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Critical Current Density and Transition Temperature Measurements of Y-Ba-Cu-O Rods

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CRITICAL CURRENT DENSITY AND TRANSITION TEMPERATURE MEASUREMENTS OF Y-Ba-Cu-O RODS

(1.0) Introduction to J_c Measurements

This report details the results of critical current density (J_c) measurements on yttrium - barium - copper oxide samples provided to DARPA from ICI. Two batches of samples, labelled OX40/C/2, and OX40/C/4, were provided. Each batch consisted of six rods 0.031" in diameter (cross sectional area $5.0 \times 10^{-3} \text{ cm}^2$) and 1.5" long. To assist in identification of individual samples within batches, we added a capital letter to the label (e.g., OX40/C/2/A). One sample in each batch (OX40/C/2/A and OX40/C/4/A) was provided with silver wire leads wrapped around the rod at four points and covered with indium and designated specifically for four-terminal transport measurements of J_c .

The measurment details for the J_c measurements and their interpretation are discussed in the literature¹ and will not be repeated here. We just mention one specific: In all specimens measured for this study, the spacing between the voltage electrodes was one centimeter.

The first J_c sample OX40/C/2/A was mounted without a problem onto the NRL cryostat, but was broken during insertion into the dewar. This sample thus became available for measurement of the superconductive transition temperature (T_c) since pieces as short as 0.250 " were quite adequate for this purpose. Subsequently a new sample OX40/C/2/B was mounted in a manner similar to the original J_c sample, inserted into the cryostat and repeatedly measured , thermally cycled, and remeasured. This sample was used for the first series of measurements listed as runs 890428, 890502, 890510, 890511, and 890512. This series of experiments studied the effect of magnetic field on

the critical current properties of the material, and the effect of repeated cycling on these properties.

In order to survey the J_c of the other samples, a second series of experiments was performed on samples designated OX40/C/2/C, OX40/C/2/D, OX40/C/4/A, OX40/C/4/B, OX40/C/4/C and OX40/C/4/D. This second series consisting of runs designated 890528, 890531 (from batch OX40/C/2), 890615, 890617, 890618, and 890624 (from batch OX40/C/4), concentrated on surveying the remaining samples to see if their properties were consistent with the results of the first series of experiments.

(2.0) Sample Mounting

Several techniques for making low resistance contacts to high T_c oxide materials have been reported in the literature. These range from the simple use of a silver-base epoxy which is then fired to leave a noble metal pad,² a more complicated method using gold wire cylinders placed in a press chamber which is then filled with powder and compressed to form gold pads,³ and an elaborate procedure involving sputtering or evaporation of gold contacts.⁴ This is not intended to be an exhaustive list of techniques but rather to illustrate the different methods available. While there is no question that these methods give good results, one would still like to have simpler techniques. To this end, several alternatives were explored with varying degrees of success. These are discussed below.

The sample mounting technique used for the first series of experiments on sample OX40/C/2/B was one that had been employed successfully in the past at this laboratory. A tin rod shaped to an edge with a point was dipped into an indium-gallium eutectic mixture. The sample was then abraded with the tin rod whereupon the eutectic mixture on the tip wetted and coated the areas of the rod where electrodes were to be attached. Silver wire previously formed on a mandril was slipped over the rod at these points. One turn of the silver wire was used for the voltage leads and several turns were used for the current leads. Once all the wires were positioned on the rod, the areas were coated with indium solder. The larger contact area of the current leads was intended

to keep the resistance low so that Joule heating would be minimized. Although this method produced repeatable contact resistances, they were too large and, moreover, we observed that lead resistance increased after each cycle. We attributed the large contact resistance to the formation of indium oxide which is a semiconductor thought to be formed when indium comes in contact with Y-Ba-Cu-O. Consequently for the second series of measurements other techniques for attaching the silver leads to the rods were employed.

The use of a silver epoxy to form low resistance contacts was reported in the literature (see reference to van der Mass et. al.). Using a silver paste (Dupont Conductor Composition) to coat an area, then wrapping 0.010" Pt wire around the rod, subsequently covering with more silver paste and firing in flowing oxygen also produced bonds with low contact resistance. We have also had some success with a metallo-organic gold ink (Engelhard). This material was painted on the sample and fired to drive off the binder. The sample was then soldered to the contacts with indium. Both silver paste and gold ink were used to form low resistance electrical contacts used in mounting the samples. The results of these methods for lead attachments will be discussed below.

(3.0) Sample Cycling Procedure

In our earlier work with a previous batch of ICI samples we noticed that J_c decreased with thermal cycling. The conventional wisdom at that time was that, during cycling unreacted Ba in the sample reacted with carbon dioxide present in the air to form barium carbonate which was detrimental to J_c . In order to eliminate this possibility, cycling of the sample was accomplished in the following manner. A stainless steel tube about 1/4 inch in diameter was placed into the dewar so that it extended to the bottom. At the conclusion of an experimental run, nitrogen gas vented from a 3000 gallon storage tank located outside of our building and piped into our lab was introduced into the cryostat through this tube. The liquid nitrogen in the dewar boiled away over a period of several hours and the positive pressure effectively kept moisture and other atmospheric components from collecting in the dewar while the system warmed to room temperature. The sample remained in the dewar bathed in flowing nitrogen gas between runs unless a contact was being remade. This technique

was used successfully on samples prepared at NIST (formerly NBS) and so was applied to these samples.

(4.0) Series One Experiments / Sample OX40/C/2/B

Sample OX40/C/2/B was measured on 28 April 89 - 890428, 2 May 89 - 890502, 10 May 89 - 890510, 11 May 89 - 890511, and 12 May 89 - 890512. The sample was cooled to liquid nitrogen temperatures and current-voltage (I-V) curves were measured. Initially we planned to make measurements at zero field, 0.1T, 1T, and 10T, at each of three convenient temperatures 77K, 64K, and 52K. During the course of these experiments two points were noted. The samples were extremely sensitive to magnetic field and they pinned flux which resulted in the decrease of zero field J_c values after they were measured at higher fields.

(4.1) Sensitivity of J_c to Magnetic Field

The sensitivity of the critical current of these samples to magnetic field is shown in Figure 1 where data taken from run number 890428 is presented. These data were taken at a temperature of 77K, at five different increasing fields taken in succession, namely 0T, 0.0206T, 0.1T, 1T, and 10T. The value of 0.021T, represents the smallest value of magnetic field that can be applied to our Bitter magnets when connected to a 6MW power supply and is governed by the 20A leakage current flowing through the magnet. We see that magnetic fields as small as 0.1T profoundly depress J_c . Thus subsequent measurements were often confined to fields below 0.1T which could be produced simply with a 150 Ampere power supply that did not require a magnet operator from the NRL High-Magnetic-Field facility and which was free of the residual current problem.

(4.2) Effect of Flux Pinning on J_c

The problem of flux pinning was more subtle. It was experimentally convenient to measure an I-V curve at room temperature to be sure all the

equipment was working properly. Liquid nitrogen was then slowly added to the cryostat and the I-V curves were taken at 77K for a series of magnetic fields which were increased monotonically. Upon completion of this series the sample temperature was lowered by pumping on the liquid nitrogen bath. Temperature was stabilized at 63K-64K, and the I-V studies as a function of magnetic field were repeated. The temperature was then decreased to 52K by further pumping and the I-V measurements as a function of magnetic field were again repeated.

When we examined the data taken by this procedure, we found that J_c was often smaller at lower temperatures. This result could only be explained by the retention at lower temperatures of some of the applied field (i.e. flux trapping) when the sample was exposed to a magnetic field at a higher temperature. This effect can be seen from Figure 2 where two traces from the data taken from 890511 are compared. One I-V curve is a virgin curve (i.e. the sample was not exposed to a magnetic field). The other is a zero field curve after the application of 0.1T. The second curve shows resistance at current values of approximately 50% of the virgin curve values. Consequently, the data obtained at lower temperatures after exposure to magnetic fields at a higher temperature was judged to be compromised due to flux trapping and was discarded. The remaining data presented in this report are selected data taken at 77K (and occasionally at lower temperatures) under conditions which prevented trapped flux from degrading the J_c .

(4.3) Repeatability of J_c

Earlier work had shown a deterioration in the measured J_c values with thermal cycling. Using the cycling procedure described in section (3.0) **Sample Cycling Procedure**, negligible deterioration in J_c was observed. This may be seen in Figure 3. The data shown in Figure 3 represents data accumulated from five sequential experiments over a period of time extending from 28 April 89 to 12 May 89.

After the run on 2 May 89, a voltage lead had broken. During the repair one current lead came loose and was also repaired. The slight variation between the earlier two runs (4/28/89 and 5/2/89 - filled symbols) and the last

three runs (5/10/89 - 5/12/89 - unfilled symbols) seems to be related to the quality of the current lead that was repaired. The poorer quality of the bond before repair could have caused heating at the contact with subsequent lowering of J_c . As part of the setup procedure the resistance of the current leads and voltage leads were measured at the top of the cryostat for the last three runs (unfilled symbols). This included lead, sample, and contact resistance. Since the lead configuration was not changed throughout the course of the experiments, and the normal state sample resistance as measured by four terminal resistance measurements before each run was found to be small on the order of hundredths of an ohm, the observed large change in current lead resistance with cycling (25 to 31 to 43 ohms for both contacts in series) was attributed to the change in contact resistance of the sample. This is believed to be due to the interaction of the sample and the indium and gallium used to form the current leads. Although some component of this resistance would be present in the superconducting state at 77K, it does not seem to have affected the I-V characteristics as measured for these three runs. The increasing resistance of the voltage leads (127 to 132 to 139 ohms for both contacts in series) is probably accounted for by the same mechanism but is not thought to be a serious problem since no current flows through these contacts.

