Bull. Mater. Sci., Vol. 14, No. 3, June 1991, pp. 803–806. © Printed in India.

Investigation of high temperature superconductivity through microwave absorption method

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Abstract. The field dependence and near zero magnetic field microwave absorption as a function of rf power in $YBa_2Cu_3O_{7-\delta}$ and Bi-Ca-Sr-Cu-O has been studied using a varian ESR spectrometer. A model of microwave absorption built on diamagnetic tensor susceptibility has been proposed which explains the observed results satisfactorily.

Keywords. Y-Ba-Cu-O; Bi-Ca-Sr-Cu-O; microwave absorption; ESR.

1. Introduction

The microwave absorption in oxidic superconductors has been extensively studied (Durny *et al* 1987; Blazey *et al* 1987; Stankowski *et al* 1987; Khachaturyan *et al* 1987; Sastry *et al* 1988; Shvachko *et al* 1989; Pozek *et al* 1989). In a dc magnetic field microwave absorption shows a maximum near zero field and begins to decrease as the field is increased. At some fields depending on the composition and microstructure the absorptions tends to saturate (Shvachko *et al* 1989). Despite considerable effort the origin of absorption is not understood. To investigate the nature of the absorption we have investigated the microwave absorption properties of superconducting ceramics of the composition $YBa_2Cu_3O_{7-\delta}$ and $Bi_2Ca_3Sr_2Cu_2O_{8\pm y}$.

2. Experimental

The ceramic samples were prepared by the standard solid-state reaction procedure using powder of Y_2O_3, $BaCO_3$, CuO, Bi_2O_3, $SrCO_3$ and $CaCO_3$. The X-ray diffraction pattern and the temperature dependence of resistance show that the $YBa_2Cu_3O_{7-\delta}$ systems are single-phase materials with $T_c = 90$ K whereas $Bi_2Ca_3Sr_2Cu_2O_{8\pm y}$ system is a mixed phase system with zero resistance at 80 K. All ESR measurements were carried out on a variable temperature standard E-varian 9.2 GHz ESR spectrometer. Spherical samples with diameters 1 mm to 2.5 mm and powdered sample ($d \sim 10\,\mu$m) were used for the measurements. A rectangular TE_{102} cavity with the microwave power varying from 0.005 mW to 15 mW was used. The external magnetic field, oriented perpendicular to the microwave field (h_{rf}), was varied from 0 to 6.5 KOe. Hf-modulation (100 kHz) had an amplitude in the range 0.5 Oe to 2 Oe.

3. Results

The field dependence of the microwave power loss (dP/dH) with the magnetic field for different superconductors is presented in figures 1 and 2. The absence of any ESR signal at room temperature for $YBa_2Cu_3O_{7-\delta}$ samples taken from two different batches as denoted by R1 and R1A indicates that the samples are of a good quality. Figure 1 shows the low-field microwave absorption at 77 K for different samples with field span of 0 to 400 Oe. Figure 2 shows the hysteresis behaviour of a polycrystalline sphere and the powder sample taken from the same batch R1 with field span of 0 to 6500 Oe. The dependence of microwave power absorption on the rf-power near zero magnetic field is presented in figure 3. The magnetization curves for the spherical and powdered samples obtained at 77 K by a Faraday balance are given in figure 4. It is noted that the hysteresis behaviour of the absorption and the magnetization curve is similar.

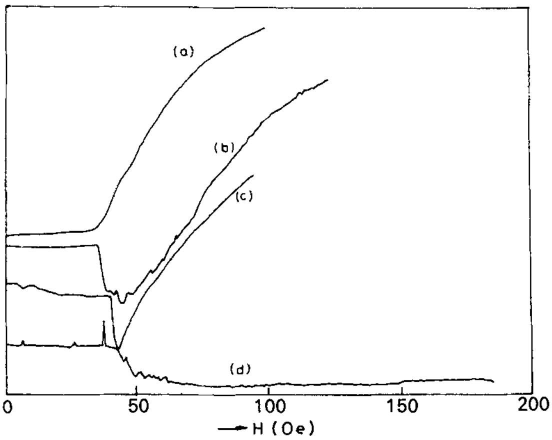

Figure 1. Low field microwave absorption at 77 K with field span of 0 to 400 Oe. (a): 1–2–3 sphere from batch R1A, (b): 1–2–3 sphere from batch R1, (c): BSCCO sphere and (d) 1–2–3 powder from batch R1.

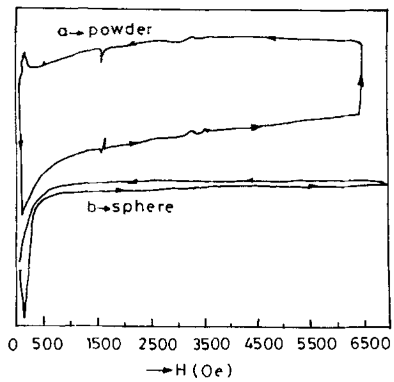

Figure 2. Hysteresis behaviour of a polycrystalline sphere and the powder sample taken from the same batch R1 with field span of 0 to 6500 Oe. (a) powder, and (b) sphere.

