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Josephson effects and dc SQUID behaviour in break junction of Y–Ba–Cu–O at 77 K

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Abstract. Break junctions of Y–Ba–Cu–O superconductor were realized by creating fresh crack in the bar shape bulk samples mounted in a specially designed probe kept in the liquid nitrogen bath. While the bulk sample was kept static, a sharp tip of a shaft was moved downward from the outside of the dewar in order to break the sample. It was possible to change the critical current of the break junctions by adjusting pressure on the tip of the shaft. The effects of magnetic field and microwave power on the I–V characteristic of the junction were studied. The junction was found to show periodic V–B behaviour and the microwave-induced Shapiro steps were clearly observed at 77 K. The flux noise spectrum of the junction was also studied.

Keywords. dc-SQUID behaviour; break junction; Josephson effect.

1. Introduction

Josephson effect and DC SQUID behaviour have been observed in high T_c superconductors by various groups. DC SQUID based on bulk (Kataria *et al* 1989), thick (Lin *et al* 1989) and thin films (Koch *et al* 1987, 1989; Nakane *et al* 1987; Hauser *et al* 1988) have been made using intergranular weak links in small constriction of the sample. RF SQUID behaviour have been demonstrated in bulk sample of Y–Ba–Cu–O at 77 K (Colclough *et al* 1987; Pegrum *et al* 1988; Tichy *et al* 1988). Several workers have also fabricated both one and two-hole RF SQUIDs using intergranular weak links in a small constriction (Harrop *et al* 1988; Shnyrkov *et al* 1988; Zhang *et al* 1989). In a break junction tunnelling occurs across freshly-cleaved surfaces of a fracture produced in a bulk material when kept in a cryogenic environment. Zimmerman *et al* (1987) demonstrated RF SQUID behaviour at 77 K with break junction as the weaklink. In this paper we report dc quantum interference effect in Y–Ba–Cu–O break junction at 77 K. The effect of microwave radiations on the I–V characteristic of the junction is studied. The flux noise spectrum of the junction is also reported.

2. Experimental

Break junctions were realized by cracking YBCO samples, kept immersed in liquid nitrogen bath. The samples of YBCO were prepared by the standard solid-state reaction technique using powders of Y_2O_3, $BaCO_3$ and CuO of 99·9% purity. Ceramic pellets were cut to form the bars of dimensions $10 \times 2 \times 2\,mm^3$ and a constriction of dimension $1 \times 1 \times 0{\cdot}15\,mm^3$ was manually carved at the centre of the bar. The sample was fixed on a U-shaped sample holder using GE 7031 varnish. The sample holder was mounted in a specially designed cryostat. The crack was created in the sample by applying pressure on its middle portion while it was kept inside the liquid nitrogen atmosphere. It was possible to change the critical current of the break junction by varying the pressure on the crack by the shaft operated from outside the cryostat. The pressure was readjusted to attain suitable resistance for a break junction showing Josephson characteristics.

A 30 turn copper coil was glued underneath the junction on the surface of the sample holder in order to apply magnetic field to the junction. X-band microwave radiations were coupled to the junction by a coaxial line. The central conductor of the coaxial line was bent and directed so as to irradiate the sample. This acted as an antenna for radiating microwaves to the junction. Current–voltage characteristics were recorded using the standard four-probe technique. Noise studies of the junctions were carried out using PAR-124A lock-in amplifier with P-116 preamplifier, the Q of the band-pass filter was chosen as 100 for all measurements. The rms value of the fluctuating voltage ΔV was measured at a fixed frequency f and at a constant Q, for fixed-biasing current across the junction. The voltage noise density, $S_v(f)$ is determined from these measurements using the standard formula (Maeda *et al* 1989). The flux noise density S_Φ of the junction was calculated using the formula $S_\Phi = S_v(f)/(\partial V/\partial \Phi)^2$, $\partial V/\partial \Phi$ being the transfer function of the break junction.

3. Results and discussion

The critical current of the sample prior to the production of crack was slightly greater than 100 mA. Its I–V characteristic was continuously monitored while pressure was applied between two arms of the sample holder for producing the crack. We have adjusted the pressure to attain critical currents $\sim 100\,\mu$A at 77 K. The critical current was found to be a periodic function of the externally applied magnetic field. Figure 1a shows the I–V characteristic of YBCO break junction at 77 K with $I_c \sim 95\,\mu$A and $R_n = 0{\cdot}49\,\Omega$ yielding $I_c R_n \simeq 46\,\mu$V, a value which is much smaller than the BCS

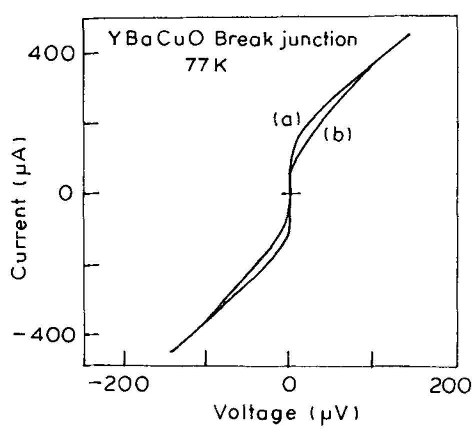

Figure 1. I–V characteristic of break junction at 77 K for (**a**) $B = n\Phi_0$ and (**b**) $B = (n + 1/2)\Phi_0$.

theoretical prediction. Figure 1b shows the maximum suppression of the critical current by applying an external magnetic field equal to $(n + 1/2)\Phi_0$, where Φ_0 is the flux quantum.

