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Critical current density of a sample of melt grown $Y_{1\cdot2}Ba_{1\cdot8}Cu_{2\cdot4}O_x$

V GANESAN, R SRINIVASAN, R GOPALAN* and T RAJASEKARAN*
Inter University Consortium, University campus, Khandwa road, Indore 452 001, India
*Defence Metallurgical Research Laboratory, Kanchanbagh, Hyderabad 500 258, India

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Abstract. Melt grown samples of $Y_{1\cdot2}Ba_{1\cdot8}Cu_{2\cdot4}O_x$ have been prepared and studied for their current carrying capacity. The composition was chosen to include Y_2BaCuO_5 (211) particles in the $YBa_2Cu_3O_x$ (123) phase. The critical current density (J_c) of these samples was studied as a function of magnetic field using magnetization technique. The micrographic investigation shows well aligned grains in this material. The magnetic hysteresis measurements were done using a MPMS SQUID magnetometer up to the fields of 5·5 T. The J_c was estimated from the remanent magnetization using Bean model. Isothermal magnetization hysteresis loops at low fields reveal the presence of only one kind of hysteresis loops (corresponding to intragrain magnetizations). This is a valid proof that the weak links are greatly eliminated in these samples prepared by MG process. The J_c behaviour as a function of magnetic field has two components, a rapidly decaying exponential function of field and the other component that predominates at higher fields. This could be explained if we assume that the sample contains two phases of superconductors, one having a low H_{c_2} becoming normal at fairly medium fields of the order of a few kilogauss will act as pinning centres for the other phase having higher H_{c_2} and hence higher J_c at high fields.

Keywords. Critical currents; high temperature superconductors; melt growth.

PACS Nos **74·30; 74·70**

1. Introduction

Advent of high T_c superconductivity above the liquid nitrogen temperature [1–3], stimulated interest in the applications of these materials. Ability for carrying high currents in the presence of magnetic fields of the order of few tesla is very important for many applications. Since the high T_c materials are granular their J_c is limited by the weak links, presence of secondary phases at the grain boundaries and the lack of texture etc. It was believed that elimination of weak links and grain alignment will improve the J_c. Grain alignment has been achieved by the controlled solidification [4–12]. One such process was Quench and Melt Growth (QMG) process successfully employed by Murakami *et al* [7] to obtain J_c of the order of 10^5 A/cm^2 or so. Transport measurements of J_c are not always possible because of the larger magnitude of J_c. Alternate way of obtaining J_c is by magnetization measurements using the famous Bean model [12]. Another advantage of this method is that the low field magnetization studies will provide information on the weak link nature of these materials. The development of two kinds of hysteresis loops (inter and intra grain) at low fields is well known in the granular superconducting materials [13–18]. The evidence for the elimination of weak links in the melt grown process can be had from micrographic studies [4–10] or from low field magnetization studies in which only one kind of hysteresis loops will present [13–18]. In this paper the J_c measurements of a sample of YBCO prepared by MG process was discussed for its magnetic field dependence.

2. Experimental

The samples of $Y_{1\cdot2}Ba_{1\cdot8}Cu_{2\cdot4}O_x$ were prepared by conventional solid state reaction using nitrate precursors and the grain alignment was achieved by following the method of Murakami *et al* [5]. This composition was chosen to yield 211 particles in the 123 phase. Murakami *et al* [8] has described in his review that 211 inclusions dispersed in the 123 matrix can be controlled by changing the initial composition. It also contains the details of all types of melt grown processes and microstructure of typical composition of Y:Ba:Cu = 1·6:2·3:3·3 which shows a clear 211 inclusions in 123 matrix. Our composition is also nearly equal to the Murakami's ratio if properly normalized. However the method of initial quenching from 1400 C was bypassed by the quenching from 1200 C to liquid nitrogen temperature. Other processes are essentially the same as that of Murakami *et al.* The samples were prepared at DMRL, Hyderabad, India and the details of preparation have been reported by Rajasekaran *et al* [19]. The material was characterized by optical micrograph, XRD, electrical resistance and DC magnetization measurements. A rectangular piece was cut out of this sample for magnetization measurements.

3. Results

Optical micrograph of the sample showed the grain alignment clearly. The powder X-ray diffraction results of this sample indicate that all the (001) reflections were pronounced and having higher intensities is a valid proof for this alignment.