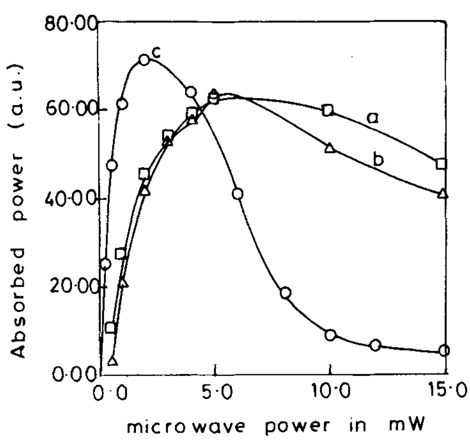

Figure 3. Dependence of microwave power absorption on the rf-power near zero magnetic field at 77 K. (a) 1–2–3 sphere from batch R1, (b) 1–2–3 sphere from batch R1A, and (c) BSCCO sphere.

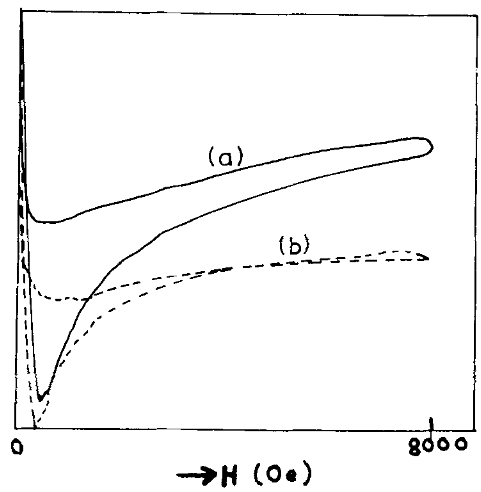

Figure 4. Magnetization curve for (a) powder and (b) spherical samples obtained at 77 K with a field span of 0 to 8000 Oe.

4. Discussion

Several mechanisms for the large microwave absorption below T_c have been proposed. Amongst these are absorption due to diamagnetic a.c. susceptibility of a granular superconductor (Durny *et al* 1987). Suggestions that these may arise from changes in x_{dia} upon transition from the Meissner phase to the mixed phase have also been made (Blazey *et al* 1988; Rettori *et al* 1987). Attempts have also been made to attribute it to flux penetration through weak links between superconducting regions (Stankowski *et al* 1987; Khachaturyan *et al* 1987; Shrivastava 1987).

Based on the present study and the data available in literature the significant experimental results are as follows. (i) The zero field microwave absorption intensity follows approximately the $|\vec{\mathbf{M}}|$ vs H curve where $\vec{\mathbf{M}}$ is the magnetization of the sample (ii) Initially the absorption is independent of the biasing field, H_0. However at a field H_0^* there is a discontinuity in the intensity of absorption and further increase in H_0 leads to a rapid decrease in absorption leading to saturation at a field of the order of 200 Oe for polycrystalline spheres. For powder samples saturation is not reached even at 6500 Oe. (iii) There is hysteresis in the absorption curve which is very pronounced in powder samples.

We propose a model based on the interaction between the Meissner and shielding currents produced by the bias, modulation and rf fields. Since the rf field is orthogonal to the bias and modulation fields the relation between magnetization and the field could be described by a complex tensor susceptibility **X**.
We obtain for

$$H_{rf} = H_{x1}\exp(j\omega t)$$
$$H_{\text{bias}} = H_{y0} + H_{y1}\exp(i\Omega t) \tag{1}$$

and $H < H^*$ the power loss from Meissner currents

$$P_M = a\lambda^2(\omega^2+\Omega^2)^{1/2}x''_{xy}H_{x1}H_{y1} + a^2\lambda(\omega x''_{xx}H^2_{x1} + \Omega x''_{yy}H^2_{y1}). \tag{2}$$

Here λ is the penetration depth and a is the radius of the spherical sample. For $H > H^*$ the superconductor is in the mixed state. The power absorbed due to shielding current is given by

$$P_s = a^3\Omega x''_{yy}H_{y0}H_{y1}. \tag{3}$$

The observed microwave absorption in the ESR cavity is given by $\mathrm{d}(P_M + P_S)/\mathrm{d}H_{y1}$. For $H < H^*$ contribution comes from P_M while for $H > H^*$, P_S contributes. We thus have

$$\partial P_M/\partial H_{y1} = a\lambda^2(\omega^2+\Omega^2)^{1/2}x''_{xy}H_{x1} + 2a^2\lambda\Omega x''_{yy}H_{y1} \quad (H < H^*), \tag{4}$$

$$\mathrm{d}P_s/\mathrm{d}H_{y1} = a^3\Omega x''_{yy}H_{y0} \sim a^3\Omega x''_{yy}x'^{-1}M_{y0} \quad (H < H^*). \tag{5}$$

If x' in (5) is independent of H the microwave loss in the region $H > H^*$ is proportional to magnetization as observed. From (4) we observe that in the region $H < H^*$, absorption is independent of H_{y0}. It is also proportional to the rf and modulation field amplitude as observed. The peak in absorption seen at $H_{x1} = 0{\cdot}12$ Oe (calculated by using the Q-value of the cavity) for 1-2-3 sample is due to the onset of shielding current which suppress P_M.

In conclusion we can say that the present model of microwave absorption built on diamagnetic tensor susceptibility explains the observed data satisfactorily.

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