(5.0) Dependence on Magnetic Field

The magnetic field dependence of the I-V curves was measured in the range of fields from 0 to 0.1T. These data taken from run 890510 are shown in Figure 4. Using an E-field criterion of 10 micro volts per cm, critical current densities were calculated from the data in Figure 4, and the results plotted in Figures 5, and 6. These data show the critical current of these samples is strongly affected by an external magnetic field, and appear to be consistent with a Josephson Junction coupling model reported in the literature⁵. The data of Figure 4 was also fitted to a power law $I=V^n$ and plotted in Figure 7. The exponent n and magnetic field value H for each set of data is included in the legend.

(6.0) Series Two Experiments

As mentioned in the introduction, many samples were surveyed in an attempt to determine if the properties measured were representative of the entire batch. In addition it provided an opportunity to try several recipes for making low resistance contacts.

(6.1) Low Contact Resistance Bonds

The three methods of preparing low resistance contacts namely Indium-Gallium eutectic, silver paste, and gold ink, described in section (2.0) **Sample mounting**, were used with varying degrees of success. The use of the Indium-Gallium eutectic with a tin pencil was the easiest to use. Contacts prepared this way were simple to make. They could be readily soldered to leads. However there was an increase in the resistance with cycling. Eventually they became unusable in our experiment. The silver paste was used and produced low contact resistance as did the gold ink. The gold ink gave the best results in this study. It did not wet well for easy soldering, however it is believed that after firing, the gold film could be wetted with the Indium-Gallium eutectic mixture using the tin pencil for application. Leads could then be easily soldered to the samples, and the gold might prevent oxide formation and insure no problems with repeated cycling.

Use of both of these materials appeared to reduce the J_c of the rods, however. From the limited work done in this report we could not be sure whether the deterioration of the samples was due to the contact material used (gold ink or silver paste), the heat treatment that each required, or possibly a sample-to-sample variation within the same batch.

(6.2) Results of J_c measurements on other samples

Two remaining samples from batch OX40/C/2 were mounted using silver paste. These were designated /C, and /D. The samples were prepared by coating contact areas with silver paste and wrapping with platinum wire. The sample was first air dried using the heat from a light bulb and then fired to

volatilize the silver paste binder. Sample /C was then placed into a furnace and ramped to 40 C at 1 deg./min., held for an hour, ramped to 500 C at 1 deg./min., held for 3 hrs, then cooled to room temperature at 1 deg./min. The bonds produced in this sequence had a resistance lower than the sample resistance in the normal state (0.11 ohms).

This heat treatment was patterned after that used by University of Houston workers in attaching electrodes to oriented yttrium-barium-copper-oxide samples using silver paste and silver wires. Preliminary measurements on these samples at NRL indicated J_c values in excess of 5000 A/cm² at 77K in 0.5 T magnetic field, and approximately 2800 A/cm² at 77K, and 1 Tesla magnetic field. These are very short sample measurements and represent the results on one sample.

While this heat treatment worked for the Houston samples, the ICI sample so treated were unable to carry a significant critical current at 77K. Measurements were made on 28 May 89 (experimental series designated 890528). The results were disappointing. The sample was not able to support a measurable critical current at 77K. Pumping on the liquid nitrogen bath lowered the temperature to 52K. At this temperature some evidence of non ohmic behavior was observed. This suggested that the superconductivity was depressed by the heat treatment. Following reference one more closely, a sample /D was mounted and heat treated differently. This sample was taken from room temperature to 850 degrees at a rate of 2 deg./min., held for 30 min., and then ramped to room temperature at a rate of 1 deg./min., all in flowing oxygen. The results of this experiment obtained during run 890531 are shown in Figure 8. In this figure, data was taken at 52K so that any superconductivity would be more readily aparent. A virgin I-V curve at zero magnetic field was taken, and compared with an I-V curve at zero field after an I-V curve at 0.1T (not shown). The curves show flux pinning, but the critical currents are very small when compared with other work in this report.

At this point the work would have stopped without more samples. Fortunately a second batch of samples designated OX40/C/4 was obtained. These were immediately pressed into service for series two experiments. Recall that one sample from the first batch OX40/C/2/A had silver wire leads

attached with indium solder but was broken while being inserted into the cryostat as was mentioned earlier. The second batch of samples OX40/C/4 also included one sample with silver wire leads attached with indium solder., OX40/C/4/A. This time it was mounted, loaded successfully into the cryostat and measured (890615). The results are shown in Figure 9. Using the same E-field criterion of 10 micro-volts/cm, and a cross-sectional area of $5.0 \times 10^{-3} \text{ cm}^2$, we obtain a current density of 684 A/cm^2 at 77K. This is considerably higher than the value of 434 A/cm^2 at 77K measured for the best sample from the first batch.

It is interesting to note the contact resistance measured at the cryostat. Recall this represents both contacts and leads in series and may be compared with the other numbers quoted in section (4.3) **Repeatability of J_c** . The current leads measured 9.1 ohms (on previous samples they ranged from 25 to 43 ohms), and the voltage leads measured 16.9 ohms (on previous samples they ranged from 127 to 139 ohms). If we consider the power dissipated in both cases we find that for sample OX40/C/4/A, 3.4 Amps with a normal state resistance of 9.1 ohms gives rise to a total of 282 watts, while for 890510, 2.1 Amps with a normal state of 43 ohms gives rise to total of 190 watts. This suggests that at least for our testing when the sample is immersed in liquid nitrogen, the critical current is a function of the sample not the contact resistance.

A second specimen from the second batch OX40/C/4/B was mounted using the gold ink described earlier. The contact areas were first coated with a metallo organic gold ink suspension which was allowed to dry and then fired. The heating sequence used was a ramp from room temperature to 100 C at a rate of 2 deg./min., dwell at 100 C for 60 min., ramp to 800 deg. at a rate of 20 deg./min., dwell at 800 C for 30 min., and then ramp down to room temperature at a rate of 1 deg./min., all in flowing oxygen. Pt wire was wrapped around the contact areas, and then soldered with pure indium. When mounted and measured at the top of the cryostat, the current lead resistance was 0.5 ohms (both contacts in series), and the voltage lead resistance was 2.8 ohms (both contacts in series). The results of critical current measurements of this sample are shown in Figure 10. This figure contains I-V curves for several field values.

These traces which illustrate the magnetic field dependance of the critical current are similar to those found in Figure 4. Flux pinning for these samples is illustrated in Figure 11. These may be compared with the curves in Figure 2.

The sample that was mounted using the gold ink was cycled once to see if there would be any change in contact resistance and sample characteristics. The contact resistance was unchanged while the sample characteristics may be seen in Figure 12. This figure shows the I-V curves measured on two separate occasions. This sample was also measured at two different temperatures. The results of these experiments are shown in Figure 13. Decreasing the temperature by 14 K approximately doubles the critical current of the sample.

For the final J_c experiment, a sample from the second batch OX40/C/4/D was mounted using the tin pencil indium-gallium eutectic and measured at 77K. The results are shown in Figure 14. This sample gave results intermediate between the sample prepared by ICI, and the sample prepared with gold contacts.

(7.0) T_c Measurements

Measurements of the superconducting transition temperature were made in an effort to see if any variations in critical current would coincide with differences in transition temperature, and to explore the possible use of these materials as a temperature standard. We have measured the real, χ' , and imaginary, χ'' , parts of the ac susceptibility of yttrium-barium-copper oxide samples made by ICI as a function of temperature and of applied ac magnetic field. The reproducibility of the ac susceptibility as a function of temperature of sample OX40/C/2/A is very precise when the ac field is kept constant, (Figure 15). The same sample, which consists of rods with diameter $\sim 1\text{mm}$ and length $\sim 10\text{mm}$, was measured in two different coil sets on two days (with a thermal cycle to room temperature in between) with the same applied magnetic field. Figure 15 also shows two distinct regions in the real susceptibility, one near the onset of superconductivity, close to 93K, and the other at a lower temperature, close to 91K. Goldfarb et al.⁶ refer to the higher temperature as the "intrinsic T_c " and the lower temperature as

the "coupling T_C ". They have found that the ac susceptibility of this material can be explained when the granularity of the material is taken into account.

In corroboration with the results of Goldfarb et al., we have found that the shape and midpoint of the coupling transition, as measured by ac susceptibility, changed drastically as a function of the applied ac magnetic field (Figure 16). In Table I are listed the values of the coupling T_C as a function of ac magnetic fields. These values were obtained from the maximum in $\partial\chi'/\partial t$ and from the maximum in the χ'' when plotted as a function of temperature. It is obvious that the coupling T_C is too sensitive to measuring conditions to be of practical value as a temperature reference standard.

