Critical currents of strongly disordered ultra-thin superconducting films

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Abstract

Quench-condensed films of various metals are well known systems for studying the superconducting state in presence of strong disorder. Critical currents of superconducting films of *Bi* and *Sn* with sheet resistance $\langle$ 500Ω were found to vary with temperature according to the relation $I_c(T) = I_c(0)(1 - (\frac{T}{T_c})^4)$. The result was found to be independent of the substrate used. The observed dependence implies a variation of the superconducting gap $\Delta(T) \sim \sqrt{1 - (\frac{T}{T_c})^4}$, near T_c. This is different from the behaviour of a BCS type gap near T_c but consistent with some existing measurements on fabricated 2-D Josephson junction arrays. The $I - V$ characterisitics of these films also show hysteresis, indicating the presence of underdamped intergrain Josephson coupling. The values of the intergrain resistances and capacitances are estimated from the ratios of the observed retrapping and critical currents.

Key words: Jesephson-junction; disorder; quench-condensed

1. Introduction

The nature of the superconducting state in a disordered system has been a topic of interest for several decades now. Quench condensed ultra-thin films have been investigated as model systems to study disorder and superconductivity. The existence of an insulator to superconductor(SI) transition in many elemental as well as multi-component systems is now established. [1].

We have studied quench-condensed superconducting films of Bi and Sn. These films exhibit SI transition as their thickness is increased. We show in this paper that experimentally obtained I-V characteristics of these films in their superconducting phase can be understood as arising from disordered arrays of Josephson junctions.

2. Experimental set-up

The experiments are done in a UHV cryostat, custom designed[2] for *in-situ* study of ultrathin films under a hydrocarbon-free vacuum better than 10^{-8} Torr. A-quartz or crystalline sapphire, mounted with adequate thermal contact on a copper cold finger, in contact with a pumped liquid Helium bath, is used as a substrate. At a time two Hall bar shaped films can be evaporated side by side. One of the films has a pre-deposited 10Å Ge underlayer. Electrical contacts to the sample films are provided with Platinum contact pads about 60Å thick, pre-deposited on the substrate. Four probe d.c. measurements are carried out using a high impedence current source and a nanovoltmeter.

3. Results

A typical set of observed I-V characteristics of a film in the superconducting regime is shown in fig. 1.

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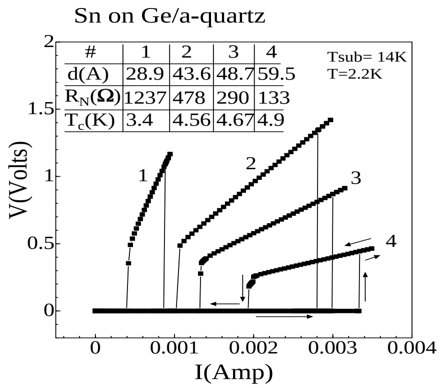

Fig. 1. Typical I-V characteristics of superconducting films showing hysteretic behaviour.

Table 1
Estimate of the bond parameters and energy scales for the 48.7$\mathring{A}$ Sn film in the limit $T \to 0$.

I_r/I_c	β	R_{bond}	I_c/bond	C_{bond}	E_J	E_c
0.44	8.4	290Ω	3.8μA	8.6×10^{-15}F	7.92meV	9.4×10^{-3}meV

The I-V curves show hysteresis similar to underdamped Josephson-junctions. We have modelled the film as a disordered array of RC[2] shunted Josephson-junctions and shown that it is possible to infer certain microscopic parameters of the junctions from the IV characteristics of the film as a whole. [3]

We study the temperature dependence of experimentally measured critical currents of the films. Fig. 2 shows a plot of normalised critical current against the reduced temperature for several Bi and Sn films. For films with sheet resistance $\langle$ 500Ω all data points show a simple power law behaviour given by

$$I_c(T) = I_c(0)(1 - (\frac{T}{T_c})^4)$$

.

Our experimental temperature range is restricted to $T/T_c \sim 0.3$. The flattening of the curves at low temperature allow us to make an extrapolation of the critical current in the limit $T \to 0$. We find that near T_c for these systems[4]

$$\Delta(T) \sim \sqrt{1 - (\frac{T}{T_c})^4}$$

.

This is not the behaviour of a BCS gap near T_c. However, we find that a similar behaviour of $\Delta(T)$ over the entire range of temperature have been seen in fabricated regular Josephson junction arrays [5]. At low temperature I_c as well as I_r tend to constant values. Hence the ratio $(\frac{I_r}{I_c})$ varies very little. We estimate values of intergrain resistance and capacitance from the ratio of observed retrapping and critical current[3]. Table 1 shows the estimated values for a superconducting Sn film.

[2] Resistance and Capacitance

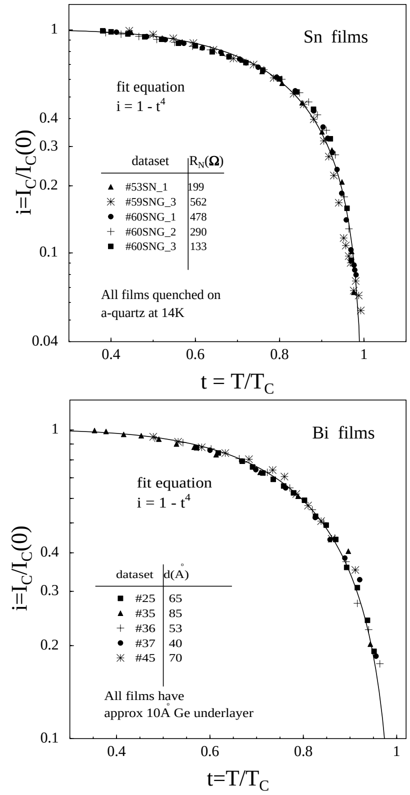

Fig. 2. The critical current of the both films (Bi and Sn) follows the same power law behaviour as described in the text irrespective of presence/absence of underlayer, grown on different substrates.

Acknowledgements

The authors acknowledge G. Sambandamurthy for his help with several measurements. This work was supported by DST, Government of India. KDG thanks CSIR, Govt. of India for a research fellowship.

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