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Non-bolometric Microwave Response of a Granular Bi(Pb)SrCaCuO Thin Film

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Abstract:

The response of a granular superconducting Bi(Pb)SrCaCuO thin film meander pattern to radiation from a 35GHz Gunn diode microwave generator was studied. The dependence of the response on film temperature, DC bias current, chopping frequency, and DC magnetic field was measured. Experimental results show that the response was non-bolometric in origin and was decreased by applying a DC magnetic field parallel to the c-axes of the grains. The mechanism of the non-bolometric microwave response is presumed to be due to microwave absorption by Josephson-type weak links embedded in the specimen.

1. Introduction

The response of high temperature superconductors to incident microwave radiation has been reported by several workers [1], [2]. The effect has been demonstrated to be non-bolometric in origin, and is greater the more granular and less perfect is the sample of superconductor [3]. It is assumed to arise from microwave absorption by Josephson junctions at the weak links which seem to be inherent in all polycrystalline ceramic superconducting materials. The effect may limit high frequency applications but could provide the basis for sensitive microwave detectors [4]. There is also evidence that the effect is influenced by the phase purity of the superconductor. It is desirable to understand the origin of the effect, to determine whether or not it can be used as a means of *characterising* samples of superconductor, and to ascertain its suitability for use as a dectector for microwave radiation. The experiments described here were carried out as part of an attempt to answer the above points. The microwave response of an inhomogeneous, two-phase granular Bi(Pb)SrCaCuO thin film, chosen to give a large response, was studied as a function of temperature, bias current, chopping frequency and presence or absence of a DC magnetic field.

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2. Experimental

A high T_c BiPbSrCaCuO thin film was prepared on an MgO single crystal substrate by single-target rf magnetron sputtering [5], [6]. X-ray diffraction showed that the film was predominantly 2223-phase but with the presence of some 2212-phase. The c-axis-aligned film, about 0.5 μm in thickness, was photolithographically patterned into a meander-type structure with a track 150 μm wide and 1 cm long. The dimensions of the patterned film were measured by a Lasertec-1LM11 laser microscope. A 40 mW Gunn diode microwave generator operating at 35 GHz and modulated by a 5-slot mechanical chopper was used as the radiation source to investigate the response of the film. The specimen was sited on the cold-finger of a helium flow cryostat. The response was measured by monitoring the electrical potential across the specimen when carrying a bias current. A lock-in amplifier with a reference frequency almost the same as the chopping frequency was used to pick up the signal of the response. A small DC magnetic field generated by a coil installed above the specimen was applied along the c-axes of the grains. The experiment was computer controlled, allowing fast and accurate acquisition of film temperature, resistance and response reading from the specimen under test. The microwave response of the film was studied as a function of several parameters such as film temperature, DC bias current, chopping frequency and DC magnetic field.

3. Results and Discussion

3.1 Temperature Dependence of the Microwave Response

The temperature dependence of the response of the Bi(Pb)SrCaCuO film to microwave radiation of 35 GHz and with a bias current of 0.01 mA is shown in Fig. 1.

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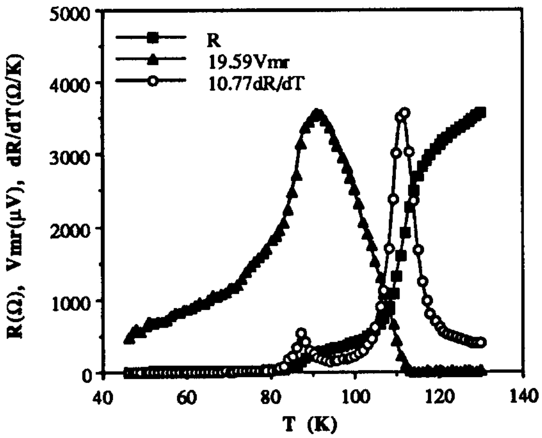

Fig. 1. Film resistance, R, dR/dT and microwave response V_{mr} of the superconducting film as a function of temperature. Bias current 0.01 mA; radiation chopping frequency 382 Hz.

