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Laboratori Nazionali di Frascati

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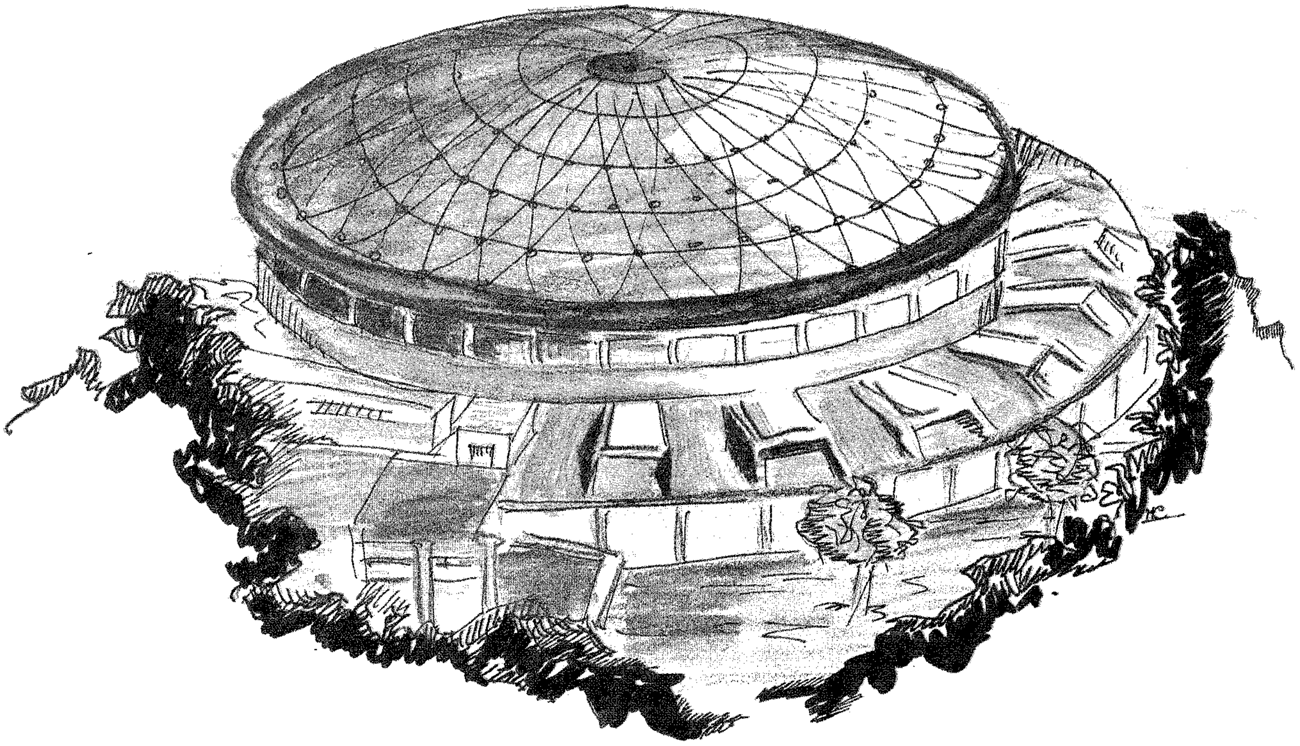

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ABSTRACT

An automatic measurement system has been set up to record the dependence of the transport critical current of $Y_1Ba_2Cu_3O_7$ samples both on the external magnetic field, and on the temperature. The automatic data acquisition is able to record the sample resistance during the whole cooldown, and can manage either the transport current through the sample or the external field value, but not the temperature. Measurements made with this system are presented toghether with previous data collected using a manual point by point recording technique. The observed behavior of the critical current on the applied field and on the temperature is briefly discussed.

1 - INTRODUCTION

The discovery of new high-T_c superconducting materials has stimulated many workers to picture a lot of potential application of superconductivity to the ordinary life. This is mainly due to the impressive growth of the critical temperature T_c at which the superconducting transition occurs, see Fig. 1, using these new superconducting oxides.

