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Effects of Electron Irradiation on Irreversibility Line in Superconducting $YBa_2Cu_3O_7$

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Abstract. We have investigated the effects of 2.5 MeV electron irradiation on the irreversibility line of a sintered $YBa_2Cu_3O_7$ by applying dc and ac measuring techniques. We find that after electron irradiation, both the superconducting transition temperature T_c and the irreversibility temperature T_{irr} , determined by either technique, decrease; the decrease in T_{irr} scales with the decrease in T_c.

Conventional zero-field-cooled/field-cooled (zfc/fc) magnetization measurements led to the discovery (Müller et al , 1987, Yeshurun and Malozemoff, 1988) of the irreversibility line (IRL) in the magnetic phase diagram of high-temperature superconductors (HTSC). The importance of this line to the basic understanding of HTSC and to their potential applications, has motivated intensive studies of the IRL by other techniques. Of these, the most efficient, in terms of time consumption, are techniques which are based on ac magnetometry. There are several variants of these measurements. Thus, e.g. the IRL may be deduced from a study of the field and temperature dependence of the peak in the loss signal (Malozemoff et al, 1988) , from the onset of third harmonics in the ac response (Shaulov and Dorman, 1988), and from screening efficiency to ac fields (Gilchrist and Konczykowski, 1990, Konczykowski and Gilchrist, 1990).

In the present article we deal with the effect of irradiation on the IRL. Irradiation has been used in numerous experimental works to induce defects in a controlled way. The main goal in these works was the enhancement of critical currents J_c by introducing new, more efficient, pinning centres for flux trapping. In most studies, however, J_c was affected only insignificantly. Only recently a dramatic improvement of J_c was achieved by van Dover et al (1989) by neutron irradiation of a single crystal of $YBa_2Cu_3O_7$ (YBCO). Civale et al (1990), however, showed, by proton irradiating their YBCO crystal, that the improvement in J_c is not accompanied by changes in the IRL. The main goal of this paper is to explore the effect of electron irradiation on the IRL.

The sample used in this experiment is a sintered YBCO with transition temperature of T_c=90.5 K and dimensions 4 x 4 x 0.1 mm^3. Low temperature (20 K) irradiation by 2.5 MeV electrons with a Van de Graaff accelerator produced damage consisting of homogeneously distributed isolated Frenkel pairs on all sublattices of YBCO (Vichery et al, 1989). However the agglomeration of small defect clusters is expected when the sample is warmed to room temperature for transfer to the measuring cryostat.

For determining the IRL we used four experimental techniques: (1) Conventional zfc/fc magnetization measurements. (2) Ac screening efficiency measurements under zfc and fc conditions. In these measurements the sample is put between the driving and the detecting coils (see Fig. 1 in Konczykowski and Gilchrist, 1990) and the 'transmittivity' of the ac signal is measured.(3) Measurements of the imaginary component of the transmittivity. The IRL is defined via the peak in this signal. (4) Measurements of the onset of odd harmonic components in the ac

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response (fundamental frequency was 20 kHz). In a forthcoming publication we compare the four techniques.

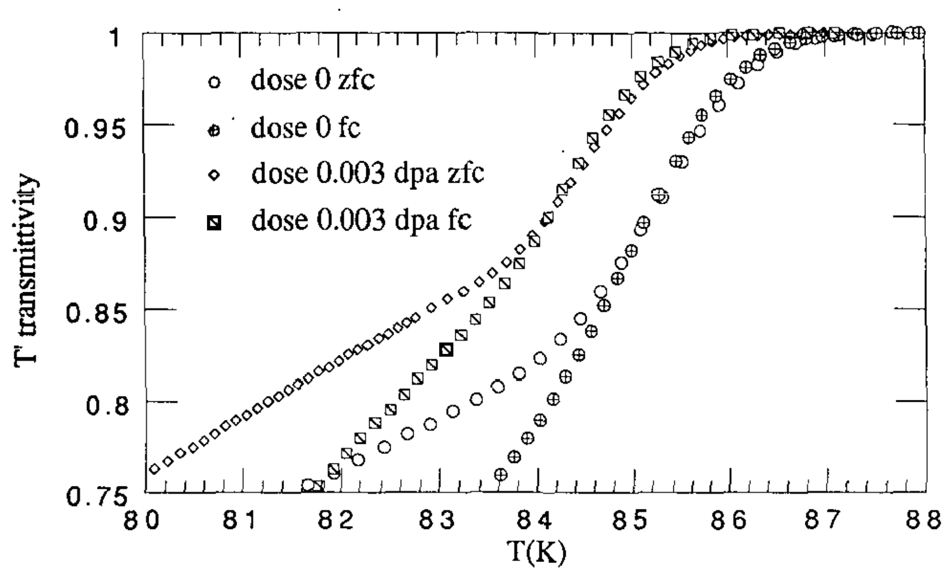

Figure 1. $YBa_2Cu_3O_7$ polycrystal irradiated at 20K by 2.5 MeV electrons. H_{dc}=250 Oe, H_{ac}=180 mOe, f=11.7 kHz.