Three normalised curves are: resistance (R) vs. temperature (T), dR/dT vs. T, and the microwave response V_{mr} vs. T. The R vs. T curve shows a major transition at 115K (2223-phase) and a smaller transition at 86K (2212-phase). These transitions are more readily distinguished as peaks in the dR/dT vs. T curve. V_{mr} shows one broad peak at about 93K, corresponding to neither transition, and a shoulder below the 2212-phase transition. This behavior is quite different from that of a 2212 epitaxial film which shows only a sharp peak in the response at just below the transition [3]. It is seen that the effect is non-bolometric in origin. The signatures of a bolometric effect are the coincidence of V_{mr} with dR/dT, and the dependence of signal magnitude on chopping frequency [3]. With a bias current of 0.1 mA there is no dependence of V_{mr} on chopping frequency, either at a temperature close to the peak (90K) or at one well below the peak (50K), Fig. 2.

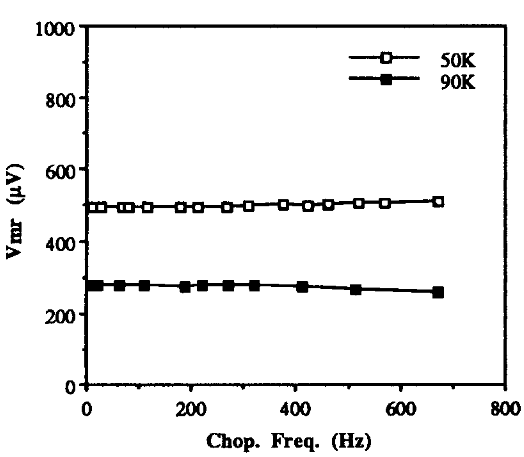

Fig. 2. Microwave response vs. chopping frequency at 50K and 90K. Bias current 0.1 mA.

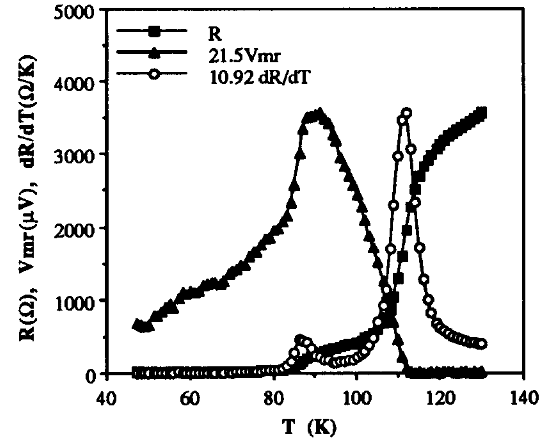

Fig. 3. R, dR/dT and V_{mr} vs. T in a magnetic field of 2.4 KAm^{-1} (30 gauss). Bias current 0.01 mA; chopping frequency 382 Hz.

If the microwave response is due to absorption by intergranular weak links, the fact that the peak occurs above the 2212-phase transition indicates that the majority of these weak links are between one 2223-phase grain and another grain of the same phase. The shoulder on the low temperature side, beginning at about the 2212-phase transition temperature, is presumed to be due to 2212-2212 and 2212-2223 weak links. At the low, 0.01 mA, bias current, the magnitude of the response falls rapidly as the temperature is lowered. This is consistent with the weak link explanation, as the inter-grain coupling strength will increase as the temperature decreases. The density of weak links is expected to be at a maximum just below the critical temperature.

3.2 Magnetic Field and Bias Current Dependence of the Microwave Response.

Fig. 3 shows R, dR/dT and V_{mr}, at the same bias

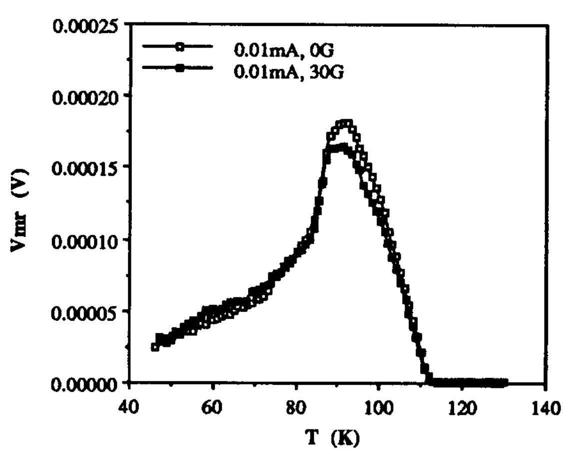

Fig. 4. Microwave response, with and without the 2.4 KAm^{-1} applied magnetic field, replotted from Figs. 1 and 3. Bias current 0.01 mA; chopping frequency 382 Hz.

