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Low-field microwave absorption in the Bi–Sr–Ca–Cu–O system

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The low-field absorption of microwave radiation by the high-temperature superconducting oxide system Bi–Sr–Ca–Cu–O has been measured at liquid nitrogen temperature as a function of the amplitude of the magnetic field modulation and of the microwave power. The results suggest that there is less flux pinning in this system than in other high-temperature superconductors.

1. Introduction

Microwave absorption is one of the techniques that have been used [1–14] to study the properties of the high-temperature superconductors. Early experiments on the Y–Ba–Cu–O system, using commercial electron paramagnetic resonance (EPR) equipment, yielded a resonance spectrum with $g \simeq 2$, attributed to Cu^{2+} ions [1–5]. It was soon realized [6, 7] that this signal was not due to the superconducting phase, but to impurities present in the samples. On the other hand, the superconducting phase shows a strong low-field, nonresonant microwave absorption [7–14] which is also observed in other high-temperature superconductors, such as the Ba–La–Cu–O and Sr–La–Cu–O systems [10]. The main features of this absorption are: (a) it is only observed below the superconducting transition temperature, as determined using other experimental techniques; (b) it shows hysteresis effects for fields exceeding a certain critical field of the order of 0.3 to 2 mT; these effects are more pronounced at low modulation fields (below about 0.1 mT); (c) it increases linearly with the modulation field for large modulation amplitudes and more slowly for small modulation amplitudes; (d) it shows power saturation effects at moderate microwave power levels (about 10 mW); (e) it goes through a maximum at magnetic fields from 50 μT to over 10 mT, depending on sample preparation.

Although all the features mentioned above can be qualitatively explained in terms of fluxon pinning and depinning by critical currents [12–14], it remains to be seen whether all of them are truly characteristic of the ceramic superconductors. It is in this spirit that we have investigated the microwave absorption behaviour of a new copper-based high-temperature superconductor, the Bi–Sr–Ca–Cu–O system.

2. Experimental procedure

The samples, nominal composition $BiSrCaCu_2O$, were prepared from high-purity $(BiO)_2CO_3$, $SrCO_3$, $CaCO_3$ and CuO. Appropriate amounts of the powders were mixed, fired at 890° C for 30 min, reground and pressed into pellets. The pellets were then sintered for 8 h at 870° C in air.

Room-temperature X-ray diffraction patterns of all samples matched the spectrum reported by Maeda *et al.* [15]. The superconducting transition temperature, T_c, as determined from mutual inductance measurements [16] was found to be 84 K.

Microwave absorption measurements were performed at 77 K on a Varian E-12 X-band EPR spectrometer using 100 kHz field modulation. The magnetic field was calibrated with a proton resonance gaussmeter.

3. Experimental results

Figs 1a and b show the microwave absorption spectra of a typical sample at 77 K as the magnetic field is swept from 5 to 100 mT and from 100 to 5 mT, respectively. No hysteresis was detected in this and similar measurements with different values of the modulation field from 0.5 to 800 μT and different power levels from 0.5 to 64 mW. The plateau below 5 mT is not significant; it corresponds to the remanent field of the magnet. Although no detailed measurements have been performed at higher temperatures, the signal amplitude decreases rapidly as the sample is heated above 77 K and presumably becomes zero for temperatures above the superconducting transition temperature T_c; the spectrum is completely flat at room temperature for fields between 5 mT and 1 T.

The dependence of the microwave absorption on the amplitude of the modulation field is shown in Fig. 2 for the Bi–Sr–Ca–Cu–O system and other high-temperature superconductors. In the case of the Bi–Sr–Ca–Cu–O system, the absorption increases linearly as the modulation field amplitude is increased from 0.5 to 800 μT (not all data points are shown in the figure); in contrast to what is seen in other high-temperature superconductors, no change in the slope of the absorption–modulation field amplitude plot is observed at low modulation field amplitudes.