Table I: Coupling T_C (K)

ac FIELD		χ''		$\partial\chi'/\partial t$	
<u>mOe</u>		<u>Max</u>	<u>ΔT_C</u>	<u>Max</u>	<u>ΔT_C</u>
5		91.0	0.8	91.3	0.8
20		90.5	1.0	90.4	1.0
200		89.0	2.2	89.0	2.0
1000		87.0	4.5	86.0	5.0

In measuring the onset of superconductivity as a function of applied magnetic field, it was observed that the onset temperature of the intrinsic T_C was independent of the ac magnetic field as may be seen in Figure 17. The onset temperature of the intrinsic T_C was obtained from χ' and $\partial\chi'/\partial t$ data and are listed in Table II for the four measuring fields. The average value obtained from Table II is 93.3K, and a line at this temperature is drawn in Figure 17. All four onset temperatures are within 0.5K of the average. Goldfarb has suggested that the onset temperature be used in reporting T_C .⁷ Our results support this position.

Table II: Intrinsic T_c (K)

ac FIELD	χ'	$\partial\chi'/\partial t$
<u>mOe</u>	<u>onset</u>	<u>onset</u>
5	93.7	92.0
20	93.0	93.5
100	93.5	93.0
1000	93.0	93.5

(8.0) Conclusions

Twelve samples were obtained for this study. At the completion of this study, measurements were made on six samples and two remained. The others were broken while handling. A summary of the results obtained are listed in Table III below. While the samples measured in runs 890528, 890531, 890615, and 890617 showed large variations in J_c values, the transition temperatures (taking the onset temperature) were all $93.3 \pm 0.5K$. The critical current density seems to be a more sensitive measure of the sample properties than the transition temperature. The results of critical current measurements is included in Table III.

The brittle nature of these fragile samples made them difficult to handle and their oxide character resulted in bonds that were less than ideal. The problem of low resistance electrical contacts for these materials appears soluable. As pointed out elaborate procedures do exist. Some of the methods we have explored appear to have potential for quick and easy contacts but should be explored further. Of these the use of an organo metallic gold ink looks most promising. It does have the disadvantage of heating to eliminate the binder material and consequently could cause a deterioration of the sample. However it does result in a low resistance bond and based upon very limited testing seems to suffer no deterioration upon cycling.

Table III: J_c Summary

RUN	DATE MEASURED	SERIES	BATCH & SAMPLE	CONTACT	J_c (A/cm²) Max. at 77K
890428	28 May 89	series 1	OX40/C/2/B	E, In-S, Ag-W	401
890502	2 May 89	series 1	OX40/C/2/B	E, In-S, Ag-W	423
890510	10 May 89	series 1	OX40/C/2/B	E, In-S, Ag-W	406
890511	11 May 89	series 1	OX40/C/2/B	E, In-S, Ag-W	434
890512	12 May 89	series 1	OX40/C/2/B	E, In-S, Ag-W	426
890528	28 May 89	series 1	OX40/C/2/C	Ag-P, Pt-W	NSCC
890531	31 May 89	series 2	OX40/C/2/D	Ag-P, Pt-W	NSCC
890615	15 June 89	series 2	OX40/C/4/A	In-S, Ag-W	684
890617	17 June 89	series 2	OX40/C/4/B	G, In-S, Pt-W	433
890618	18 June 89	series 2	OX40/C/4/C	G, In-S, Pt-W	428
890624	24 June 89	series 2	OX40/C/4/D	E, In-S, Pt-W	536

Table III is a compilation of the results obtained for this study. The first column lists the run designation and the sample measured for this run. The designations A through F were arbitrarily chosen for this study to indicate when the same or different samples were used. The day these samples were measured is indicated in the DATE MEASURED column. The SERIES indicates whether samples were measured to study cycling deterioration (series 1), or screening (series 2). BATCH indicates which batches the samples came from. CONTACT describes the contact materials used for each run, E (indium-gallium eutectic), In-S (Indium solder), Ag-W (silver wire), Ag-P (silver paste), G (gold ink) and Pt-W (platinum wire), and the last column indicates the maximum critical current density measured for each particular run NSCC-(no significant critical current).

The J_c values obtained ranged from 401 A/cm² to 684 A/cm². The reason for these variations are not clear. They could be due to sample inhomogeneity or deterioration due to the technique used to form electrical contacts. The variations aside however these values

are in a range which suggest some useful applications. Furthermore, we have shown that cuprate superconductors can provide temperature references in the temperature region near 100K with a precision of at least 1K.

9.0 References

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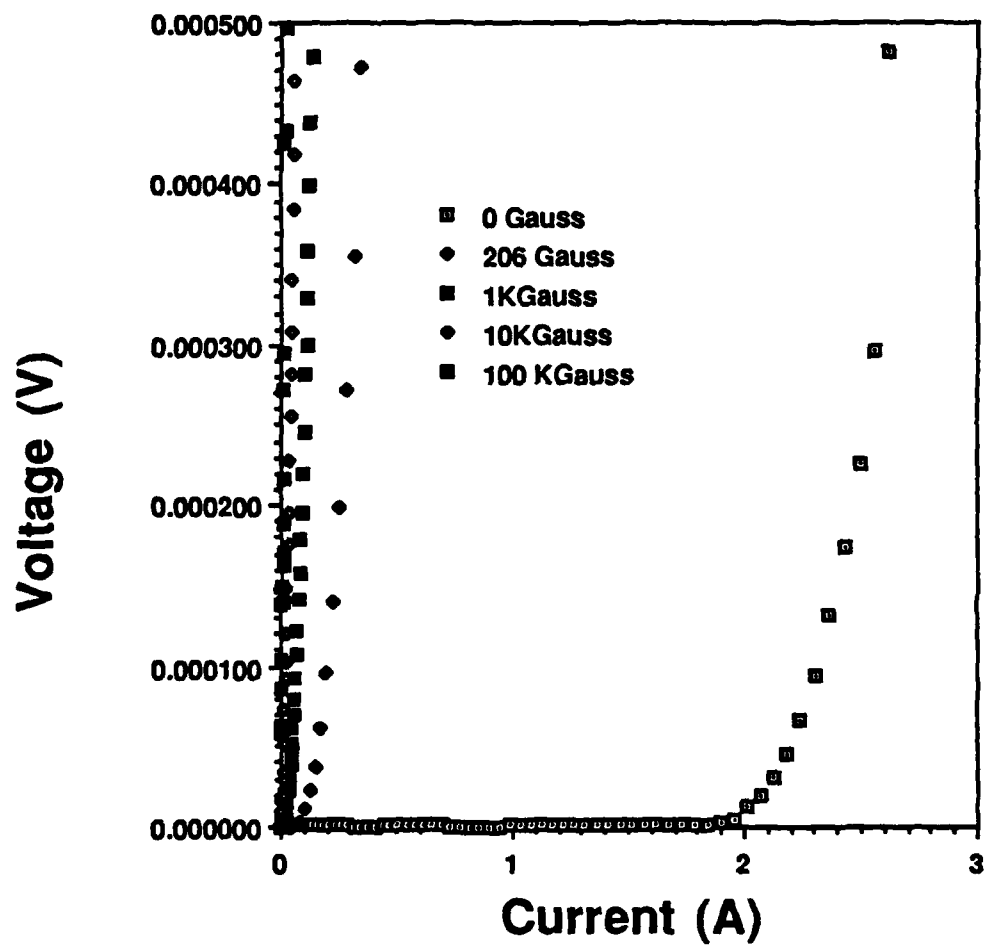


Fig. 1 - Current voltage curves as a function of magnetic field at 77K (Sample OX40/C/2/B).

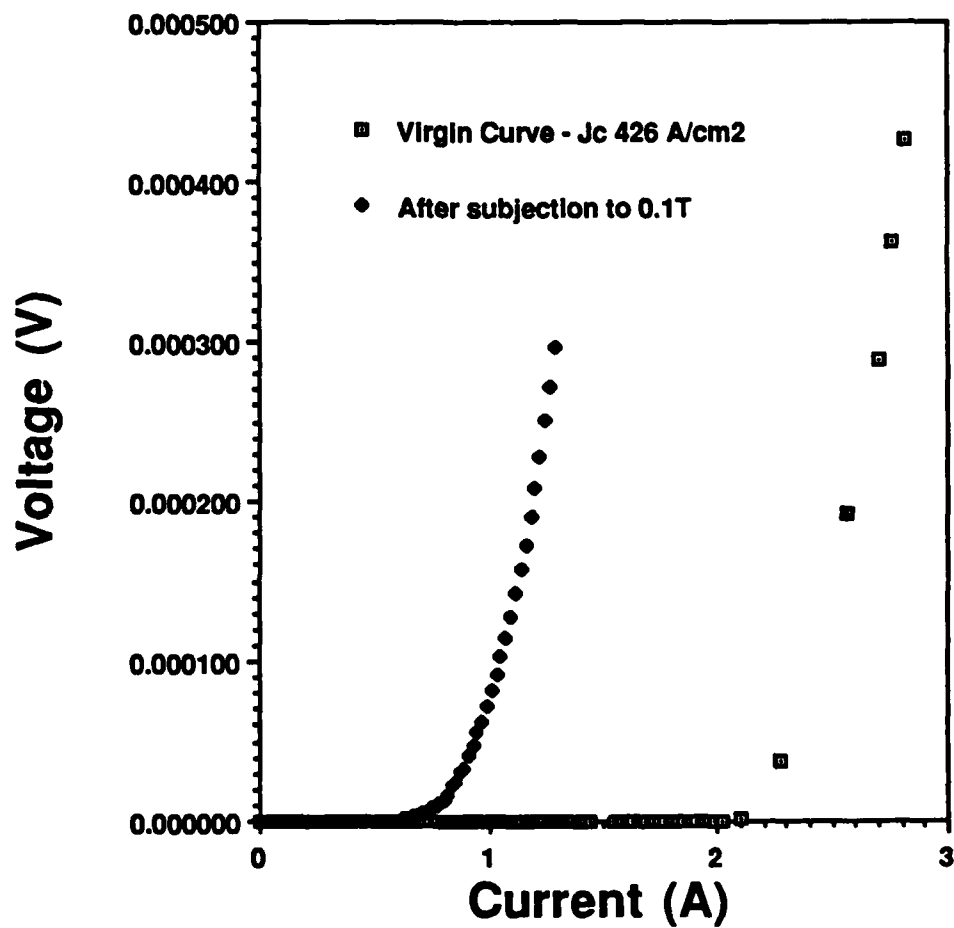


Fig. 2 - Current Voltage curves at 77K, one is a virgin curve the other was taken after taking an I-V curve in a 0.1T (1000 Gauss) field (Sample OX40/C/2/B).

