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Observation of inter-grain Josephson effects in Y-Ba-Cu-O samples

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Abstract. Josephson effects have been observed in bulk samples of Y-Ba-Cu-O. The magnitude of the zero-voltage current is found to change systematically with externally applied small magnetic fields of a few mG. It is also found to vary when samples are irradiated with microwaves. These observations suggest the presence of inter-grain Josephson junctions.

Keywords. High temperature superconductivity; Y-Ba-Cu-O; Josephson effect.

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The recent discoveries of superconductivity at 30 K in La-Ba-Cu-O (Bednorz and Müller 1986) and at 90 K in Y-Ba-Cu-O (Wu *et al* 1987) have resulted in an unprecedented flood of research activity in superconductivity. It has been pointed out by several groups that the superconducting grains in high T_c ceramic superconductors may be weakly coupled by Josephson tunnelling (Bednorz and Müller 1986; Cava *et al* 1987; Razavi *et al* 1987). In the usual resistivity measurement the zero resistance state can be observed only if the bias current is less than the smallest critical current of all the Josephson junctions in the sample and therefore the resistivity data is usually found to be dependent on the biasing current (Bednorz and Müller 1986; Ganguly *et al* 1987). Generally one uses the smallest possible bias current to find the superconducting onset temperature and the zero resistance state. Possible presence of inter-grain Josephson junctions have been inferred by observation of inverse a.c. Josephson effect (Chen *et al* 1987; Gupta *et al* 1987), flux jump studies (Cai *et al* 1987) and weak field magnetization studies (Farrell *et al* 1987).

We report the observation of Josephson effects first time in bulk samples of Y-Ba-Cu-O, confirming the presence of inter-grain Josephson junctions which are formed by the presence of either normal or thin insulating regions between the superconducting grains.

The $YBa_2Cu_3O_{9-\delta}$ samples used in the present experiments were prepared by solid state reaction of the appropriate amounts of Y_2O_3, $BaCo_3$ and CuO each with purities of 99·9% as described earlier (Jayaram *et al* 1987). The resistivity measurements using standard four-probe technique showed onset of superconductivity at 91 K while the zero resistance had been observed at 83 K. For the present studies, the samples were cut in the forms of strips of dimensions 1 mm × 1 mm × 10 mm. The stored samples develop nonsuperconducting layers on their surface. Therefore the samples used always had freshly cut surfaces. Four-probe contacts with low contact resistance (~ 1 ohm) were made using air drying silver paste. The separation between the voltage contacts was deliberately kept as small as possible (0·5 mm) so that cumulative effects of a small number of Josephson junctions could be observed.

The sample is mounted inside an X-band waveguide which was short circuited using a fixed plunger. It is mounted at a distance of about $3\lambda/4$ from the plunger. No other special effort is taken to optimize the coupling of the microwaves to the sample. The sample holder is connected to a highly stabilized phase locked microwave source having a frequency stability of one part in 10^9 over a period of 2 hr. Microwave power is measured at the source using a microwave power meter. Small d.c. magnetic fields may be applied to the sample using a single turn copper solenoid surrounding the sample holder.

Figure 1 shows *I-V* curves of the sample at 77 K showing both the zero voltage current and the quasi-particle tunnelling characteristics in the finite voltage regime. The value of the critical current decreases with application of even very weak d.c. magnetic fields suggesting the presence of inter-grain Josephson junctions. Curve 1 corresponds to zero field while other four curves show magnetic field effects at different fields. Self-induced steps are clearly seen in the curve 1 while they smear out with the application of magnetic field. Figure 2 shows change in voltage (V) as a function of externally applied magnetic field (H) at four different biasing currents above the critical current value. In a usual Josephson junction the *V-H* curve shows several periods. In the present case there are a large number of inter-grain junctions which are randomly connected, one can expect a large cumulative profile in oscillatory phase dependent voltage (V) and magnetic field (H) curves. Figure 3 shows *I-V* curves of another sample at 77 K when it is irradiated with microwave radiations of frequency