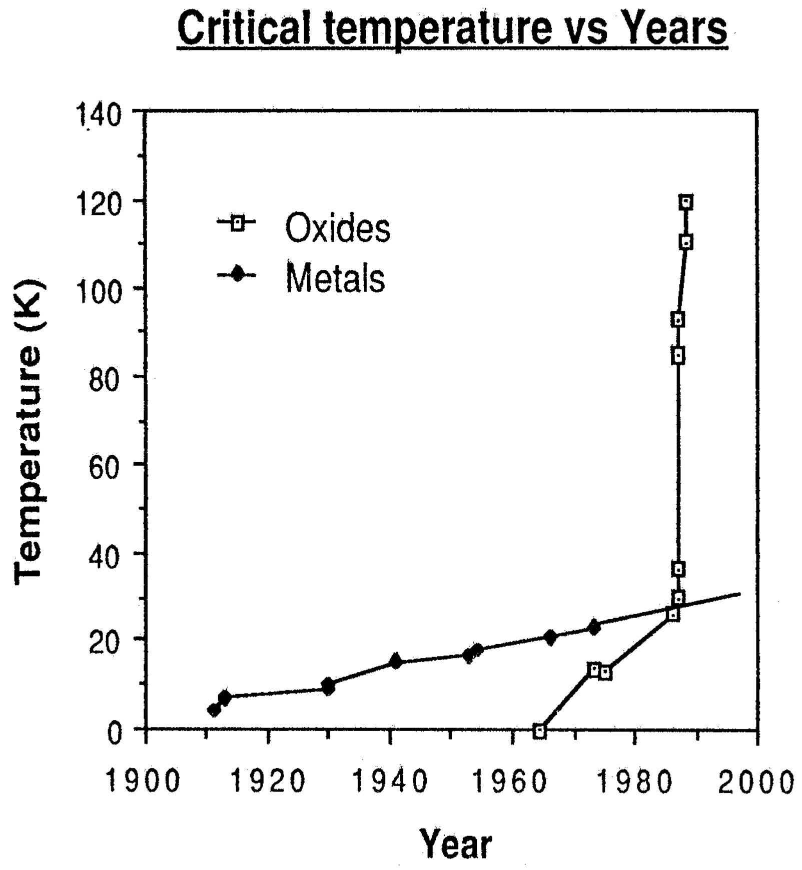

FIG. 1 - T_c improvements of usual metals and new oxides.

Though the theoretical mechanism which gives rise to the superconducting state in the high-T_c superconductors has not yet estabilished, an intense experimental work has been already made. For many applications it would be useful to know the critical current density J_c of these new superconductors, which have been accounted for very high values ($J_c \approx 10^5$ A/cm^2)[1]. Unfortunately these J_c values indirectly come from the early magnetization measurements, using a theoretical model valid for bulk materials[2]. Because of the granular nature of the high-T_c compounds, this model only gives informations about the grain currents, but it do not take into account the current flow among grains, which is of interest for practical applications. To take into account the effect of grain contacts, direct current flow measurements have been performed testing several $Y_1Ba_2Cu_3O_7$ samples. Moreover the dependence of the maximum superconducting current both on the temperature and on the magnetic field has been investigated.

Because the complete recording of the sample characteristics tooke several hours, after the early measurements we decided to build up an automatic system and to improve the reliability of the measure. In Sec. 2 the experimental conditions and a typical measure run are described. In Sec. 3 both data got using a point by point recording technique, and the data automatically collected are presented and discussed. The conclusions in Sec. 4 are devoted to further improvements to carry out on this kind of measurements.

2 - EXPERIMENTAL CONFIGURATION

All the tested samples were prepared by using mixed powders of CuO, BaO_2 and Y_2O_3, by C. Alvani and S. Casadio[3]. The X-ray diffraction pattern indicates that our specimens are comparable with ceramic samples reported elsewhere[4]. The experiment is performed in a helium gas flow variable temperature cryostat provided with a temperature controller. On the sample holder there is a calibrate silicon diode thermometer for accurate temperature reading, placed in closed contact with the $Y_1Ba_2Cu_3O_7$ sample. The geometry of the sample is arranged to keep low the current values, thus minimizing self-heating effects due to the contact resistance between wires and the sample surface. To improve electric connection between the sample and the measure wires we deposited silver pads in a linear four probe configuration, consisting of 6000 Å thick film, by e-beam on the sputter cleaned surface of the specimen. Both current and voltage wires have been soft welded with indium. By using this technique current contacts with resistance lower than 0.3 Ω were achieved, while voltage contacts had a little higher resistance (few Ohms) due to their smaller size. However the resistance of voltage contacts enables to reduce the noise of the fluctuating thermal emf at values lower than 0.2 μV.