Figure 3 shows the dependence of the microwave absorption on the microwave power for the Bi–Sr–Ca–Cu–O system and for the $YBa_2Cu_3O_y$ compound. In the case of the Bi–Sr–Ca–Cu–O system, the absorption is proportional to the square root of the microwave

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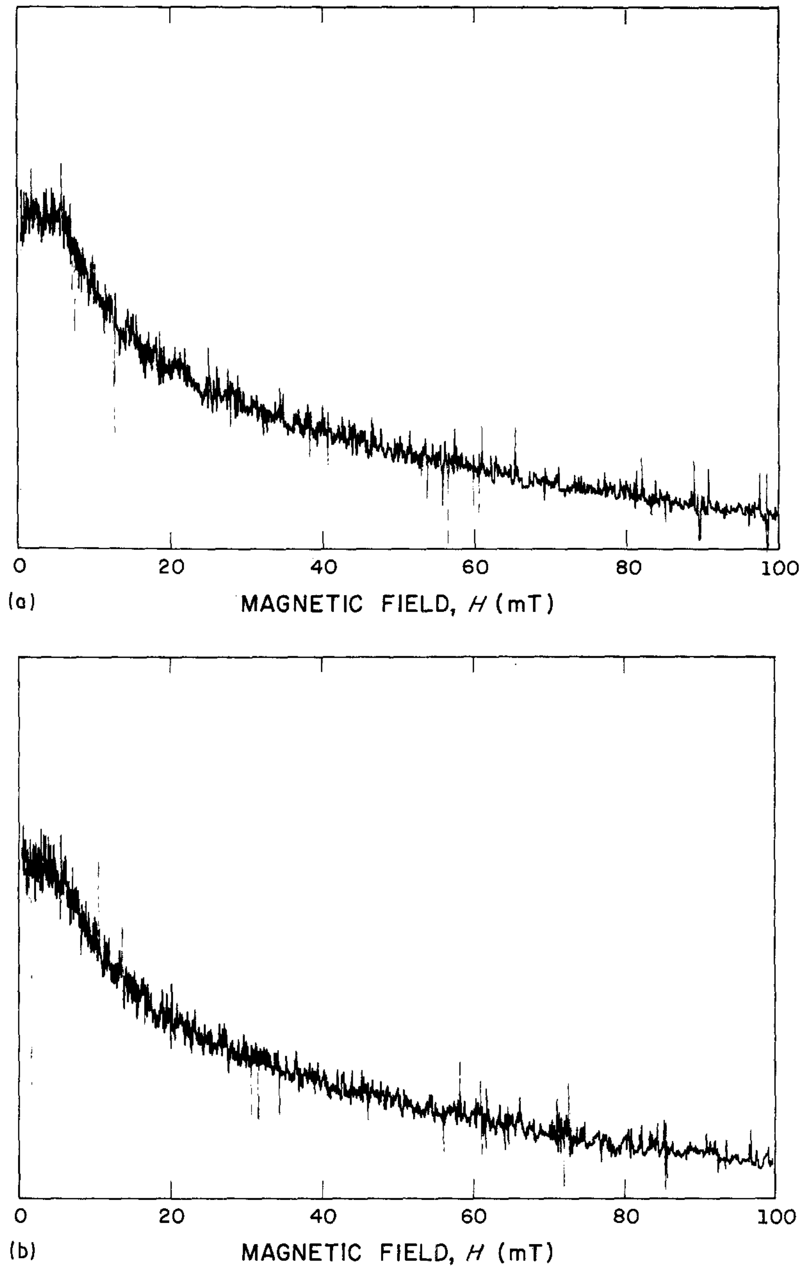

Figure 1 Microwave absorption derivative spectrum of the Bi–Sr–Ca–Cu–O system at 77 K. (a) Spectrum taken with the field increasing from 5 to 100 mT; (b) spectrum taken with the field decreasing from 100 to 5 mT. The experimental parameters are microwave power 15 mW; microwave frequency 9.1 GHz; modulation amplitude, 10 μT.