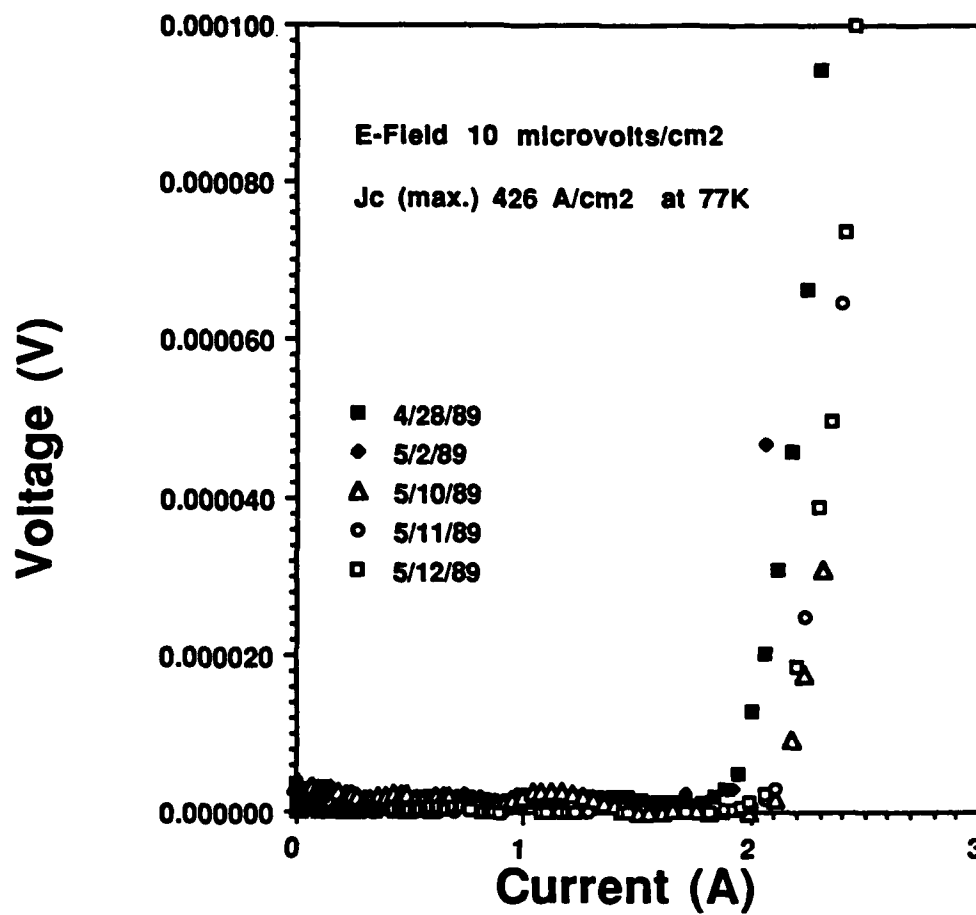


Fig. 3 - Current voltage curves showing repeatability with cycling (Sample OX40/C/2/B). See discussion in section 4.3 Repeatability of J_c .

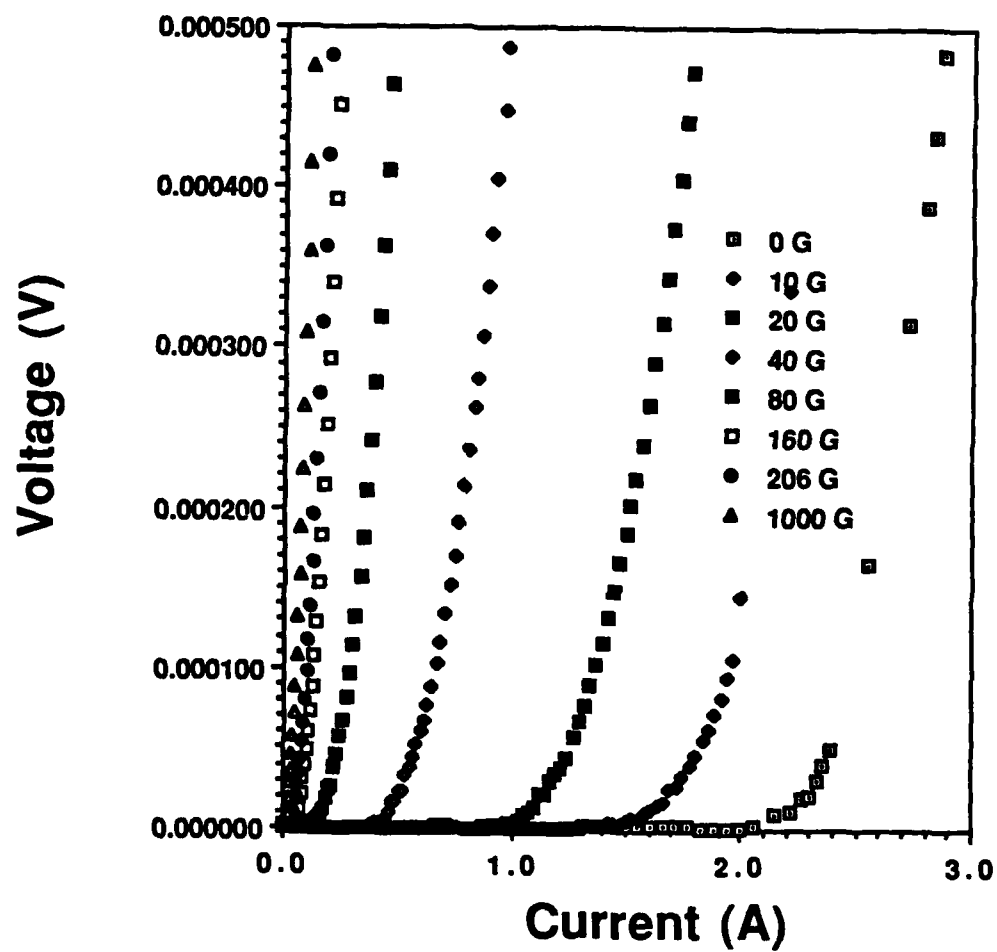


Fig. 4 - Current voltage curves to study the magnetic field dependence (Sample OX40/C/2/B).

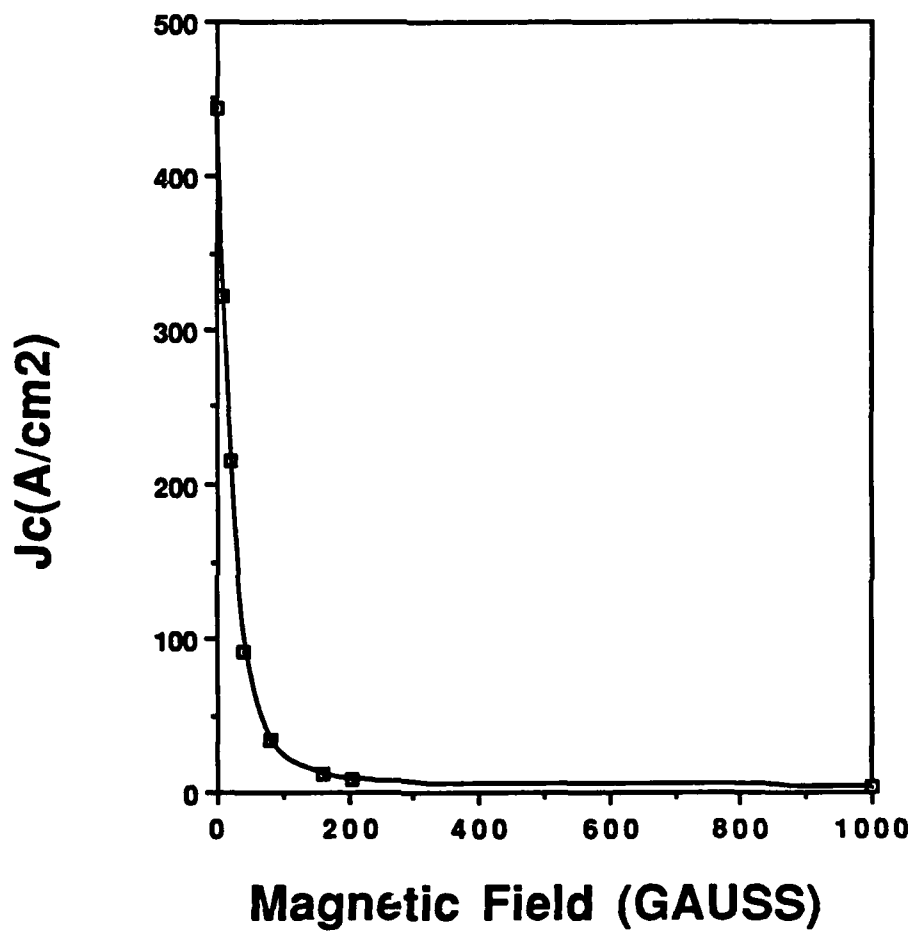


Fig. 5 - Critical current density (E-field 10 microvolts/cm) as a function of magnetic field (Sample OX40/C/2/B).