The scheme of instrument arrangement is shown in Fig. 2, where the set up for the measure of critical current is reported. The resistance R vs temperature T is always recorded using a low bias current I_{bias}=1 mA, to unaffect the superconducting transition of the sample by the current flow. This, toghether with the low specimen resistance, made necessary to sense the sample voltage with a nanovoltmeter and to adopt usual low noise precautions. In particular, to avoid the large fluctuating thermal emf during the cooldown, the system automatically peforms double reading, with direct and inverse current flow, of the sample voltage. The nanovoltmeter output is connected to the DMM scanner and read by the computer control. The calibrated thermometer is always fed by a 10 μA constant current generator and the thermometer voltage is read by the computer control directly from the DMM scanner. This voltage is then suitably processed by a software subroutine to get the temperature. The magnetic field is generated by an external split coil, fed from a programmable power supply, and it is always perpendicular to the direction of the current flowing through the sample. The magnetic field value is computed by the coil conversion factor $\alpha \approx 0.00223$ Gauss/mA and the shunt resistance $R_a \approx 5.5\ \Omega$ in the control program.

Once the sample is cooled under its T_c, the critical current is measured, taking well care of self-heating effects that may arise from the current flow when the sample becomes resistive. For this reason we assume that the maximum superconducting current is the current value which gives rise to the appearance of a 1μV voltage across the sample.

The mesuring steps are as follows:

a. set the temperature and/or the magnetic field, and read it;

b. start the ramp reference voltage which controls the power supply, thus linearly increasing the current. The voltage derivative is set at low values ($<10^{-2}$ V/s) for better accuracy;

c. sense the voltage across the sample;

d. when a voltage larger than 1 μV is recorded then the computer reads the current flowing by means of the voltage across the shunt resistor R_b=24 mΩ and resets the reference voltage ram to zero.

These steps are repeated for each value of temperature and/or magnetic field.

Presently it is not possible to get a remote control on the temperature, so the temperature values are manually set, while the magnetic field can be remotely controlled.

