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Critical current densities of high pressure oxygen sputtered thin films of $YBa_2Cu_3O_{7-x}$ by non-resonant rf absorption method

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Abstract. The critical current densities (J_c) have been measured at 77 K in high pressure oxygen sputtered thin films of $YBa_2Cu_3O_{7-x}$ superconductor using the non-resonant rf absorption technique. High values of $J_c(\sim 10^5\,A/cm^2)$ are observed in these relatively large area ($\sim 1{\cdot}2\,cm^2$) films.

Keywords. Oxide superconductors; thin films; critical current densities; low field rf absorption; flux pinning.

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The method of studying the microwave and rf responses of high T_c superconductors using the conventional continuous wave electron paramagnetic resonance (EPR) [1, 2] and nuclear magnetic resonance (NMR) [2] spectrometers has by now been established as a very convenient way of characterizing these materials. Recently we have shown [3] that the analysis of the intensity of the response signal in the rf range as a function of the amplitude of the modulating field provides a procedure for determining the critical current density J_c of superconducting thin film samples. The method is particularly convenient since a) it is a contact-less method and b) there is no need to form a narrow strip of the sample as in the case of the transport measurement thus eliminating the uncertainty due to the measurement of the dimensions of the strip. It was also shown [3] that the critical current densities obtained using this technique are in agreement with those determined by conventional transport current measurements. The films used in the study were prepared by the laser ablation technique. It was thought to be interesting to apply this technique for the measurement of J_c of films prepared by different techniques. In this report we present the results of J_c measurements carried out by the non-resonant rf absorption method on $YBa_2Cu_3O_{7-x}$ thin films prepared by high pressure oxygen sputtering [4]. The special feature of these films is their relatively large area ($\sim 1{\cdot}2\,cm^2$).

The film deposition system has a simple DC diode configuration in sputter down mode. It is evacuated to the base pressure of 4×10^{-6} mbar by a diffstack and rotary pump combination. Ultra high pure oxygen is then introduced as the sputter medium. The oxygen pumping during the deposition is taken care of by a sorption pump. The substrate is heated using a quartz halogen lamp. The detailed description of the system is presented elsewhere [5, 6]. The films are deposited at different inter electrode

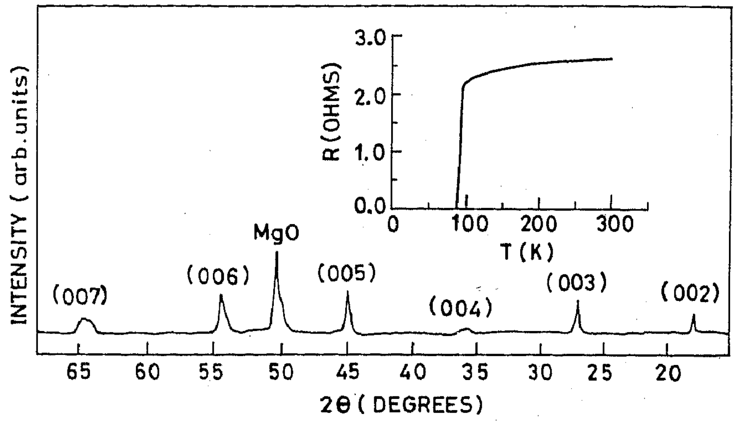

Figure 1. X-ray diffraction pattern of the film marked 3 in the table. The inset shows the temperature dependence of the resistance for the same film.

Table 1.

Film No.	IED mm	ΔT_c °K	T_c(on set) K	R_{300}/R_{100}	$T_c(0)$ K	J_c 10^5 A/cm^2
1.	17	7	92	1·34	85	3·1
2.	21	4	90	2·23	86	2·5
3.	19	3·5	92	1·19	88·5	0·95

distances (IED) with the operating pressure of 2 mbar. The films were characterized by the measurement of resistance (R) as a function of temperature (T) and X-ray diffraction using CoKα radiation. A typical R vs T plot and the corresponding X-ray diffraction pattern are shown in figure 1. The figure clearly shows the (001) orientation of the film and the T_c onset at 92 K and $T_c(0)$ at 88·5 K. The thickness of the film is measured using Talysurf and is found to be ~ 5000 Å.

The results on three such films along with their characteristics are reported in table 1. The film with a larger ΔT showed an unidentified peak at $2\theta = 52{\cdot}5°$ whereas the other two clearly showed all (001) peaks indicating c axis orientation.

