)$$

and the supercurrent at $\mathbf{E} = 0$ is given by

$$\frac{\partial}{\partial t}\Lambda\mathbf{J}_s - \mathbf{E} = 0 \qquad (11)$$

where

$$\frac{1}{\Lambda} = \frac{ne^2x}{m}. \qquad (12)$$

In the superconducting state, the response function (9) becomes

$$\chi'' = \frac{\ell \delta\Omega}{\Lambda \xi_0 \left[(\omega - \omega_J)^2 - (\delta\Omega)^2\right]} \tag{13}$$

where $\ell = (\hbar/m)\tau k_F$ is the mean free path of the electron in the normal state and $\xi_0 = \hbar^2 k_F / 2m\Delta$ is the coherence length. In terms of the life time τ of the electron we write (13) as,

$$\chi'' = \frac{2\Delta\tau\delta\Omega}{\Lambda\hbar\left[(\omega - \omega_J)^2 - (\delta\Omega)^2\right]}. \tag{14}$$

In figure 1 we show the low field electron-paramagnetic resonance signal at a temperature of 3 K. There is a large period as expected from the sin term in (3) and in addition the noise is associated with the cosine term in (3). However, the signal disappears for temperatures above 10 K. The height of this signal at the maximum is shown in figure 2 and it follows the gap as expected from (14).

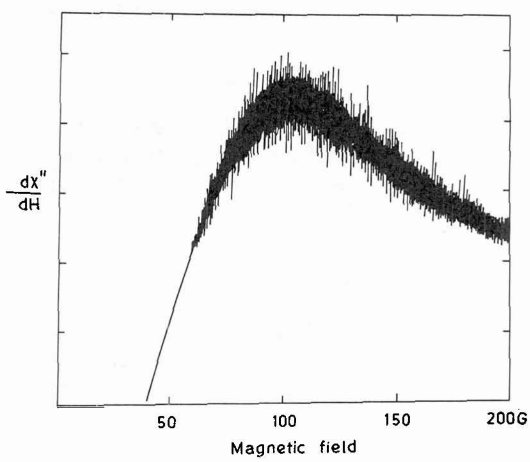

Fig. 1. – $d\chi''/dH$ as a function of magnetic field at a temperature of 3 K. The large period is caused by $(\sin x)/x$ type term and the noise is caused by $\cos(n\pi)$ term which is ± 1 for every e/h flux hopping. The height of this signal called I_c is temperature dependent. The noise signal vanishes for temperatures above 10 K.

According to (7) the peak field of $H = 100$ G of figure 1, corresponds to $x(t + 2\lambda) = 0.2 \times 10^{-8}$ cm^2. Since $t \ll \lambda$ and $\lambda \simeq 200 \times 10^{-8}$ cm, we estimate $x \simeq 10^{-3}$ cm which measures the size of the insulating barriers within a superconductor. The logarithm of the height I_c of the signal of figure 1 is plotted as a function of ln $(T_c - T)$ with $T_c \simeq 92.5$ K in figure 3. It is found that $I_c \sim (T_c - T)^{2.7}$. The exponent of 2.7 is rather unusual. However, we believe that it is caused due to different parts of the sample having different T_c. It is also believed that the different parts of the sample have slightly different chemical formula.

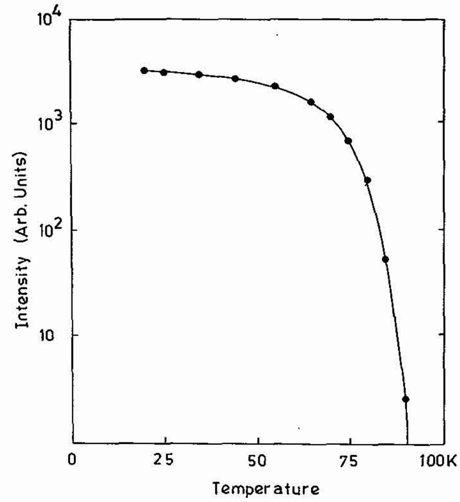

Fig. 2. – The height of the signal of figure 1 as a function temperature appears like a gap with $T_c \simeq 96$ K.

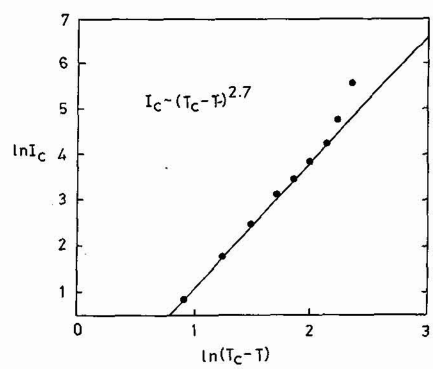

Fig. 3. – The ln I_c with ln $(T_c - T)$ showing the exponent 2.7.

In conclusion, we have found that $d\chi''/dH$ as a function of magnetic field peaks at the Josephson frequency and shows flux oscillations. The discovery of high-temperature superconductivity by Bednorz and Müller [2] has thus opened the doors to a whole wide variety of new effects. The noise signal seen here has a T_c of about 10 K while the large period has a $T_c \simeq 92.5$ K. The signal of large period has also been seen by Blazey *et al.* [3] independent of our work [4].

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[4] Shrivastava, K. N., *Solid State Commun.* **68** (1988) 259.