Figure 2 shows the V–B characteristics of the break junction at 77 K for various bias currents I_b. The magnetic field was produced by passing current through a 30 turn copper coil. The plane of the coil was at a distance of 3 mm from the junction resulting in a field of $2{\cdot}11 \times 10^{-3}$ T/A. The quasi-periodic voltage oscillations in the V-B curves are due to superconducting quantum interference effect. The break junction consists of two or more weaklinks being incorporated in a superconducting loop (dc SQUID). One period of the oscillation corresponds to one flux quantum, transfer

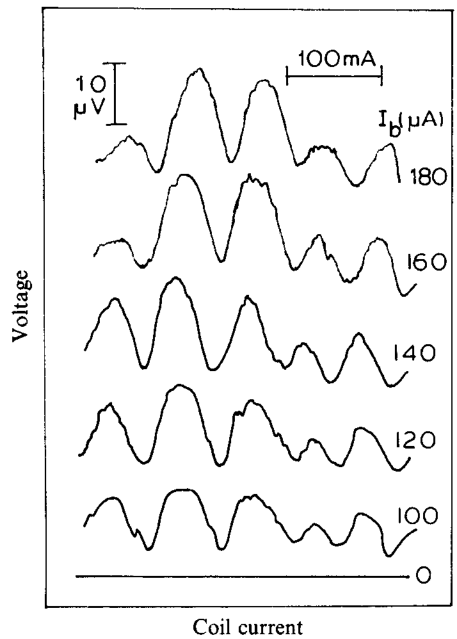

Figure 2. Typical V–B characteristic of the break junction at different biasing currents. The magnetic field strength is represented by the current passing in the field coil.

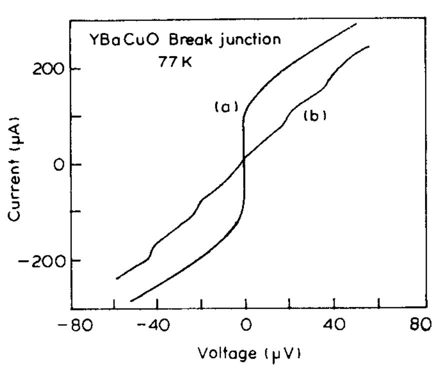

Figure 3. I–V characteristics of the junction (**a**) in the absence of microwave radiations and (**b**) when the junction is irradiated with microwave radiations.

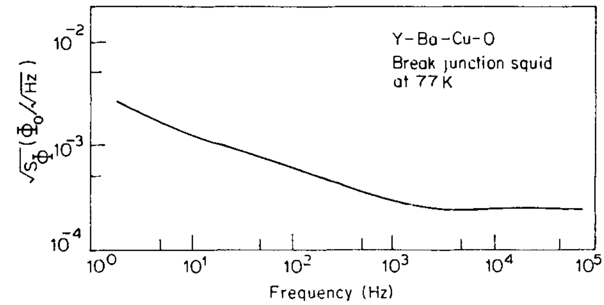

Figure 4. Flux noise vs frequency of the Y–Ba–Cu–O break junction measured at 77 K.

function of the V–B curve, $\partial V/\partial \Phi$ is $30\,\mu V/\Phi_0$. It is noted that the period and the amplitude of the oscillations were no more constant. This is understandable when the break junctions are formed by more than two weaklinks (multi-junctions) and as the magnetic field increases, some of the weak links turn normal and thus the area of the SQUID loop gets redefined depending upon the percolation path available through the remaining weaklinks. Increase in the loop area leads to reduction in the period of oscillations.

We have also studied the effect of microwave radiations on the device as seen in I–V characteristic of the junction. As the microwave power is increased the critical current decreases and almost vanishes at a microwave power $\sim 300\,\mu$W. Figures 3(a) and 3(b) show the I–V curves at 77 K in the absence and presence of 300 μW radiations respectively. Microwave-induced Shapiro steps are seen clearly in figure 3(b).

Figure 4 shows the flux noise density spectrum $S_\Phi^{1/2}(f)$ from 2 Hz to 100 kHz. $S_\Phi^{1/2}(f)$ shows a fall up to 2 kHz, indicating strong presence of $1/f$ noise. At higher frequencies the noise is mostly white noise.

4. Conclusions

DC SQUID effect has been observed in YBCO break junction at 77 K indicating the probable use of these low-cost and easy-to-fabricate junctions for dc SQUID application. The flux noise density of the break junctions is comparable to the high T_c superconducting SQUIDs realized by others (Zimmerman *et al* 1987; Harrop *et al* 1988) using bulk materials.

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