All these techniques - except number (2) - have been employed in the past for determination of the IRL. Their adequate interpretation enables the IRL to be obtained even for polycrystalline material. To demonstrate the new technique (2) we show typical data in Fig. 1. The split of zfc and fc branches of the ac screening efficiency of polycrystal, corresponds to the split of the zfc/fc curves in conventional measurements of intragranular dc magnetization. Figure 1 also demonstrates the main result of this paper, namely that as a result of the irradiation, T_c and the irreversibility temperature T_{irr} are slightly decreased. However, **the reduction in T_{irr} scales with the reduction in T_c.**

To further demonstrate this important point we summarize in Fig. 2 our results for the irreversibility line - before and after irradiation - measured by the conventional zfc/fc magnetization (squares) and by the onset of the third harmonic signal (circles).The open symbols denote data taken before irradiation, whereas the filled ones refer to the irradiated sample (0.003 displacements per atom, as for Fig. 1). The solid lines are fits to the unirradiated data assuming a power-law dependence of field on the reduced temperature. The difference between the ac and dc data described in Fig. 2 is apparently due to the dependence of the IRL on the measuring frequency, as reported by Malozemoff et al (1988). We find that not only T_{irr} increases with frequency but also the slope (i.e. the exponent in the power-law) depends strongly on frequency. We find a slope of 1.6 for the dc magnetization data, in agreement with previous experiments (e.g. Yeshurun and Malozemoff, 1988); the exponent deduced from the onset of third harmonic is 2.5 and that deduced from transmittivity measurements (not shown here) yields 3. This point will be discussed further elsewhere.

As a result of 0.003 dpa elecron irradiation damage, the critical current J_c, as deduced from measurements of magnetization curves at low temperatures, is increased by a factor of 2. Further indirect evidence for the increase in J_c is deduced from the lowering of the height of the peak in the third harmonic signal measured as a function of temperature.

Figure 2 demonstrates that the IRL, described as a function of the **reduced** temperature, is not affected by irradiation. Our results are in agreement with those of Civale et al (1990). It is important to note, however, that in their experiment protons produced defects of 30 Å in size, somewhat larger than the coherence length, while in our experiment electrons cause damage on a much finer scale, perhaps the finest possible scale (Vichery et al, 1989). The fact that neither experiment shows any significant change in the IRL may indicate that only much larger defects might be effective in shifting it.

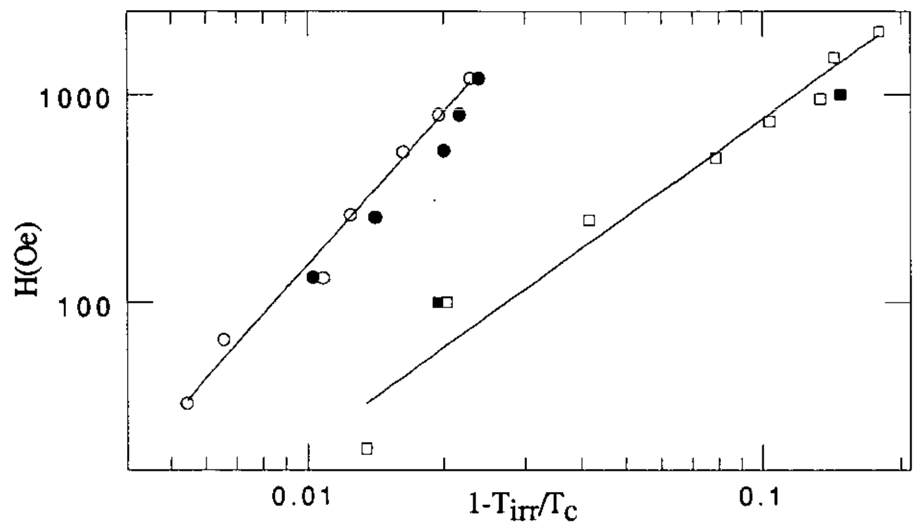

Figure 2. Irreversibility line for $YBa_2Cu_3O_7$ polycrystal from zfc/fc measurements (squares) and from onset of third harmonic signal (circles) before (open symbols) and after (filled) irradiation.

The conclusion that the IRL is not altered by irradiation whereas J_c is increased seems to contradict the simple flux creep interpretation. However, Malozemoff and Fisher (1990) have recently pointed out that normalized relaxation rates S, in numerous experiments, exhibit unexpected universality, being independent of J_c and interpreted the results within vortex glass (Fisher et al, 1990) and collective flux creep (Feigel'man et al, 1989, Nattermann, 1990) models. We believe that their surprising observation may be correlated with the behaviour of the IRL for a given measuring technique. The IRL may be defined as the loci of points in the field-temperature plane for which the relaxation rates are of the same order of magnitude as the measuring frequency. Constancy of S would thus imply a constancy of the IRL.

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