Electrical resistance of this sample was measured as a function of temperature using standard four-probe technique. The resistance drops to zero at 88 K. The details of characterization and the results of melt grown YBCO will be published elsewhere. In this paper we report the magnetization studies on $Y_{1\cdot2}Ba_{1\cdot8}Cu_{2\cdot4}O_x$.

The DC magnetization measurements were carried out on MPMS SQUID magnetometer of quantum design. Figure 1 gives the variation of field cooled DC magnetic susceptibility as a function of temperature for this sample measured at a field of 100 G. It can be seen that the diamagnetic transition was quite sharp with the onset at 88 K.

The isothermal magnetization hysteresis loops were measured at 75 K for this sample at various maximum fields like 5, 10, 20, 30, 50, 100, 200, 300, 500, 1000, 10000, 55000 G etc.. Figure 2 gives the low field hysteresis loops showing only one kind of growth of loops justifying the elimination of weak links to a greater extent in these melt grown samples. Hence the use of Bean model as followed by Murakami *et al* [11] for the estimation of J_c in these MG samples is valid and more appropriate than ordinary sintered ceramic materials and the use of bulk sample dimension instead of grain dimension will yield the bulk J_c in these samples. Figure 3 gives the high field hysteresis loop of this sample from which we estimate the J_c of the material. Figure 4 gives the variation of J_c as a function of magnetic field obtained from 5·5 T hysteresis loop.

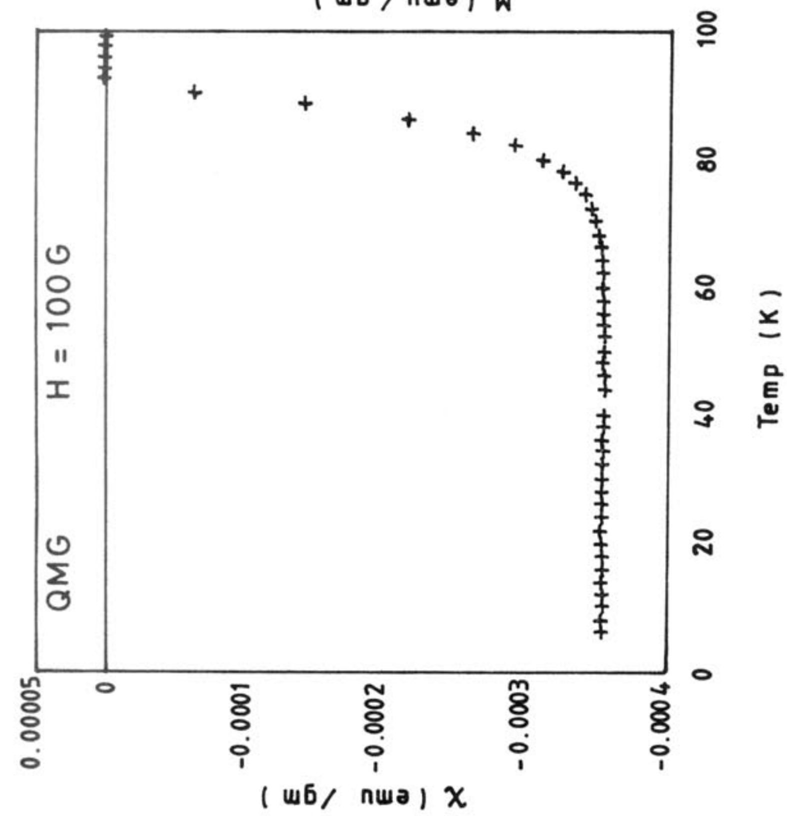

Figure 1. Field-cooled DC magnetic susceptibility as a function of the temperature.