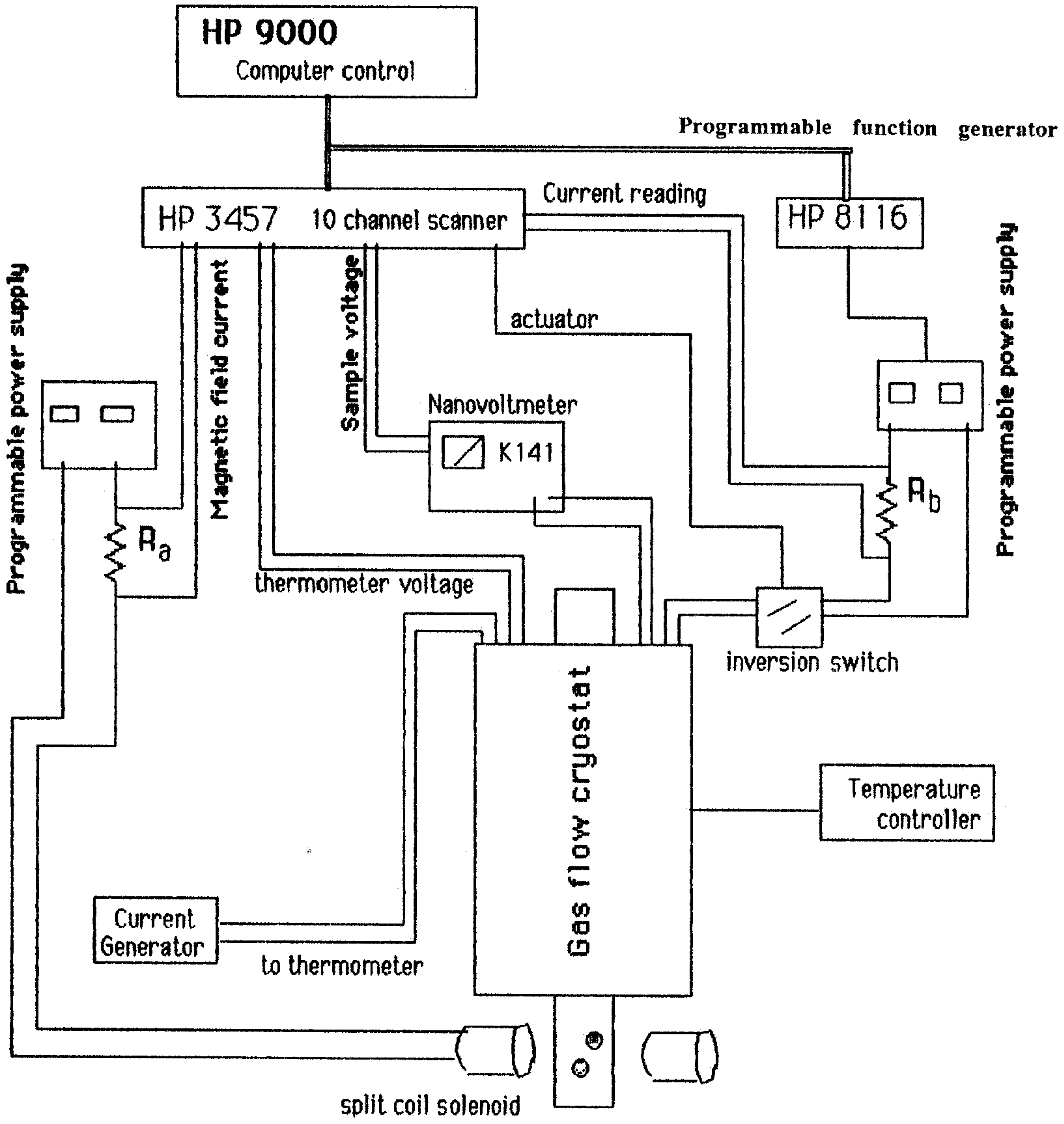

FIG. 2 - Instrumentation arrangement for critical current measurements.

3 - EXPERIMENTAL RESULTS

The typical record of R-vs-T got with our system is reported in Fig.3, and it indicates the usual resistance ratio between ambient temperature and the temperature just before $T_c \approx 92$ K. In Fig.4 the critical current dependence on the sample temperature is shown. In Fig. 5 the ordinary Ginzburg-Landau theory for a superconducting granular sample [5] is plotted on a log-log scale, toghether with data of Fig. 4 where currents and temperatures have been respectively normalised to the measured critical current (5770 mA) in LHe bath, and T_c. In this figure the x axis represents the log argument $(1-T/T_c)$. This plot shows some discrepancies expecially at temperatures closed to T_c. Finally in Figs. 6 and 7 the magnetic field behavior of the critical current at temperature of 78 K is plotted, for two samples having different geometrical densities. As can be noted there is a large dependence of the critical current on the applied magnetic field, even at field of few Gauss. Because the lower critical field H_{c1} for these kind of materials is about 100 Gauss [6], the observed strong reduction of the critical current cannot be ascribed to the magnetic penetration within the superconductor. It seems better to consider how the superconducting coupling between grains is affected by the magnetic field. The observed behavior is reminescent of the Josephson current, where also there is a strong reduction of the current when the magnetic flux $\o$ threading the junction approaches to a quantum flux $\O_0$ ($\O_0$=2.07x10^{-7} Gauss cm^2). For a $Y_1Ba_2Cu_3O_7$ sample one could imagine that grains are arranged to form parallel junctions, each one threading a different magnetic flux, so that the normalised total current is[7]:

$$\frac{I_c(B)}{I_c(0)} = \frac{1}{N} \sum_{i=0}^{N} \left| \frac{\sin(\pi B/B_0\beta_i)}{\pi B/B_0\beta_i} \right| \qquad (1)$$