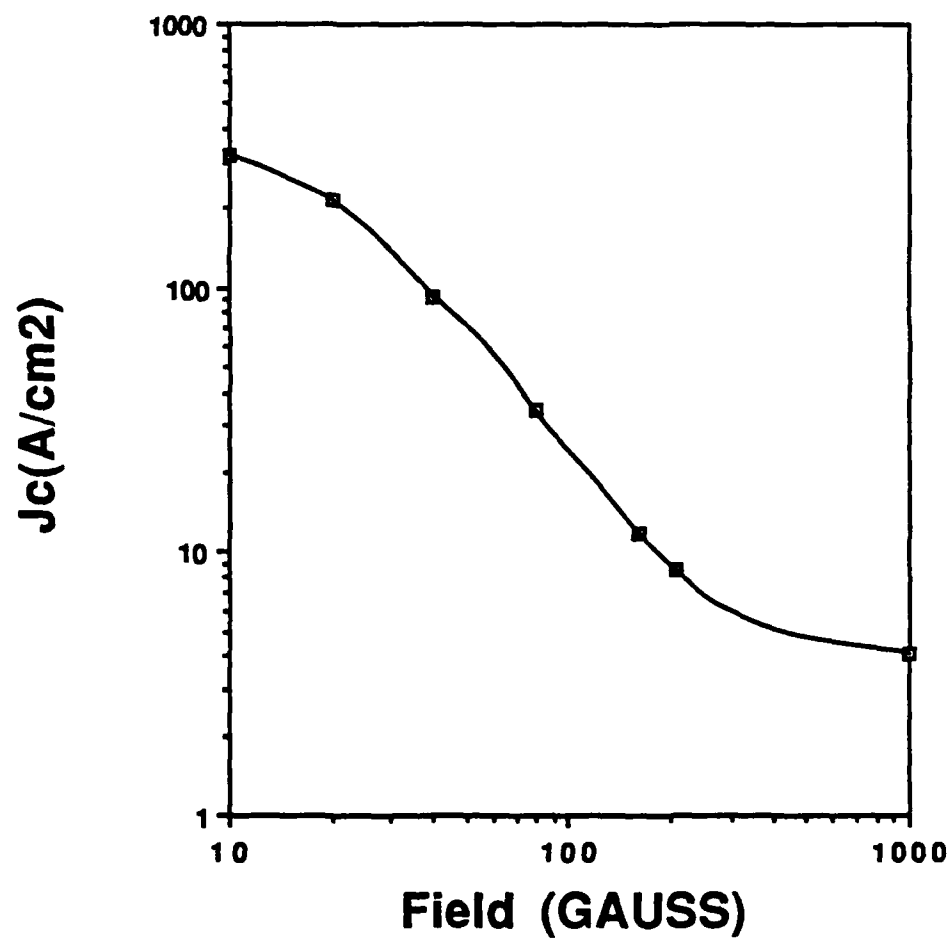


Fig. 6 - Data from figure 5 (Sample OX40/C/2/B) plotted on a log-log scale to facilitate comparison with Josephson Junction model.

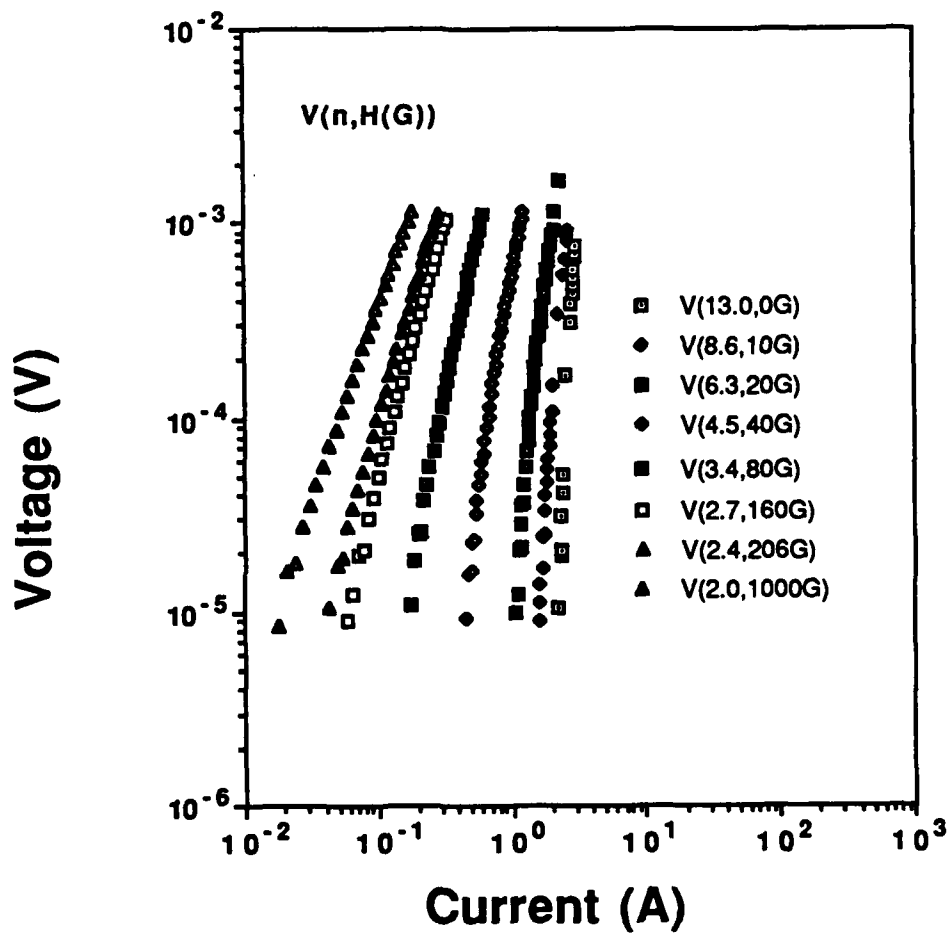


Fig. 7 - Log-log plot of current voltage curves for voltages greater than 10 microvolts (Sample OX40/C/2/B). The Exponent n and field value $H(G)$ are indicated in the legend.

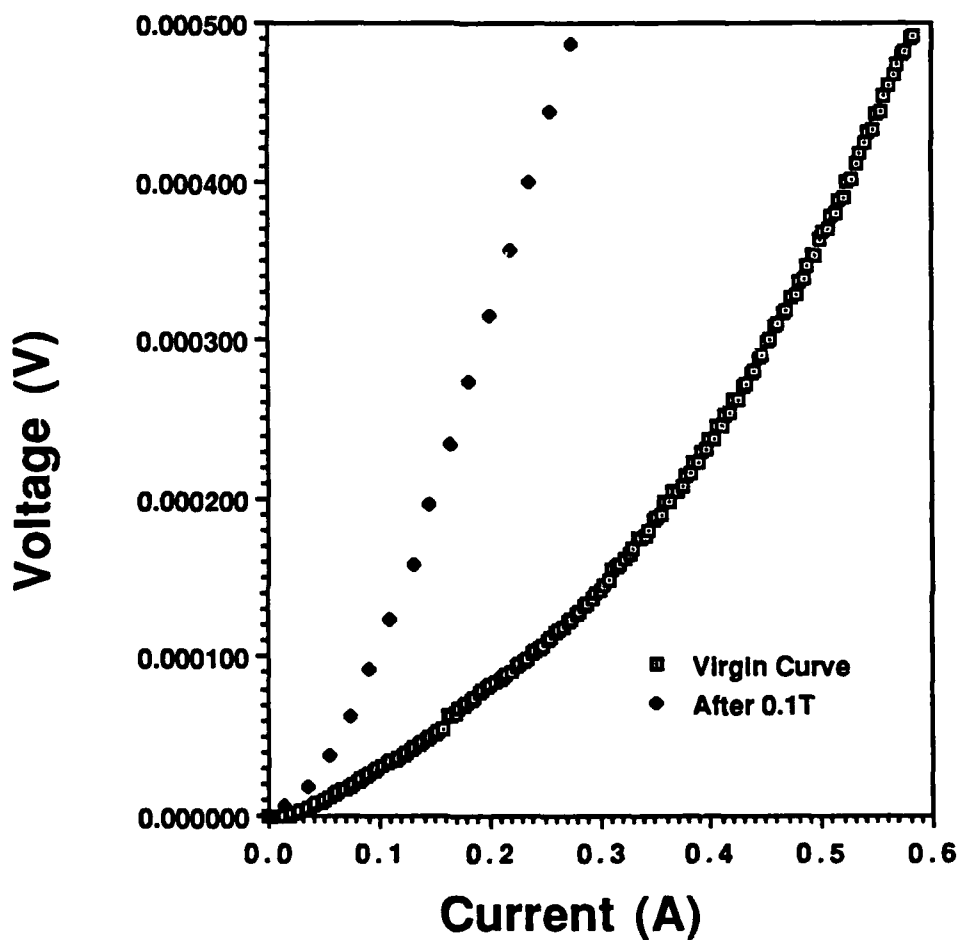


Fig. 8 - Current voltage curves of specimen (OX40/C/2/D) believed to be damaged by heat treatment used to make electrodes using silver paste. Contacts were low resistance, but the superconducting properties were greatly diminished.

