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High resolution V–I characteristics measurements on high T_c superconductors

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Abstract. V–I characteristics of sintered superconducting pellets of $YBa_2Cu_3O_{7-\delta}$ was measured with a resolution one order of magnitude better than the usual dc techniques employing nanovoltmeters. For this purpose software-based lock-in-amplifier technique was developed and used. A square-wave excitation current was used. The voltage signal was digitized into a time series and Fourier-analysed on a computer in this technique. Our results show a very small frequency-dependent resistance in some samples which are nominally superconducting. These results help in checking the material quality and defining the critical current densities better.

Keywords. Critical current; lock-in technique; frequency-dependent resistance.

1. Introduction

The need to standardize measurement techniques and characterize the new high T_c superconducting materials has been recognized. Accurate measurements of T_c and the critical current density J_c involve recovering low-level voltage signals from noise. This is because the usual pellets used in measurements are small in size and the material has low J_c values.

For recovering low-level signals, the signal-to-noise ratio (S/N) can be improved by averaging, filtering, correlation or coding. If the signal of interest is a repetitive waveform, the use of phase sensitive detection provides a large gain in the S/N. Some high resolution dc voltmeters use the averaging technique. The improvement in S/N by such averaging is proportional to the square root of the number of readings averaged. It is advantageous to use ac techniques whenever the system under test can respond to both dc and ac stimulii. We have developed a software-based high resolution lock-in-amplifier (LIA) which has a voltage resolution ~ 3 nV, limited by the input noise of the preamplifier used. Whereas commercially available LIAs are restricted in the lowest frequency to about 1 Hz, our technique is usable at arbitrarily low frequencies. We have investigated yttrium-based (1:2:3) superconducting samples in the frequency range 0·125–32 Hz and studied their V–I characteristics.

2. Experimental set-up

A schematic of the set-up is shown in figure 1. A regular bath-type cryostat was used. The current and voltage leads were separated and shielded both inside and outside the cryostat to minimize the pick-up. The sample was excited by a low-frequency square waveform with zero mean from a current source (two Keithley model 220's in parallel). The voltage signal from the sample was preamplified by a low-noise

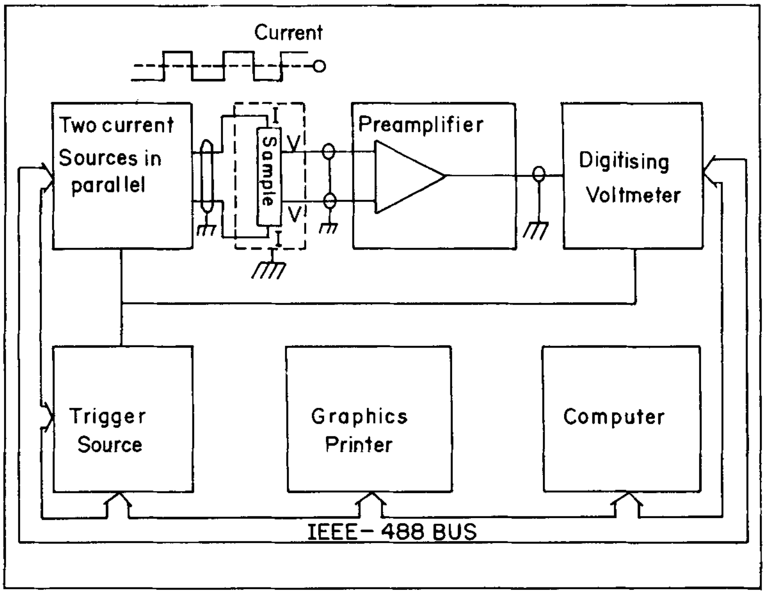

Figure 1. Schematic of the experimental set-up.

differential preamplifier (Ithaco model 1201) with a gain of 10,000. The output of the preamplifier was digitized by a digitizing voltmeter (Keithley model 194A). To prevent overdriving the voltmeter by unwanted broadband noise the bandpass filter on the preamplifier was set around the excitation frequency with a low Q. The current sources and the digitizing voltmeter were triggered by the same trigger source (Hewlett Packard model 3314A). The frequency of the current excitation was measured by a frequency counter (Enertec model 2720). All the instruments were connected to a desktop computer via an IEEE bus. The set-up was calibrated with a standard $10\,\mu\Omega$ resistance for all desired frequencies of operation. The voltage time series generated by the voltmeter was transferred to the computer for analyses.

