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LOW FREQUENCY ELECTRICAL NOISE ACROSS CONTACTS BETWEEN A NORMAL CONDUCTOR AND SUPERCONDUCTING BULK $YBa_2Cu_3O_7$

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Abstract– Virtually every practical device that makes use of the new ceramic superconductors will need normal conductor to superconductor contacts. The current-voltage and electrical noise characteristics of these contacts could become important design considerations. This paper presents I–V and low frequency electrical noise measurements on contacts between a normal conductor and superconducting polycrystalline $YBa_2Cu_3O_7$. For small current densities, current through the contacts was found to be proportional to $V^{1.7}$. The voltage spectral density, $S_V(f)$, very closely followed an empirical relationship given by, $S_V(f) = C(V_c R_c)^2/f$, where V_c is the DC voltage across the contact, R_c is the contact resistance, f is frequency, and C is a constant found to be $2 \times 10^{-10}/\Omega^2$ at 78° K. This relationship was found to be independent of contact area, contact geometry, sample fabrication technique, and sample density.

INTRODUCTION

In the past few years the discovery of new high-transition temperature (high-T_c) superconductors has led to an abundance of research on the fundamental properties of these materials. For practical devices to be constructed from these materials the electrical contacts to the superconductor need to be investigated. Several researchers have investigated the theoretical[1,2] and experimental[3,4,5] characteristics of normal metal to low-temperature superconductors. The normal metal to bulk superconducting $YBa_2Cu_3O_7$ contact is of particular importance because the material is not a traditional metal. One method of investigation is the current–voltage (I–V) characteristics of the contact. This information is needed for device work if the contact resistance is not a constant. Another important tool in investigating materials and junctions is noise measurement. Noise measurements can be used to define the minimum sensitivity of a device as well as illuminate physical processes occurring in a material or junction. The Noise and Reliability Research Laboratory at the University of South Florida has been investigating the noise characteristics in $YBa_2Cu_3O_7$ superconductors since these materials were discovered.

In this paper, we investigate the current–voltage and noise characteristics of the normal–superconductor (N–S) contacts at liquid nitrogen (LN_2) temperatures for several contacts of different geometries and contact resistances. The noise experiments lead to an important empirical formula for predicting the noise voltage in an N–S contact.

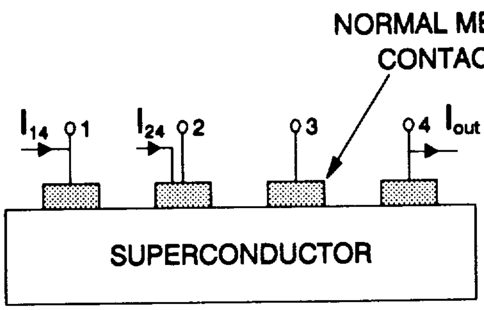

Figure 1: Typical sample contact configuration for normal metal (Ag) to superconductor (bulk $YBa_2Cu_3O_7$) junction.

EXPERIMENTAL METHODS

For this experiment, the $YBa_2Cu_3O_7$ bulk samples used were of three different densities (4.44, 4.46, and 5.02 g/cm^3) and two different fabrication techniques: oxalate precipitation (OP) and solid–state reaction (SSR). All the samples had transition temperatures around 90K and were verified to be deep within the superconducting region at the experimental temperatures (78K).

Each sample consisted of at least four contacts with a typical contact configuration show in figure 1. The contacts made to these samples were made in the following manner. The bulk $YBa_2Cu_3O_7$ surface was sanded with very fine grain sandpaper to remove any of the exposed surface which may have oxidized. It was then ultrasonically cleaned for two minutes in a 100% ethyl

Table 1: Parameters for the 5 different contacts used in this investigation.

Samp no.	Samp name	Dens g/cm^3	Area mm^2	Contact shape	Contact no.	Max Res (Ω)
1	Trak	4.46	15	Rect	1	1.1
2	Trak	4.46	15	Rect	2	0.65
3	Trak	4.46	15	Rect	4	2.5
4	Fsu25	5.07	12	Semicr	1	0.91
5	Fsu26	4.44	7	Circ	2	1.6

alcohol bath. The contact mask was then fastened to the sample and it was then sputtered with a 300 nm layer of gold–palladium (AuPd). The AuPd pads were then covered with silver epoxy and silver coated wires were pressed into the epoxy. The epoxy was cured at 180°C for 1 hour. These contacts usually yielded a contact resistance between 0.5–2.5Ω for a 0.25 cm^2 area contact. Table 1 shows the various parameters for the sample contacts used.