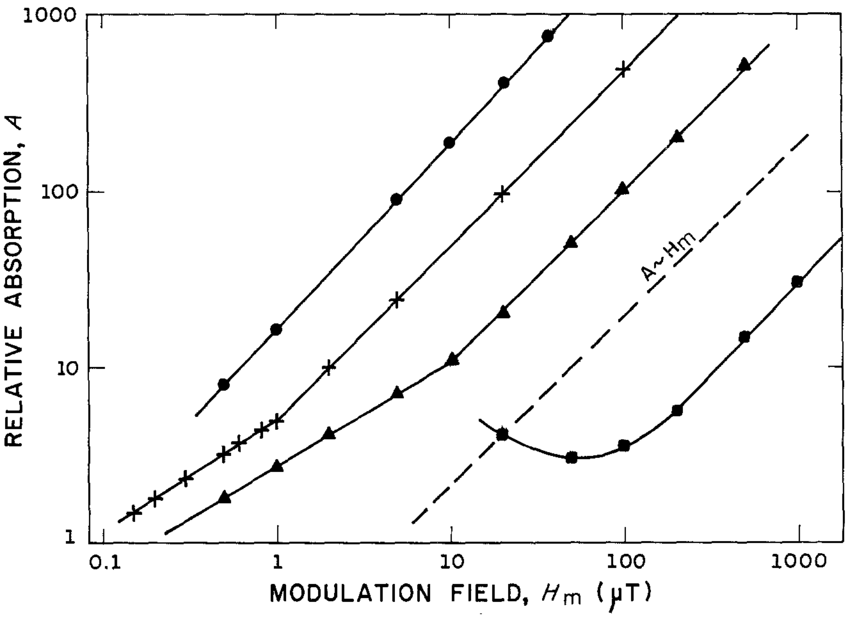

Figure 2 Microwave absorption as a function of modulation field amplitude for several high-temperature superconductors: (●) Bi–Sr–Ca–Cu–O, present work; (+) Ba–La–Cu–O, (▲) La–Sr–Cu–O and (■) Y–Ba–Cu–O [13].

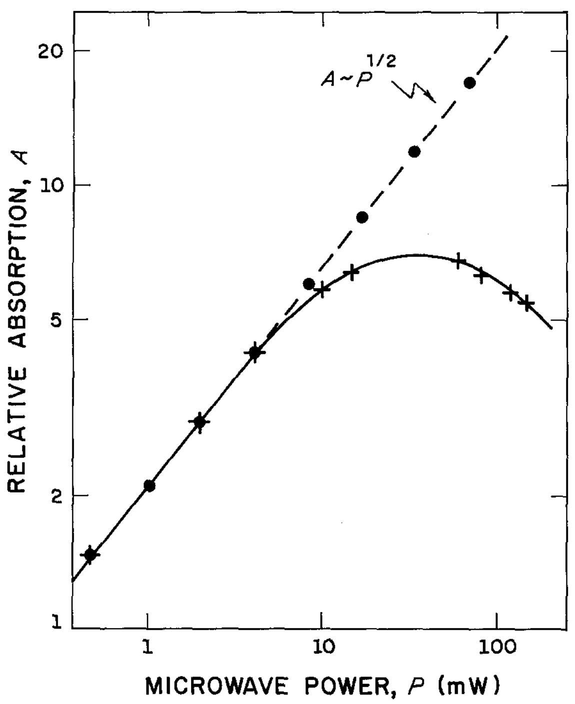

Figure 3 Microwave absorption as a function of microwave power for two high-temperature superconductors: (●) Bi–Sr–Ca–Cu–O, present work; (+) Y–Ba–Cu–O [14].

power up to the highest power investigated (64 mW); no saturation effects are observed.

4. Discussion and conclusions

When the microwave absorption behaviour of the Bi–Sr–Ca–Cu–O system is compared with that of other high-temperature superconducting systems, some similarities are apparent, such as the disappearance of the low-field nonresonant absorption above T_c and the absence of a resonance spectrum due to copper ions. There are, however, some striking differences. First, no hysteresis behaviour is observed; second, the microwave absorption increases linearly with the modulation field amplitude, even for low field amplitudes; third, there are no power saturation effects up to fairly high power levels. While the first two differences may be attributed to a reduced flux pinning, it is still not clear whether all three are due to the physical state of the sample (grain size, for instance) or to some basic difference between the Bi–Sr–Ca–Cu–O system and previously investigated high-temperature superconductors.

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