The software included a precalculated cosine reference function with the same sampling period as used by the digitizing voltmeter (16 points per cycle). The reference and signal time series were multiplied and averaged over a large number of cycles to give the component of signal in phase with the excitation. The quadrature signal could be obtained by using a sinusoidal time series for the signal. This whole calculation is equivalent to calculating the single Fourier component of the noisy signal at the excitation frequency. It is also possible to simultaneously measure $\mathrm{d}V/\mathrm{d}I$ and $\mathrm{d}^2V/\mathrm{d}I^2$ as a function of I with this set-up by using a dc current bias and a small ac modulation. The Fourier component at the excitation frequency gives $\mathrm{d}V/\mathrm{d}I$ and the Fourier component at twice the excitation frequency gives $\mathrm{d}^2V/\mathrm{d}I^2$.

3. Results and conclusions

We measured the V–I characteristics of several samples at 77 K in the frequency range 0·125–32 Hz. We found small resistance values for many samples even at low currents at all frequencies (figure 2). These resistance values would not be measurable using usual nanovoltmeters. On some other samples much higher currents were required before dc voltages could be detected across the samples, limited by sample heating due to power dissipation in contacts. We found frequency-dependent resistances in some other samples with the resistance increasing with frequency (figure 3). Samples where high dc currents were required to observe a voltage drop also started showing frequency-dependent resistance at low currents after exposure to atmosphere, which pointed to the degradation of the material. Dissipation in superconducting samples has been observed for short time scales (Yeh *et al* 1987; Mohamed *et al* 1988).

In view of the above results 1 μV/cm type of criteria used for defining J_c values can lead to erroneous results. Also, with samples showing frequency-dependent effects, J_c measurements made with pulsed currents would lead to erroneous values if the pulse duration were to be short. It is thus important to study frequency dependence of $V–I$ characteristics to properly characterize the samples.

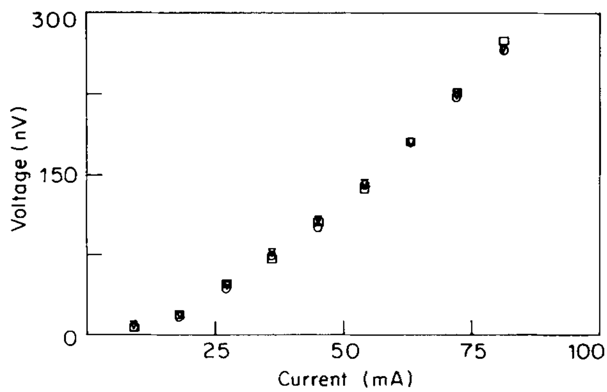

Figure 2. Typical $V–I$ characteristic of a "superconducting" sample at 77 K showing a finite resistance even at very low current bias at several frequencies; ▽, 16 Hz; □, 4 Hz; ○, 0·5 Hz.

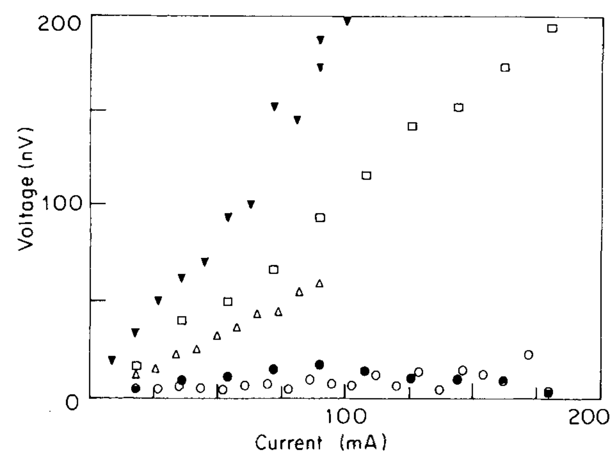

Figure 3. Typical $V–I$ characteristic of a sample at 77 K showing frequency-dependent resistance; ▽, 16 Hz; □, 8 Hz; △, 4 Hz; ○, 1 Hz; ◇, 0·5 Hz.

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