The samples were then wired and connected to the measurement equipment. Each sample was suspended about 1 inch above the LN_2 level in a 3-liter MVE dewar. The temperature at this level was 78K and was found to remain constant for at least 12 hours. The sample was first connected to verify superconductivity in the region to be measured. Refering to figure 1, the current was passed from 1 through 4 and the voltage was checked across contacts 2 and 3 for zero resistance. After superconductivity was verified, the current is passed from 2 to 4 and the voltage is measured across contacts 2 and 3. Since the bulk material in that region was already found to have no resistance or noise, any resistance or noise generated must come from the junction between the normal metal at contact 2 (now current carrying) and the superconducting $YBa_2Cu_3O_7$. The sample contact was then subjected to I–V measurements. The contacts were connected to a Keithley Constant Current Source with a Keithley Nanovoltmeter for reading the contact voltage (V_c). The measurement equipment was controlled by a PC-compatible computer with software written for this experiment. The noise measurement system was constructed as shown in figure 2. The system consisted of a DC biasing circuit consisting of 2–12V gel cells connected in parallel and various wirewound resistors for selecting different bias currents through the sample contact. The current flowing in the system was measured by reading the voltage across V_s and dividing by $R_{control}$.

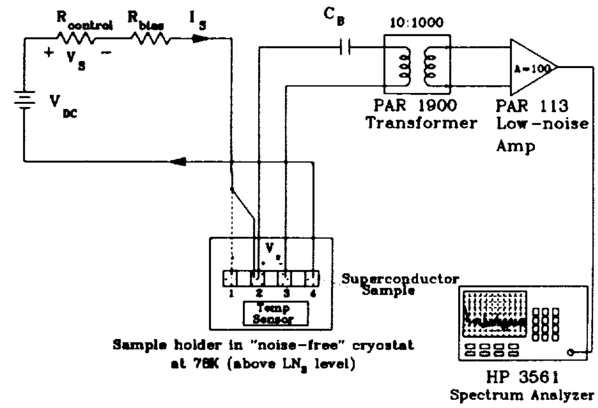

Figure 2: Experimental apparatus for contact noise measurements.

The R_{bias} resistor was used to adjust the biasing current in the system. The current was passed through contact 2 to contact 4. The blocking capacitor, C_B, was used to block DC current from magnetizing PAR-1900 transformer. The PAR-1900 transformer was connected from the 10:1000 turns ratio giving a gain of 100 through the transformer. It was connected to a PAR-113 Low–noise Amplifier with the gain set at 100. This combination of the transformer and amplifier gave an overall gain of 10 000. The HP 3561 Spectrum Analyzer was used to collect the noise traces. The traces were collected in the low-frequency region of 1–51 Hz with 25 averages per trace to yield more than sufficient resolution.

Excess noise checks were made at various stages of the experiment to assure that the noise measured was coming from the N–S contact and not an element of the measurement system. Also the silver epoxy was tested and showed no excess noise.

RESULTS AND DISCUSSION

I. Current–voltage experiments

The results obtained for the I–V relationship of these contacts were a little surprising. These contacts showed a decreasing resistance as the voltage across the contact increased. This same effect was observed by Van Schevicoven and De Waele [6] for bulk point contacts between a normal metal and high–T_c superconductor. Moreland, et al[7], also found similar results in break junctions in a bulk $YBa_2Cu_3O_7$ sample. Figure 3 shows a typical I–V curve for the bulk contacts used in this investigation. The figure shows the parabolic nature of the curve as well as the symmetry in both the positive and negative voltage regimes. The parabolic shape of the curve was common for all the contacts investigated and led to an

Table 2: Experimental results of current–voltage measurements.

Sample number	A	λ	Zero-bias Res. (Ω)
1	9.57	1.68	1.1
2	13.8	1.76	0.65
3	3.47	1.66	2.5
5	3.34	1.57	1.6

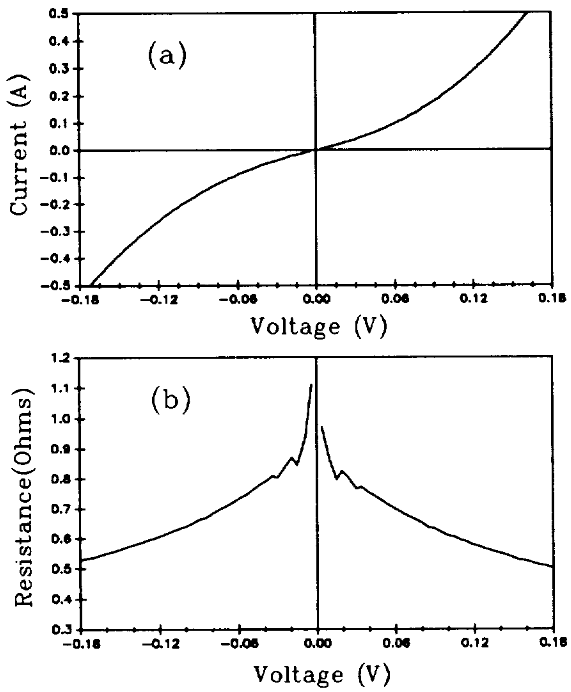

Figure 3: Typical electrical characteristics of a normal metal–superconducting $YBa_2Cu_3O_7$ contact; (a) Current–Voltage graph; (b) Resistance–Voltage graph.

empirical formula

$$I = AV_c^{\lambda} \quad (1)$$

where I is the current flowing through the contact, V_c is the voltage across the contact, A is a constant related to the resistance of the sample, and λ is a power factor which is around 1.7 for the samples tested. Table 2 gives the A and λ values for the various contacts used in this investigation. Van Schevicoven and De Waele attribute this parabolic behavior to normal electron tunneling between the normal metal contact to high-T_c superconductor.