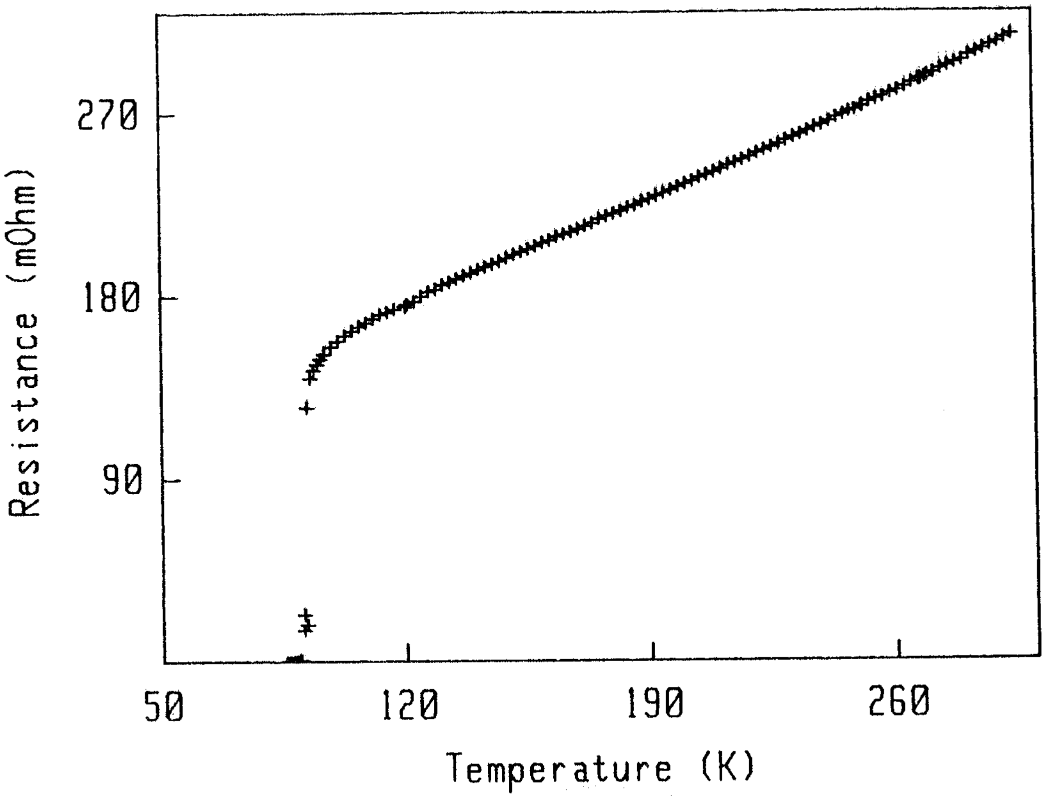

FIG. 3 - Typical R vs T behavior of our samples.

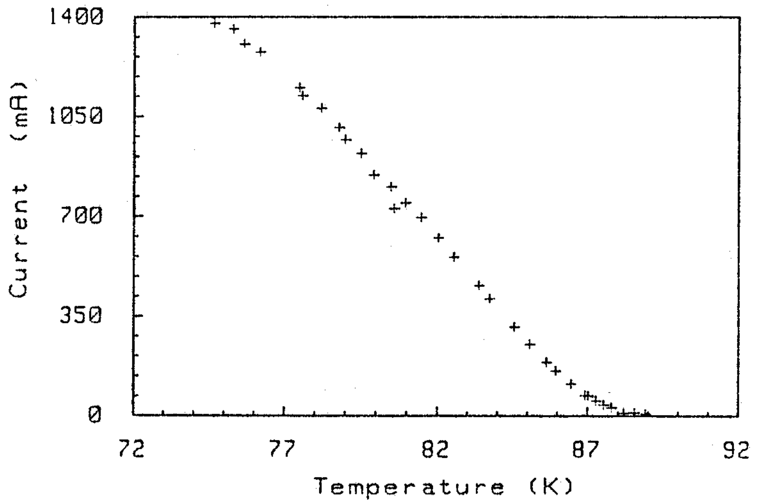

FIG. 4 - Critical current vs temperature of the sample SC3.