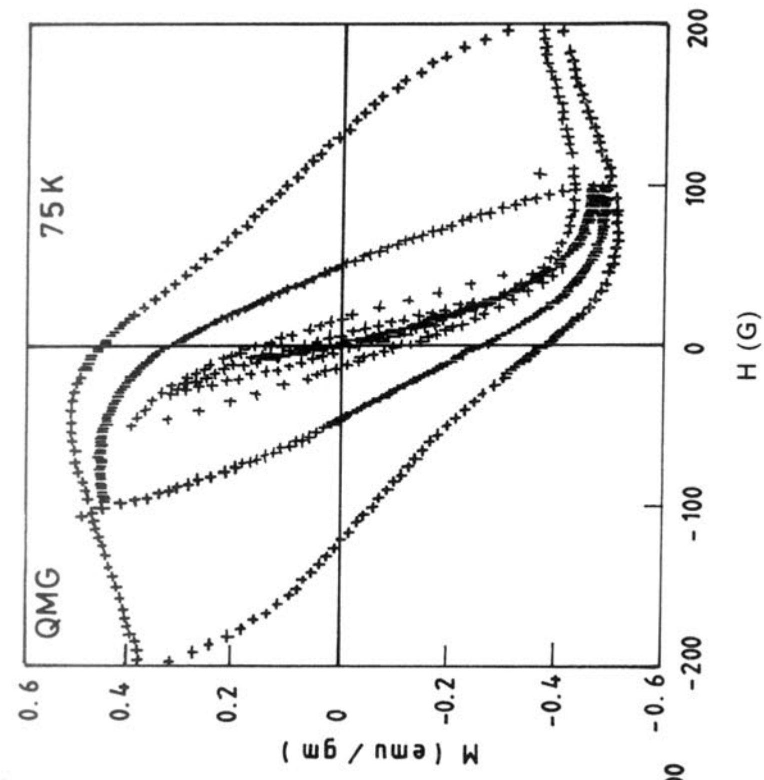

Figure 2. Low field magnetic hysteresis loops.

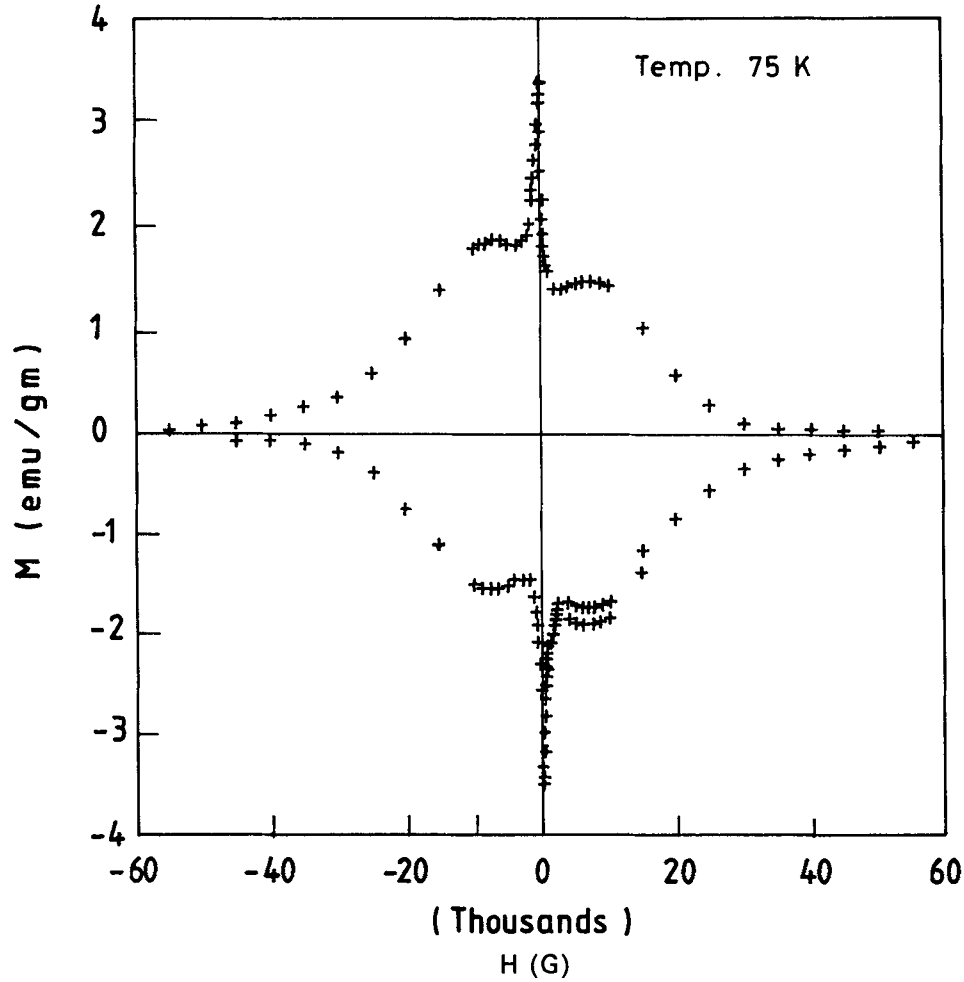

Figure 3. High field magnetic hysteresis loop.