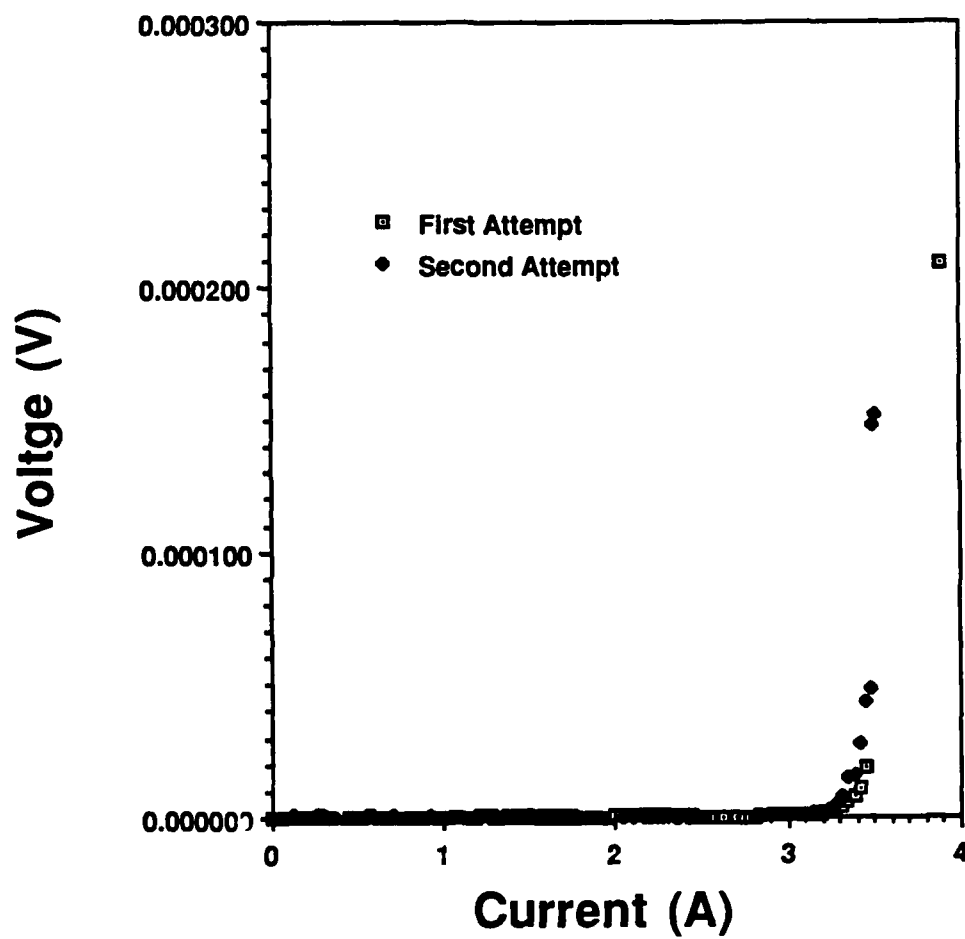


Fig. 9 - Two successive I - V curves at 77K, in zero magnetic field for prepared sample (with leads already attached) from OX/40/C/4/A.

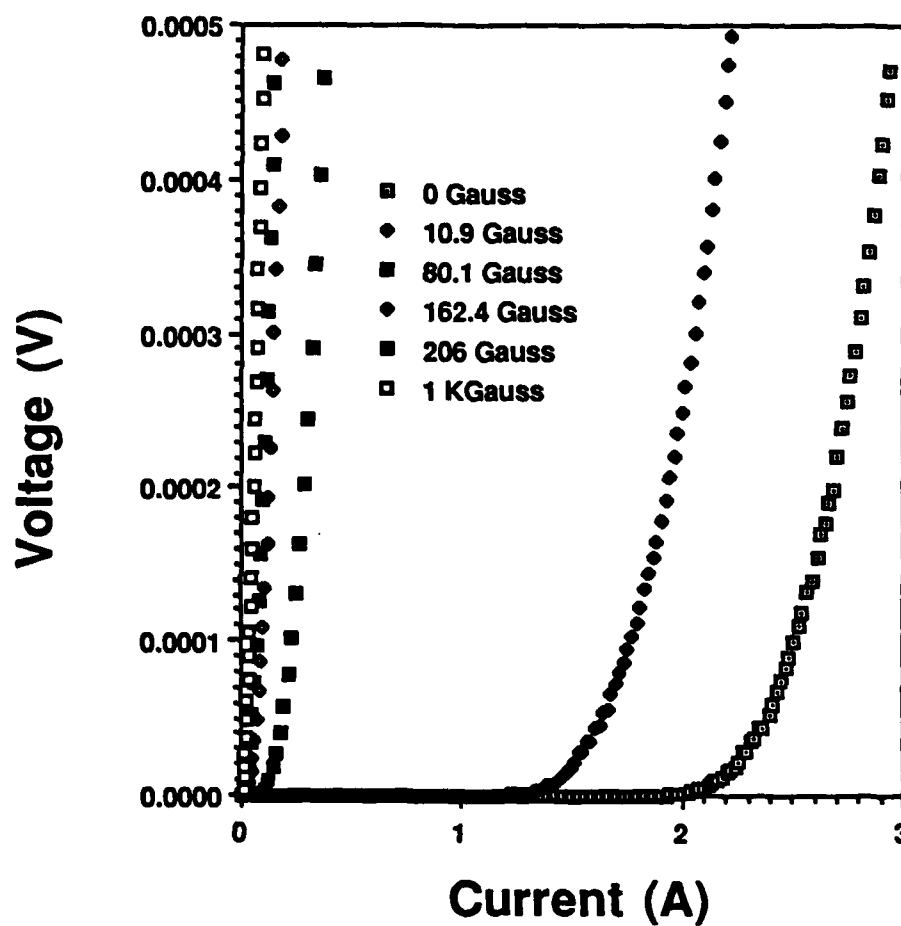


Fig. 10 - Current voltage curves at 77K for different increasing magnetic fields. This sample OX40/C/4/B, run 890617 used gold contacts and was mounted using platinum wire that was indium soldered to the gold.

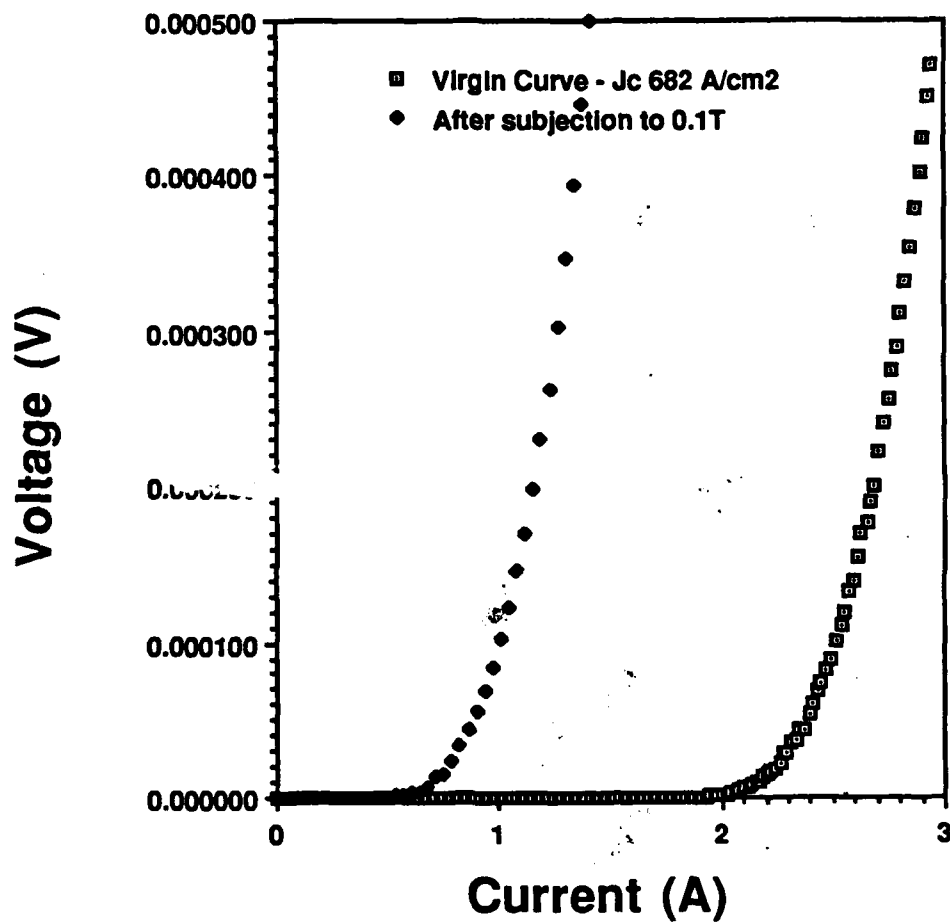


Fig. 11 - Current voltage curves for the sample OX40/C/4/B with gold contacts at 77K. One is a virgin curve the other is taken after taking an I-V curve in a 1000 Gauss field.