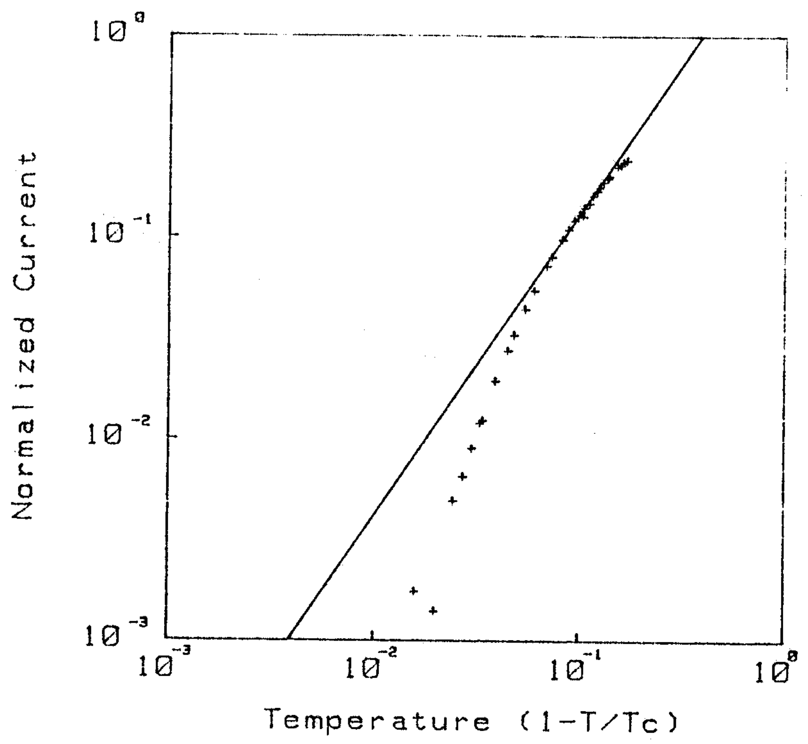

FIG. 5 - The normalised Ginzburg Landau theoretical curve for granular superconductors (solid line) $I_{norm}=\log(1-T/T_c)^{3/2}$+Cost. and experimental data of the sample SC3 normalised to the 4.2 K critical current (5770 mA) and $T_c \approx 92$ K.