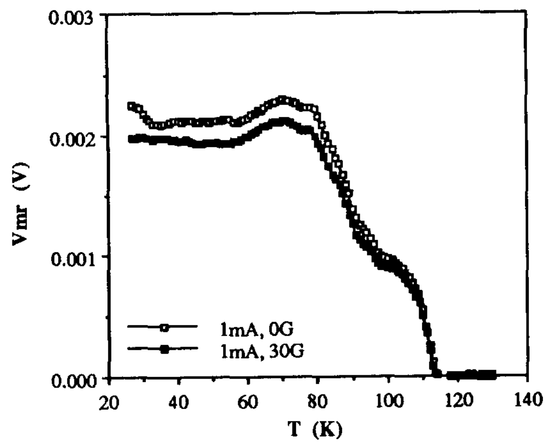

Fig. 5. Microwave response, with and without the 2.4 KAm^{-1} applied magnetic field, with 1 mA bias current.

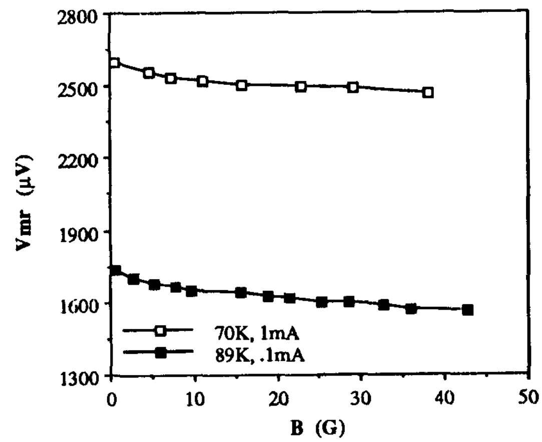

Fig. 7. Effect of applied magnetic field on microwave response at 70K and 89K. Bias current 1 mA.

current as in Fig. 1, 0.01 mA, but in the presence of a small DC magnetic field of 2.4 KAm^{-1} (30 gauss), versus temperature. The general features of the curves are similar to those in Fig. 1. The effect of the magnetic field can best be demonstrated by plotting the two response peaks on the same graph, Fig. 4. The field has both depressed the response and shifted the maximum to a slightly lower temperature.

The major component of the magnetic field is normal to the surface of the c-axis oriented film. As it penetrates the intergranular regions, it is expected to switch-off some of the weak links. A similar effect is seen at the considerably higher level of bias currents, 1 mA and 1.5 mA, shown in Figs. 5 and 6 respectively. A new feature in these curves is that at the position of the previous peak there is now a shoulder, of magnitude some five times greater than the previous peak, and that an even stronger signal is found down to much lower temperatures. With a bias current of 1 mA V_{mr} shows a maximum at about 70K, but with 1.5 mA this becomes a shoulder and V_{mr} continues to increase as the temperature falls to 50K. The effect of the bias current is much greater than that of the externally applied magnetic field. This is not surprising, as a current of 1.5 mA in a film of thickness 0.5 μm and width 150 μm gives a current density of 20 MAm^{-2} (2000 Acm^{-2}), an appreciable fraction of the critical current density of the film.

The magnitude of V_{mr}, with a bias current of 1mA at temperatures of 70K, corresponding to the maximum value, and 89K, corresponding to the high temperature shoulder, are plotted as a function of increasing magnetic field in Fig. 7. At both temperatures the effect of increasing the field is to decrease the response.

Finally, the effect of level of bias current on V_{mr} at the fixed temperatures of 50K, 70K, 90K and 110K is shown in Fig. 8. At the three lower temperatures, V_{mr} initially rises with increasing bias current, passes through a maximum and then falls. The value of bias current corresponding to the maximum signal increases from 0.38 mA to 0.93 mA to 1.3 mA as the temperature falls from

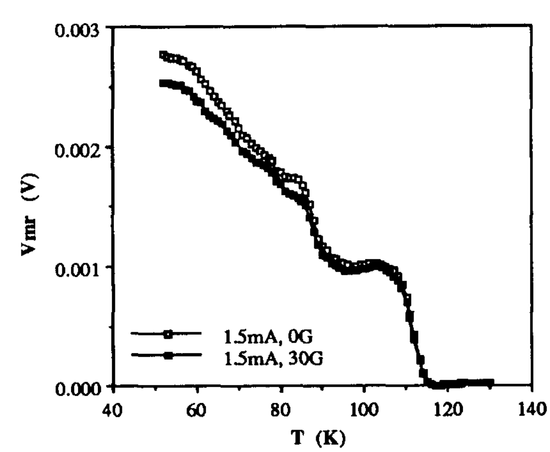

Fig. 6. Microwave response, with and without the 2.4 KAm^{-1} applied magnetic field, with 1.5 mA bias current.