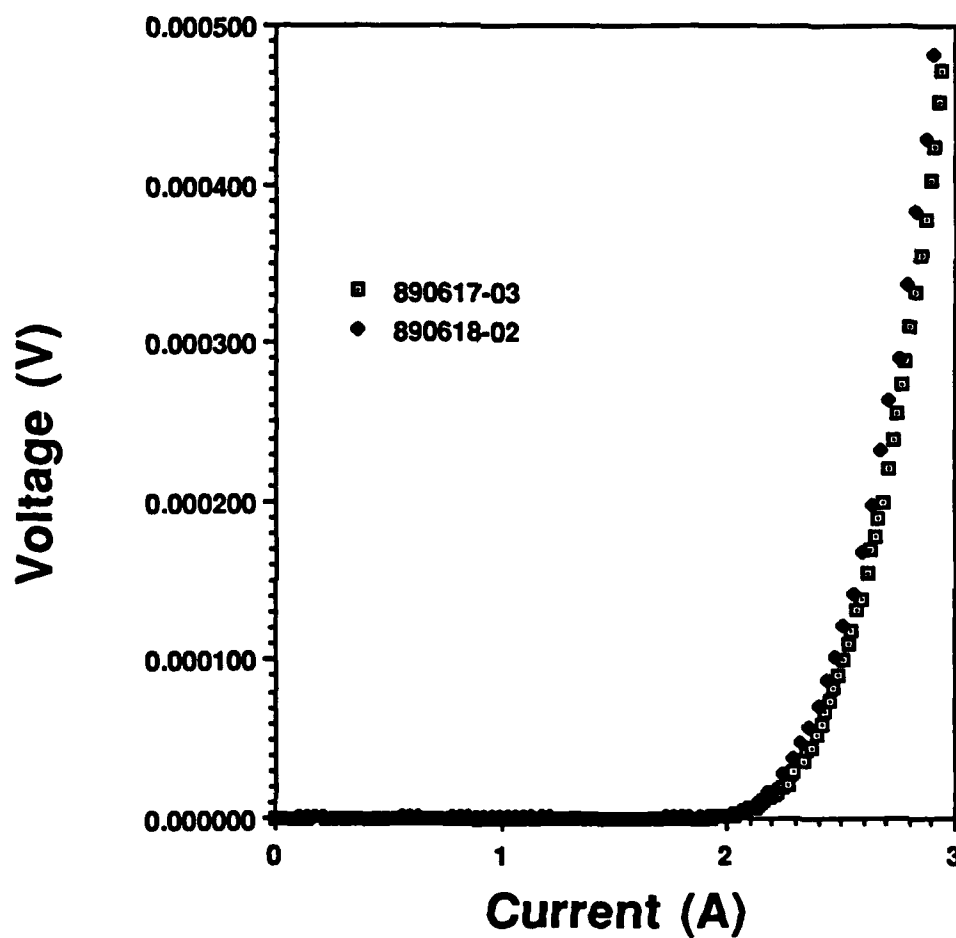


Fig. 12 - Current voltage curves of sample OX40/C/4/B prepared with gold ink contacts measured on two successive days. The critical current characteristics are essentially unchanged.

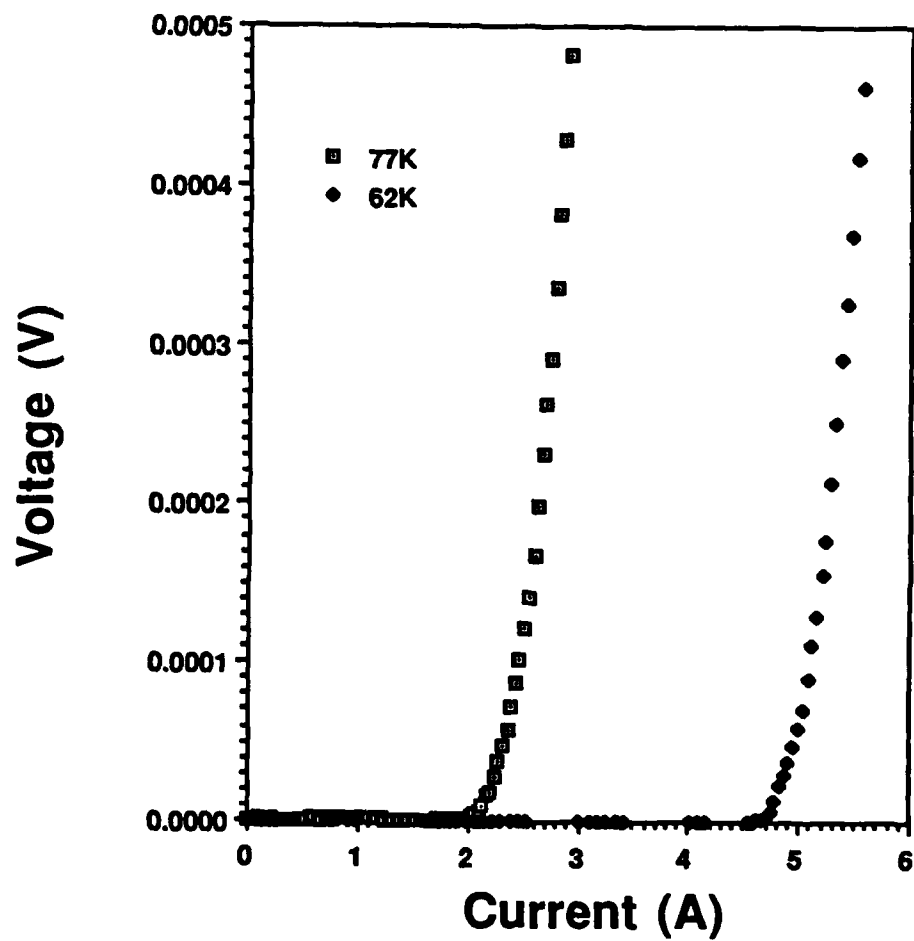


Fig. 13 - Current voltage curves of the sample OX40/C/4/B prepared with gold ink contacts, measured at two different temperatures.

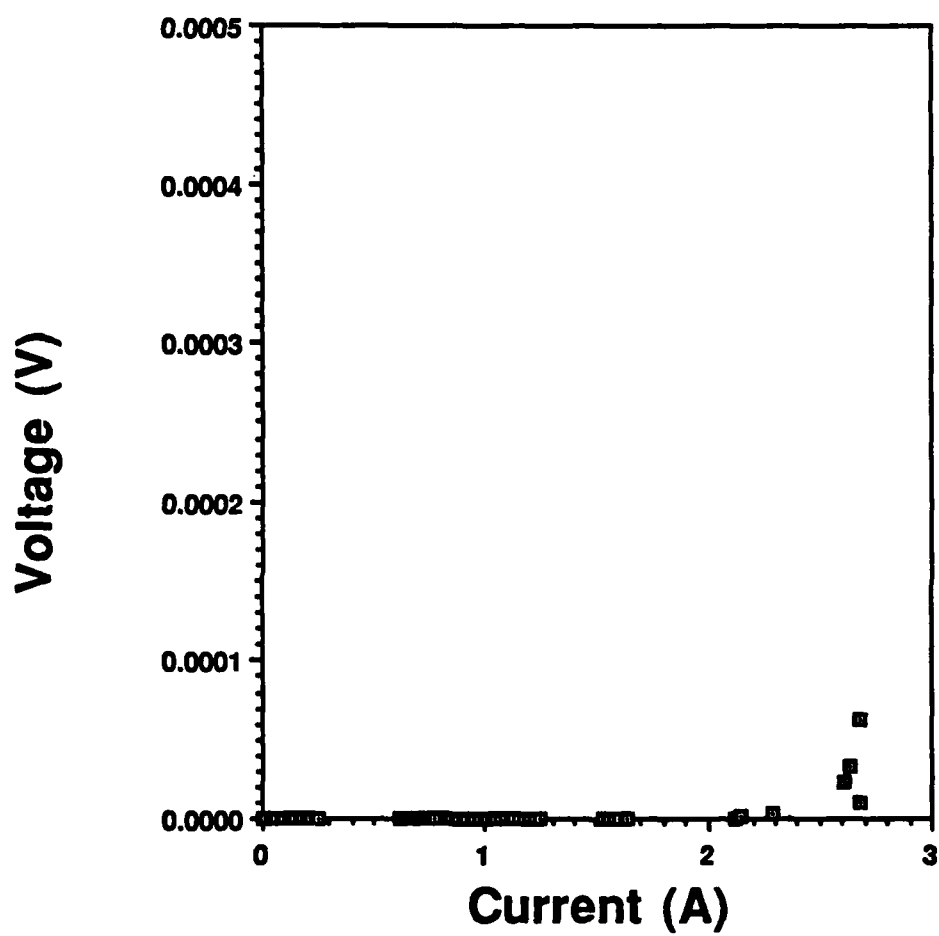


Fig. 14 - Current voltage curve for sample from OX40/C/4/C. This critical current was less than the sample having leads already attached but more than those leads attached with gold ink.