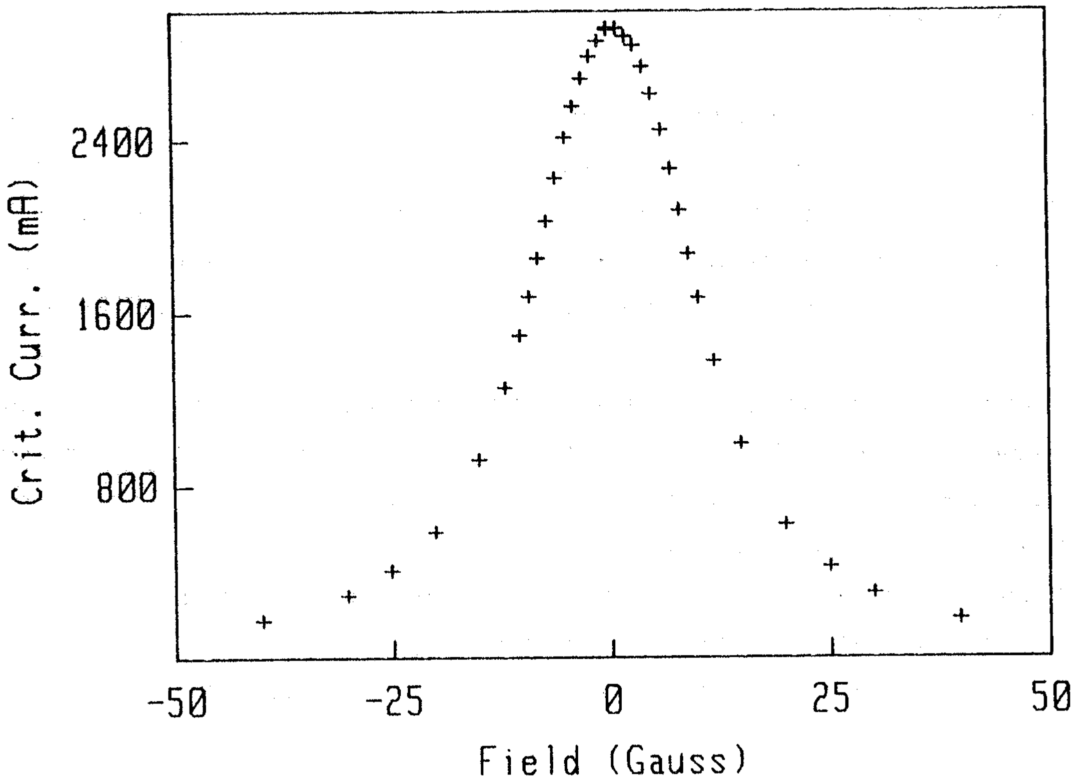

FIG. 6 - Magnetic field behavior of the sample SC4 at T≈78 K.

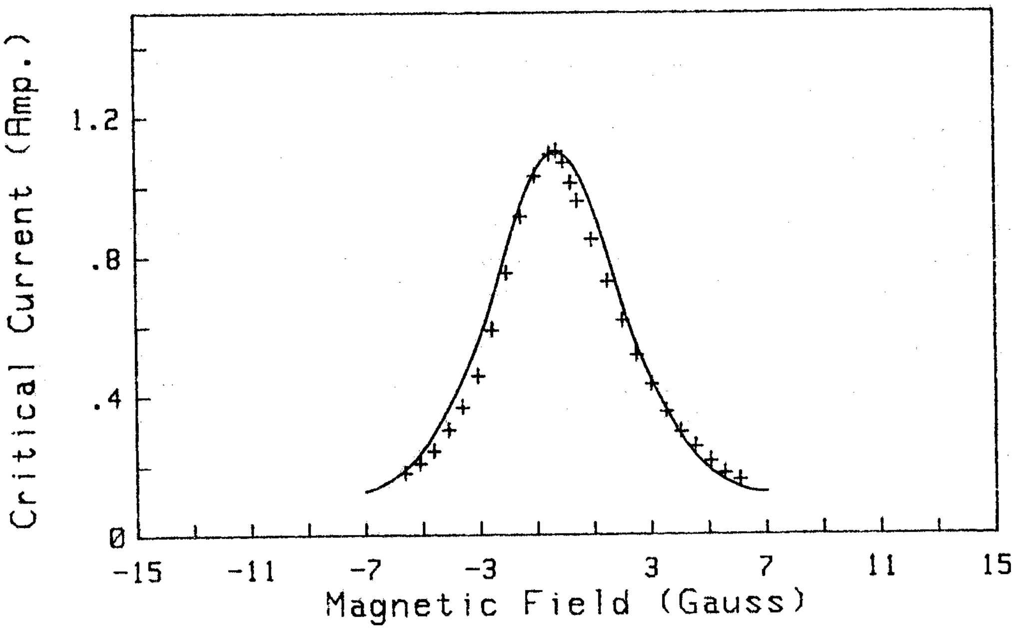

FIG. 7 - Magnetic field behavior of the sample SC3 at T≈78 K. Solid line represents eq. 1.

where the factor β_i accounts for the different effective areas of each junction. In Fig. 7 the solid line represents eq. 1 where β_i has the simple expression $\beta_i=0.5+0.05\ i$ (i=0, 1, ..., 25), which implies a parallel of 26 different junctions: the agreement is suggestive.

4 - CONCLUSIONS

In order to improve the reliability of critical current measurements on $Y_1Ba_2Cu_3O_7$ samples we arranged an automatic measuring system which moreover allows a standing alone operation. This is especially useful when long time recording are requested, i.e. slow cooldown of the sample. With this system we recorded the critical current dependence on the temperature and on the external magnetic field. The system revealed good tool for such investigations, allowing accurate and reliable records.

The previous and present data both indicate strong reduction of the critical current with applied magnetic field of few Gauss. Moreover deeper investigations on the temperature dependence both of the critical current and on the magnetic behavior have to be carried out in order to get some relation between fabrication process and electric features..

After these experiences we realised the measurement system improvements to pursue, which mainly concern to the complete remote control on the temperature. This, in fact, will make possible an automatic measure of the interesting properties with higher reliability even without operator assistance.

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