The details of the non-resonant rf absorption method used to measure J_c have been published earlier [1, 2] and here we only briefly describe the essential aspects. A conventional CW NMR spectrometer is used in the usual NMR configuration, i.e., the rf field is perpendicular to the static field which is collinear with the modulation field. A level limited Robinson type oscillator working at a nominal frequency of 13·3 MHz is used. The frequency of the modulating field is 87 Hz. The film is oriented in such a way that the static field H is perpendicular to the plane of the film (i.e., $H \parallel c$). The derivative of the rf absorption is recorded after lock-in detection. The measurements are carried out at 77 K by directly immersing the sample in liquid nitrogen. A typical recording is shown in figure 2. The peak-to-peak signal intensity is measured as a function of the amplitude of the modulating field. Figure 3 shows such results for one of the films. It is seen that initially the signal increases linearly with the modulation amplitude until 1·5 Oe where there is a departure from this linear dependence. Following our earlier work [3], we identify the field at which this departure occurs with the field value H^* when the complete penetration of the sample

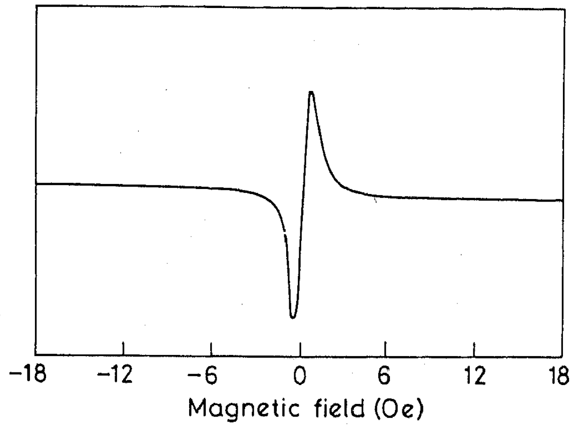

Figure 2. The non-resonant rf absorption signal recorded in the derivative form for the film marked 3 in the table.

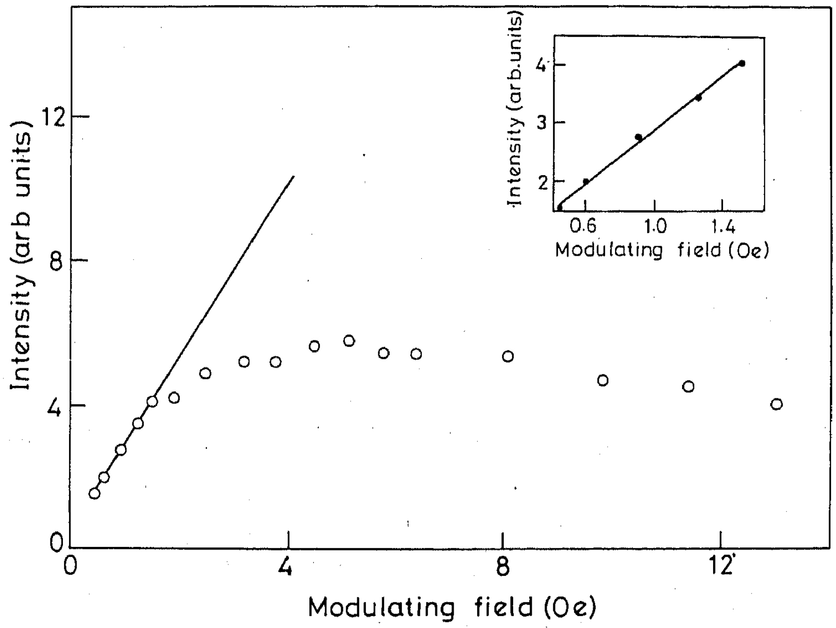

Figure 3. The peak-to-peak intensity variation of the non-resonant rf signal with the amplitude of the modulating field for film #3. The inset shows the straight line fit of the data points till H^*.

by the magnetic field has occurred. According to the Bean critical state model [7],

$$H^* = 2\pi J_c D/10 \tag{1}$$

where J_c is the critical current density and D is the dimension of the sample in the direction along which the field penetration is considered. H^* here is the sum of the modulating field and the value of the static field at which the departure occurs. As recently shown by Baczewski *et al* [8] for thin film samples due to the considerations of the demagnetization factors even though the static field is perpendicular to the plane of the film the dominant field gradient term would be along the thickness of the film. This conclusion is consistent with the earlier finding [9] for a disc-shaped superconductor (with radius $r_0 >$ thickness d) that the magnetic field trapped at the centre of the disc is $J_c d$ and not $J_c r_0$. Further, the detailed study of demagnetization factor for a sample with the shape of a general ellipsoid [10] is also noteworthy in this connection. Therefore, in equation (1), D represents the thickness of the film. For our sample thickness ~ 5000 Å. We have estimated J_cs for different films in this way and the values are given in table 1.

It is clear from table 1 that the J_c values are higher for the first two films compared to the third one. This may be due to the better quality of the former as reflected in their R_{300}/R_{100} values. Among the first two, film #1 shows a slightly higher J_c though its R_{300}/R_{100} ratio is lower than the second one. This might be the result of the additional pinning provided by the impurities present in film #1 as indicated by the extra peak observed in its X-ray diffraction pattern. To be noted however, is the result that the order of magnitude of J_c of these relatively large area ($\sim 1{\cdot}2\,\mathrm{cm}^2$) films prepared by the high pressure oxygen sputtering method is essentially the same as that of the films prepared by the technique of laser ablation reported earlier [3]. Another point of relevance is the homogeneity of the films. It is expected that additional precautions need to be taken to ensure homogeneity of these large area films. We have evidence (Srinivasu *et al.*, to be published) that the technique of non-resonant rf and microwave absorption can be used to check the films for homogeneity. Further studies on this aspect as well as the effect of impurities on J_c value are under way.

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