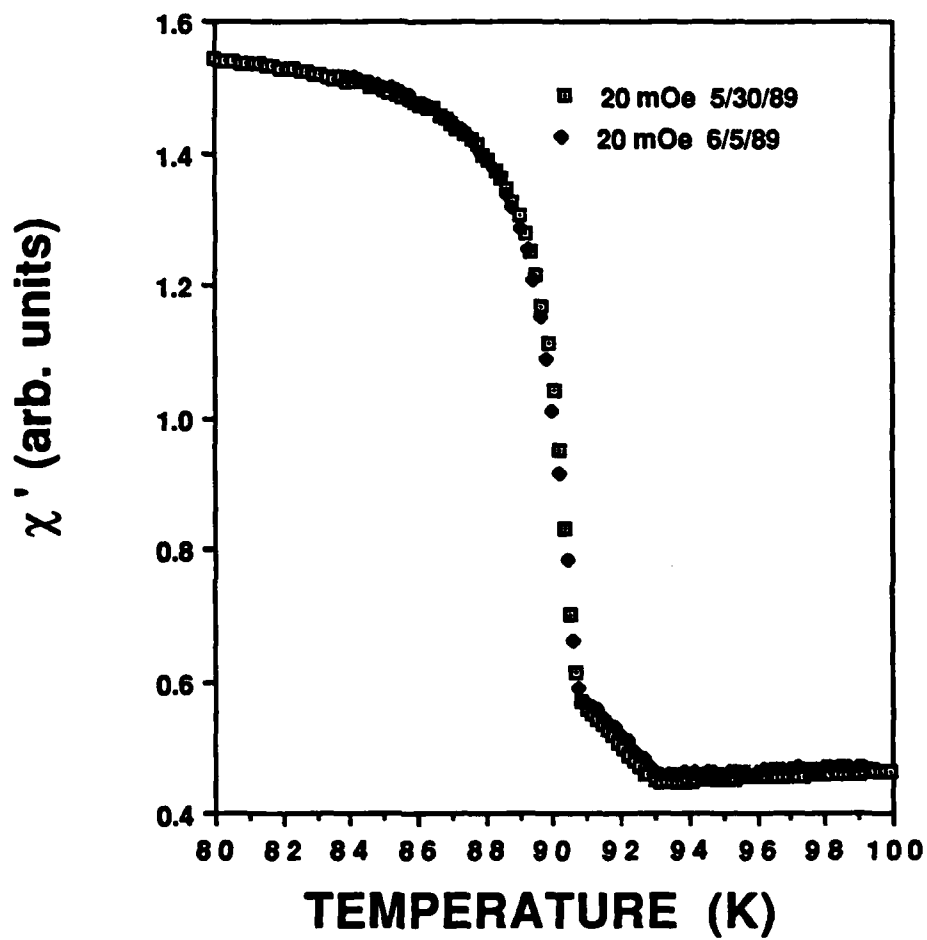


Fig. 15 - Reproducibility of susceptibility (Sample OX40/C/2/A) as a function of temperature.

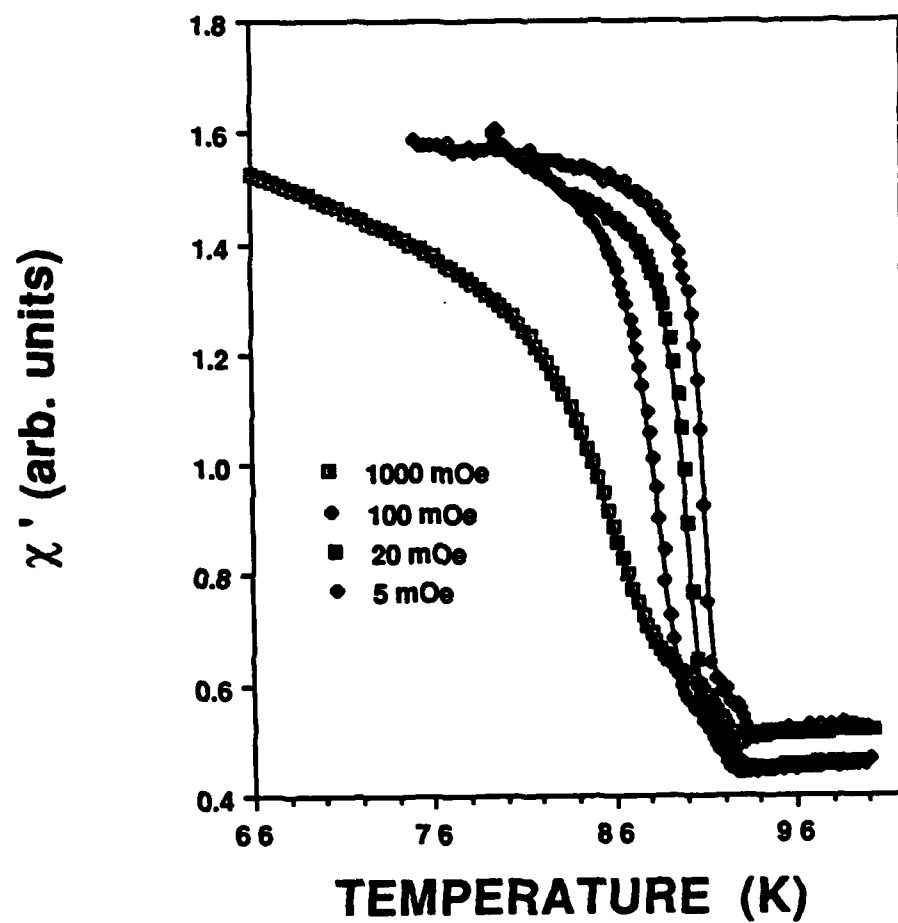


Fig. 16 - Susceptibility as a function of the amplitude of the ac magnetic field.

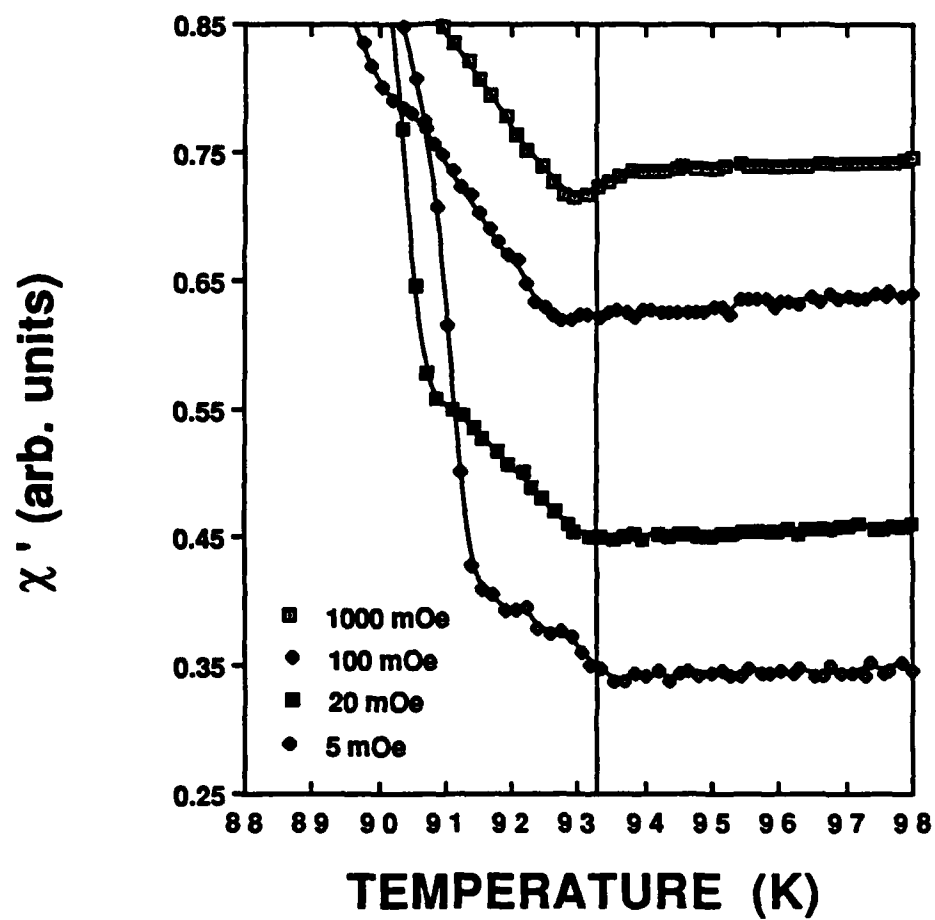


Fig. 17 - Onset of superconductivity.