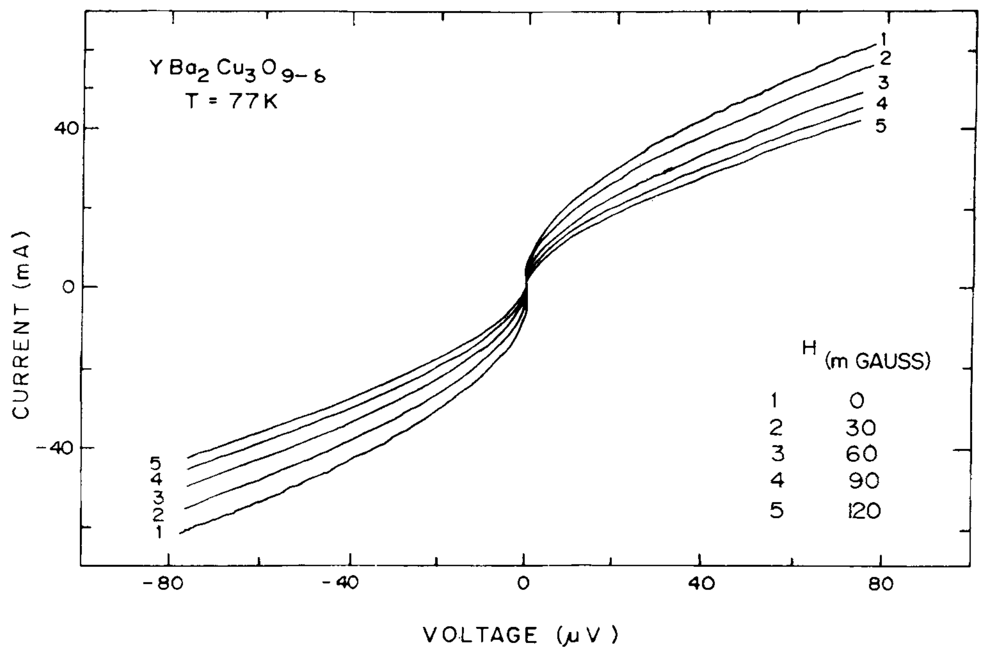

Figure 1. *I-V* curves for Y-Ba-Cu-O bulk samples at 77 K. Curves 1 to 5 corresponds to magnetic fields of 0, 30, 60, 90 and 120 mG respectively.

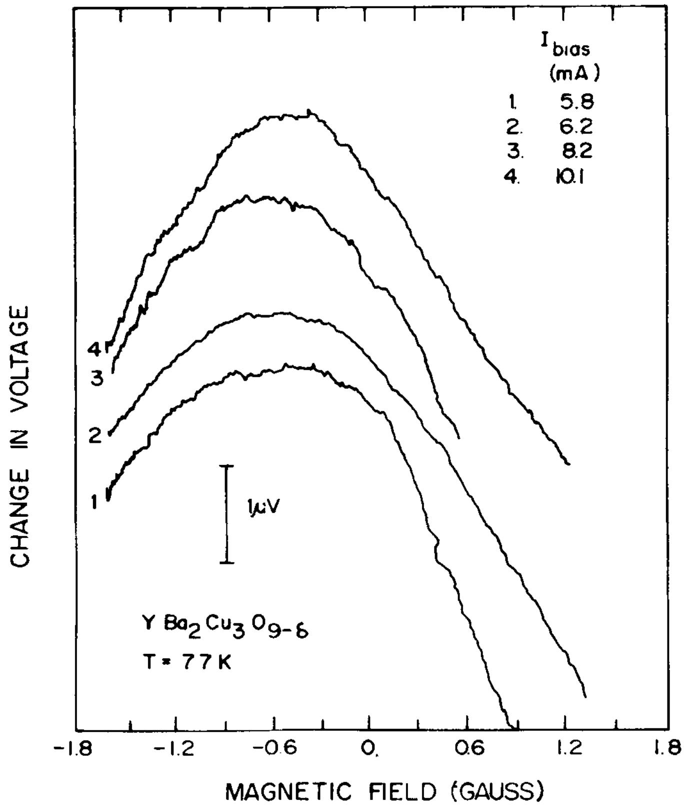

Figure 2. Change in voltage vs magnetic field V-H curve at different biasing currents for Y-Ba-Cu-O at 77 K.