II. Noise experiments

The noise measurements were taken over a 0.1 to 30 mV bias voltage range for the five contact samples. The noise traces were dumped from the HP 3561 into a lab computer where they were analyzed using a least-squares line fitting method to determine the slope as a function of frequency. All the noise traces were "$1/f$ noise" where "$1/f$ noise" is defined as noise proportional to $1/f^{\alpha}$ where α ranges between 0.8 and 1.2. After this data was analyzed, the value of each trace at 10 Hz was recorded and compared to the bias voltage, current, resistance, and other parameters. All the experimental noise current spectral densities were found to follow an empirical formula. Figure 4 shows the plot of the noise current spectral density ($S_I(f)$ or $S_V(f)/R_c^2$) vs. the contact voltage (V_c) for the five sample contacts used. The log $S_I(f)$ vs log V_c forms a straight line for which all the data collected lies in close proximity. The empirical formulas for the noise voltage spectral density and the noise current spectral density, respectively, are

Table 3: Contact noise measurement results for the equation $S_V(f) = CV^{\beta}R^2/f$.

Sample number	Zero-bias Res (Ω)	C ($1/\Omega^2$)	β for V^{β}
1	1.1	2.1×10^{-10}	1.90
2	0.65	3.3×10^{-10}	2.06
3	2.5	2.1×10^{-10}	1.98
4	0.91	1.6×10^{-10}	1.90
5	1.6	7.8×10^{-11}	1.98
Empirical formula	—	2.0×10^{-10}	2.00

$$S_V(f) = \frac{C(V_cR_c)^2}{f} \quad (2)$$

$$S_I(f) = \frac{CV_c^2}{f} \quad (3)$$

where C is an empirical constant found to be approximately $2 \times 10^{-10}/\Omega^2$, V_c is the contact voltage, R_c is the contact resistance, and f is the frequency. Table 3 shows the experimental values of C for the various contacts. The noise which was measured in the contacts was very different from the results found in bulk $YBa_2Cu_3O_7$ which has been reported by several experimenters[8,9,10]. The implications of this empirical equation are that the noise voltage spectral density can be predicted by measuring the contact resistance which may be of great advantage when practical devices are to be fabricated from high-T_c materials.

CONCLUSIONS

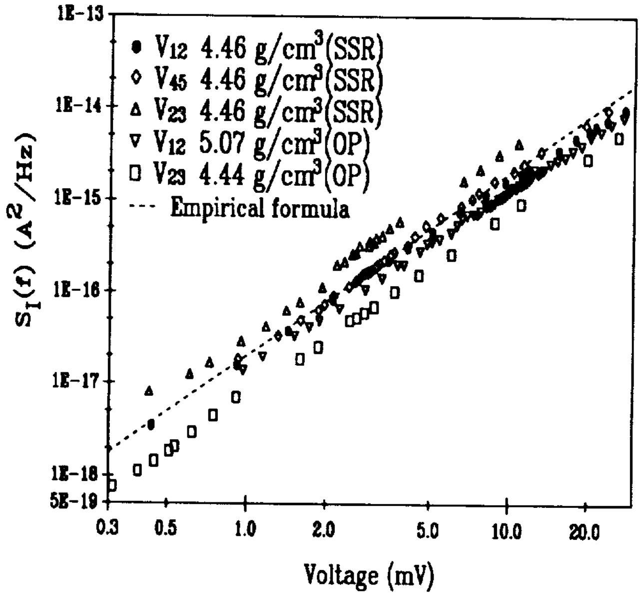

Figure 4: Graph of noise current spectral density ($S_I(f)$ or $S_V(f)/R^2$) for normal metal–superconducting $YBa_2Cu_3O_7$ contacts. The dotted line shows the empirical formula obtained from the data.

Five normal metal–superconducting $YBa_2Cu_3O_7$ sample contacts were thoroughly studied for their current–voltage and noise characteristics. The I–V measurements led to an empirical formula, $I = AV^{\lambda}$, to describe the parabolic relationship between I and V. The noise measurements yielded an empirical equation of the form, $S_V(f) = C(V_cR_c)^2/f$, which describes the noise voltage spectral density for a contact with resistance, R_c, and voltage, V_c.

The N–S contact characteristics are very important and need to be thoroughly understood for any practical device made from superconducting $YBa_2Cu_3O_7$. The noise limits the sensitivity of any device and since the superconductor itself yields no measurable noise in the superconducting region, the normal metal contact noise would most likely be the source of excess noise in such a device.

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