The experimental data could be fitted as a sum of two current components, one a rapidly decaying exponential function of magnetic field and the other which predominates at high fields. [$J_c = J_{c_1} + J_{c_2}$, where $J_{c_1} = A_1 * \exp(-gB)$ and $J_{c_2} = A_2 + A_3 * B + A_4 * B^{0.5}$ and A_1 to A_4 and g are constants and B is the magnetic field. At least up to the fields we measured, (because the second component J_{c_2}, which increases with B may give physically meaningless results at very high fields, we restrict our discussion up to the fields we measured) the fit is reasonably good and this behaviour could be explained on the basis of a model that the sample contains two phases of superconductor, one having lower H_{c_2} becoming normal at fairly intermediate fields like 10–20 kG and acting as a pinning site for the other superconducting phase having higher H_{c_2}. This may be attributed to the oxygen inhomogeniety in the interior of the bulk sample because of the higher density of the MG sample.

Similar variations of J_c with B can be found in the melt processed and textured samples of YBCO [9, 20]. Matsumoto *et al* [9] analysed the behaviour of J_c vs B using Kramer's plot and attributed it to the nature of saturated pinning properties.

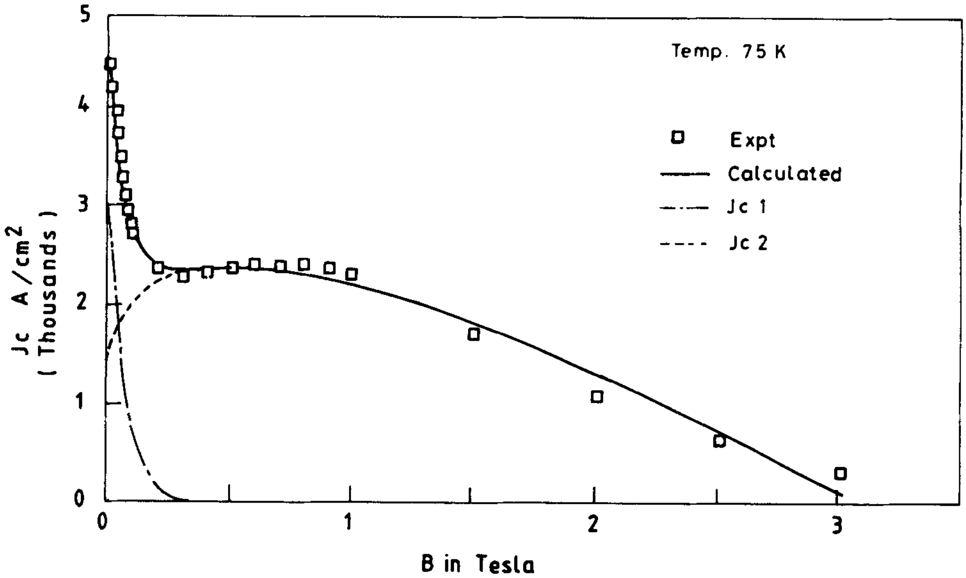

Figure 4. Variation of J_c as a function of the applied field.

According to them the field dependence of the pinning force can be expressed as $F_p \alpha b^p(1-b)^q$ where $b = B/B_{c_2}$, $p < 1$ and $q = 2$ and this type of variation is quite common even in conventional superconductors like Nb_3Sn in which crystal grain boundaries are the major pinning sites. These types of analysis on our samples were also made and reported by Ganesan *et al* [21]. These results along with the nature of J_{c_1} suggests that in these samples the grain alignment is still insufficient. The presence of cracks as well as the absence of sufficient 211 precipitates to act as pinning centres are the reasons of the low critical currents as compared to Murakami *et al* [7, 8, 11]. We are trying to prepare the samples of high J_c by controlling the microstructure of the phases and changing the preparation techniques.

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