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Microwave absorption spectrum and reentrant phase in Bi2212 single crystal: microwave power dependence

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Abstract

Microwave power (P_m) dependence of microwave absorption (MA) was investigated on $Bi_2Sr_2CaCu_2O_x$ crystals at liquid nitrogen temperature. At low P_m of 0.1 mW, MA spectrum shows only a sharp first peak near zero magnetic fields (H_a), which corresponds to Meissner phase, for $H_a \| c$-axis. MA spectrum shows a dip and a broad second peak when P_m is increased. These dip and broad peak reflect reentrant liquid phase and solid phase. The broad peak shifts to lower fields with increasing P_m. The real sample temperature is raised by 4 K with increasing P_m to 50 mW.

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Keywords: Bi2212 single crystal; Reentrant phase; Microwave absorption; Microwave power; Temperature rise

1. Introduction

Demanding for tunable high temperature superconducting microwave filters is urgent to save spaces occupied by transmission base stations. The stacked superconducting/ferromagnetic thin films are employed as the tunable microwave filters. They are operated under magnetic fields [1–5]. Then it is important to study the microwave loss properties of superconducting materials such as $Bi_2Sr_2CaCu_2O_x$ (Bi2212) under the fields. Such a research under high microwave power is also necessary for high power components like antennas [6].

In this work, we investigated the microwave power dependence of microwave absorption (MA) in Bi2212 crystals. Combined with temperature dependence of the absorption spectrum in a solid state region of a reentrant phase [7], rises of sample temperature by the MA are estimated as a function of microwave power.

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2. Experimental

Superconducting Bi2212 single crystals ($T_C = 86.5$ K) were grown by self-flux method [7]. Non-resonant MA measurement was carried out on the samples employing "cavity perturbation method" [8–11]. The sample in a cryostat was put in dc magnetic field (H_a) and a modulation field was superimposed on the dc field with an amplitude of 5 G at 100 kHz. The MA signals (S) were measured on the samples at around liquid nitrogen temperatures (T) as a function of H_a. The microwave power (P_m) was varied in a range of 0.1–50 mW. The dc field H_a was applied on the sample along its c-axis ($H_a \| c$) [12].

3. Results and discussion

The MA spectra of the sample measured at various P_m at low T are shown in Fig. 1. At very low P_m of 0.1 mW, the MA spectrum shows only a sharp first peak at near zero field below 50 G. When P_m is increased to 10 mW, MA spectrum evolves to show the same first peak,

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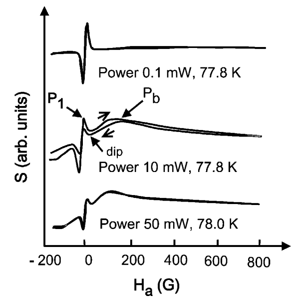

Fig. 1. MA spectra various P_m.

followed by a dip and another new broad peak at 100–350 G. Henceforth, we call these peaks "first peak (P_1)" and "broad peak (P_b)". Beyond this power up to 50 mW, MA spectrum is always composed of three characteristic parts; the first peak, the dip and the broad peak. However, the field positions of these structures seem to be shifted with increasing P_m.

The field position of the maximum of broad peak (H_{Pb}) is plotted in Fig. 2 as a function of P_m. H_{Pb} shifts to lower fields with increasing P_m. The temperature dependence of H_{Pb} (H_{Pb}–T) has been already obtained by the previous work as shown in inset of Fig. 2 [7]. H_{Pb} also shifts to lower fields with increasing T. From the same tendencies of H_{Pb}–P_m obtained in this work and H_{Pb}–T, it can be concluded that the real sample temperature T_{samp} must be raised with increasing P_m due to the larger MA, although the ambient temperature is almost the same. From these two data, we can obtain a new relation T_{samp}–P_m which is plotted in Fig. 2. The result indicates that T_{samp} rises by about 4 K when P_m is increased from 0.1 to 50 mW. This temperature rise is a considerable amount which must be taken into account when the supercouducting materials are used for the high power microwave devices.

We need to explain why H_{Pb} is shifted to the lower fields with increasing T. According to T-dependence of MA spectrum reported by us [7], the three structures of MA should reflect the reentrant phase diagram [13,14] as

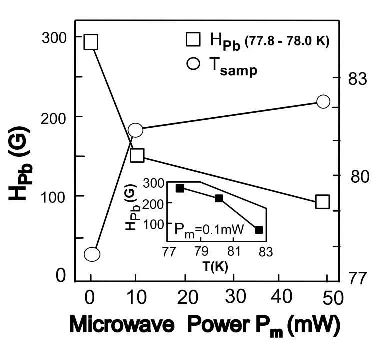

Fig. 2. H_{Pb} and estimated sample temperature T_{samp} as a function of P_m. The inset shows the previous result of H_{Pb}–T [7].

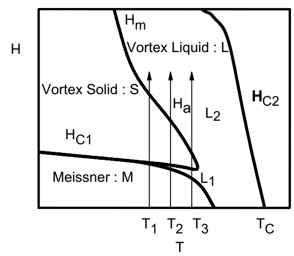

Fig. 3. Model reentrant phase diagram proposed by Fisher and Lee [13], and Nelson [14]. H_{C1}: lower critical field, H_{C2}: upper critical field, H_m: melting line.

shown in Fig. 3. The first peak and the broad peak reflect Meissner phase and vortex solid phase, respectively. While the dip reflects the reentrant liquid phase (L_1) lying just above Meissner phase. Because of "nose shape" of the solid phase, the fields of H_a passing in the solid state are shifted to the lower side with increasing T as $T_1 \rightarrow T_2 \rightarrow T_3$ as shown in Fig. 3. This is the reason why the broad peak and H_{Pb} are shifted to the lower side.

4. Conclusion

We investigated P_m-dependence of MA on Bi2212 at liquid nitrogen temperature. MA spectrum shows only the first peak at the low P_m while it shows the first peak, the dip and the broad peak at the higher P_m. These are reflecting Meissner phase, L_1 phase and solid phase in the reentrant phase diagram. H_{Pb} shifts to the lower fields with increasing P_m. With the combination of H_{Pb}–P_m with H_{Pb}–T, the real sample temperature is raised by 4 K with increasing P_m due to the larger MA.

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