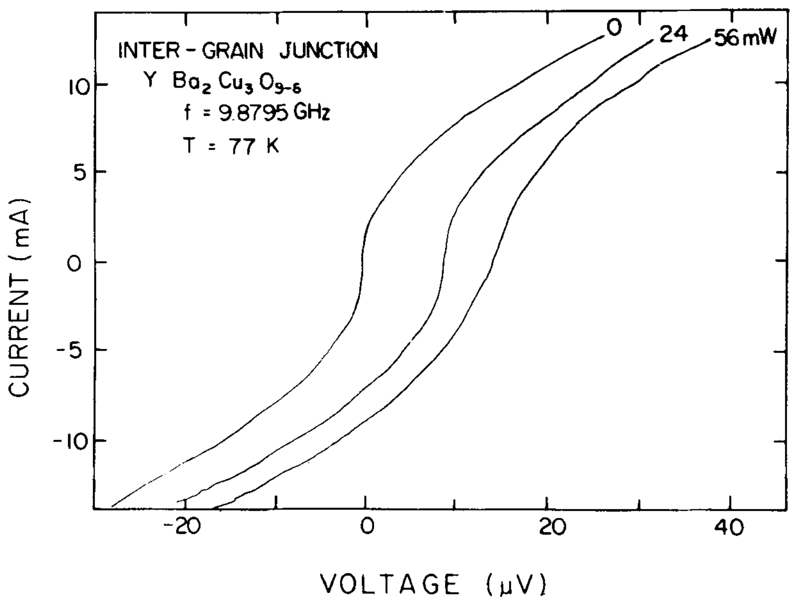

Figure 3. *I-V* curves for Y-Ba-Cu-O sample. Application of microwave leads to shifting of zero current points. The positive offset voltages arise due to inverse a.c. Josephson effect.

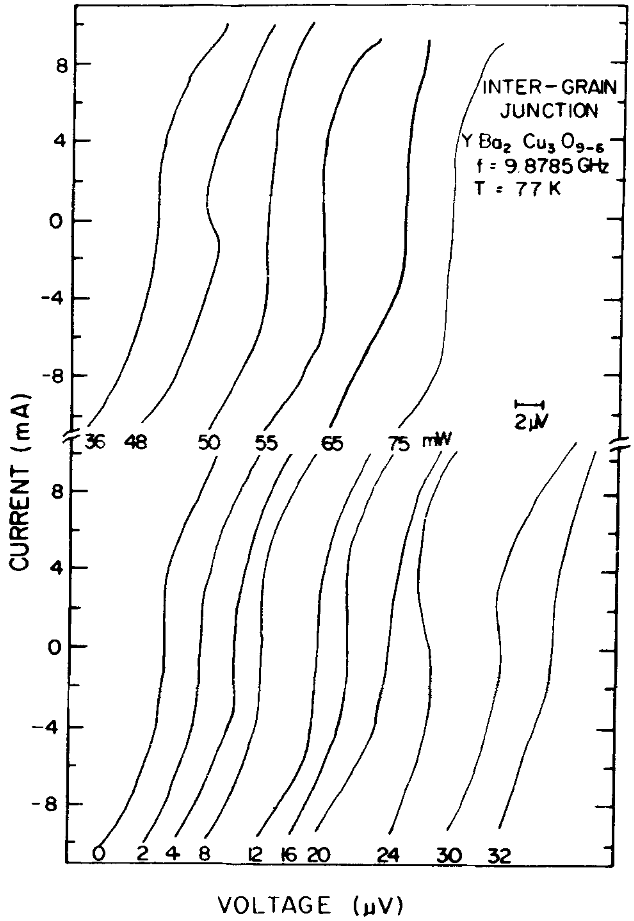

Figure 4. *I-V* curves for several microwave powers at 9·8795 GHz at 77 K.

9·8795 GHz. Although the origin for zero voltage and zero current is kept same for all the curves, the offset voltages are clearly seen at zero current by virtue of microwave induced d.c. voltages due to inverse a.c. Josephson effect (Chen *et al* 1987; Gupta *et al* 1987). The value of the critical current is suppressed due to impressed microwave power. Figure 4 shows the *I-V* curves of the sample as a function of microwave power. As the microwave power is gradually increased, the value of the critical current changes with the microwave power in a random way. Even enhancement of supercurrent at several microwave power levels is observed. Switching to negative differential resistance regions are also observed at several microwave power levels (24 and 48 mw). Similar behaviour has been observed in lead-lead oxide-lead weak links (Gupta *et al* 1983). We are unable to observe microwave induced constant voltage steps at any microwave power level which suggests that the Josephson junctions are not connected coherently. Present experiments clearly indicate that superconductivity in Y-Ba-Cu-O samples originate through weak coupling between the grains.

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