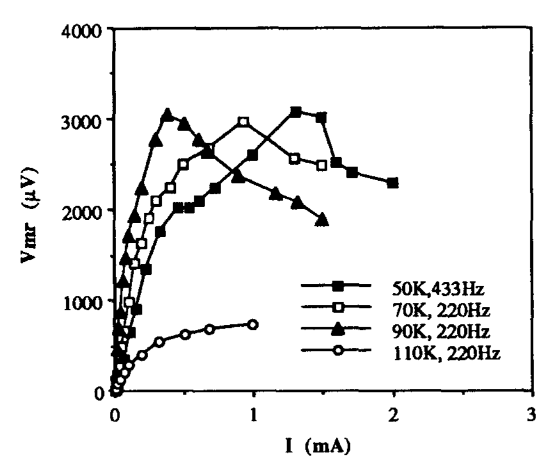

Fig. 8. Microwave response versus bias current, at 50K, 70K, 90K and 110K. Chopping frequency as indicated.

90 K to 70 K to 50 K. At 110K the magnitude of V_{mr} was much smaller and no maximum was observed for biascurrents up to 1 mA.

It is presumed that there is a distribution of both intergranular coupling strengths, and of the number density of links, in a granular superconductor. The average coupling strength will be expected to increase as the temperature is reduced from the transition temperature T_c. The number density distribution will also be a function of temperature. At a given temperature and level of bias current, the weak links in a slice of this distribution become active. Weaker links have been turned off; stronger links have yet to be turned on. As the bias current is increased, the distribution of links is sampled. The bias current producing a maximum microwave response is that which activates the links at the maximum in the distribution. A larger current will be required to do this at a lower temperature, where the average coupling strength is greater. A temperature of 110K is insufficiently below T_c(115K) for the density of active weak links to be high, and at this temperature the 2212-phase is still in the normal state.

3.3 The Cut-off Temperature

In the region of the critical temperature, with rising temperature the microwave response falls steeply to a minimum value at a cut-off temperature T_b, which might be supposed to be associated with T_c for the sample, then rises to a small but finite value in the normal state, Fig 9. Increasing the bias current from 0.1mA to 1.5mA raises T_b by 2.5K from just under 115K to just over 117K, a behaviour which is contrary to expectation if T_b is in fact T_c for the specimen. No explanation can be offered for this unusual behaviour.

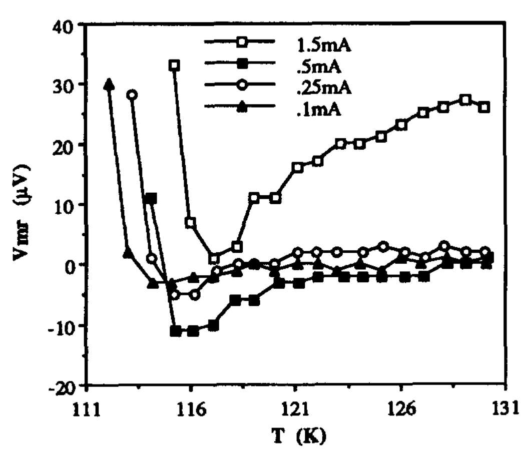

Fig. 9. Magnified plot of V_{mr} versus T close to T_c, for different values of bias current.

4. Conclusions

The response of a granular Bi(Pb)SrCaCuO superconducting thin film to 40 mW radiation from a microwave generator operating at 35 GHz has been investigated. The origin of the response is shown to be non-bolometric. The influence of film temperature, bias current and external magnetic field are all consistent with the response being due to the inverse AC Josephson effect from intergranular weak links in the sample.

The onset of the response may be used to define the critical temperature, though its increase with bias current is puzzling. The response is sensitive to the presence of other phases, as can be inferred from the shoulders on the low temperature side of the peaks at low bias currents, and the high temperature shoulder at high bias currents. Thus the effect is valuable in assisting sample characterisation.

The magnitude of the response is large, particularly at bias current levels of the order of 1 mA, and the effect can clearly be used as the basis for a microwave detector, though the frequency response has not yet been investigated. The detector could be tuned for maximum sensitivity by matching the bias current to the operating temperature.

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