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**FAST NEUTRON IRRADIATION EFFECTS ON MAGNETIZATION
RELAXATION IN YBCO SINGLE CRYSTALS***

J.G. Lensink and R. Griessen

Faculty of Physics and Astronomy, Free University, NL-1081 HV Amsterdam, The Netherlands

H.P. Wiesinger, F.M. Sauerzopf, and H.W. Weber

Atominstiut der Osterreichischen Universitaeten, A-1020 Wien, Austria

and

G.W. Crabtree

Materials Science Division, Argonne National Laboratory, Argonne, IL 60439

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Third International Conference on Materials and Mechanisms of Superconductivity High-Temperature Superconductors, M²S-HTSC III Proceedings, Kanazawa, Japan, July 22-26, 1991, to be published in Physica C.

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*Work supported in part by FWF, Wien under contract # 7970, by the EC SCIENCE program and by the U.S. Department of Energy, BES-Materials Sciences under contract #W-31-109-ENG-38.

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High-Temperature superconductors
M²S-HTSC III
Kanazawa Japan

Fast Neutron Irradiation Effects on Magnetization Relaxation in YBCO Single Crystals

J.G. Lensink and R. Griessen, Faculty of Physics and Astronomy, Free University, NL-1081 HV Amsterdam, The Netherlands.
H.P. Wiesinger, F.M. Sauerzopf, and H.W. Weber, Atominstytut der Österreichischen Universitäten, A-1020 Wien, Austria.
G.W. Crabtree, Materials Science Division, Argonne National Laboratory, Argonne, IL 60439, U.S.A.

A high-quality YBa₂Cu₃O_{7-δ} single crystal has been investigated by torque magnetometry prior to and following fast neutron irradiation to a fluence of $2 \times 10^{21} \text{ m}^{-2}$ ($E > 0.1 \text{ MeV}$). In addition to large enhancements of the critical current densities, which have been observed in similar form previously by Sauerzopf et al.¹, we find a dramatic change in the relaxation behavior following irradiation. At low temperatures ($\leq 50 \text{ K}$) the relaxation rates are lowered by factors up to 4 in the irradiated state in a magnetic field of 1.5 T. At higher temperatures, on the other hand, they are enhanced compared to the unirradiated state. Both before and after irradiation, the magnetization relaxation follows a logarithmic time dependence, which we ascribe to thermally activated flux motion.

1 INTRODUCTION

Soon after the discovery of high- T_c superconductivity² it was found that magnetic relaxation effects play an important role³. The observed logarithmic time decay of current $j(t)$ or magnetic moment $M(t)$ indicates that the relaxation can be described by means of a thermally activated flux motion (TAFM)-model. For technological applications it is important to minimize the relaxation effects in high- T_c superconductors. One possibility to do so is to introduce strong pinning centers in the material. From earlier studies of single crystals^{1,4} of YBa₂Cu₃O_{7-δ} it is known that fast neutron irradiation gives rise to an enhancement of the critical current density. Since the defect structure is modified by irradiation one expects also a change in the relaxation behavior.

In this paper we report on a study of fast neutron irradiation effects in a high-quality single crystal of YBa₂Cu₃O_{7-δ}. The temperature dependence of both the critical current and the magnetic moment relaxation has been determined before and after fast neutron irradiation. The relaxation data after irradiation are described within a collective pinning model.

2 EXPERIMENT

The single crystal was prepared by a flux method⁵ and subjected to an extended post-

annealing treatment in flowing oxygen. The irradiation was done in the central irradiation facility of the TRIGA Mark II reactor in Vienna. During irradiation the sample was in a pure He-atmosphere and the temperature was lower than 50°C. The crystal was irradiated to a fluence of $2 \times 10^{21} \text{ m}^{-2}$ ($E > 0.1 \text{ MeV}$). The magnetic moment relaxation measurements have been done by means of a capacitance torque magnetometer in a 1.5 Tesla electromagnet. For magnetization relaxation as well as for the critical current density measurements the field was applied under an angle $\theta = 45^\circ$ with respect to the c-axis. The critical currents are determined from the torque $\tau = R \times \mu_0 H$ acting on the sample by assuming that the critical current has the same magnitude everywhere in the sample. We have then $j_c = 3\Delta\tau / (2VR \sin\theta \mu_0 H)$ where V is the volume of the sample, R its radius, and $\Delta\tau$ is the hysteresis of the torque measured from up-sweeps and down-sweeps of the field H at a rate of 10 mT/s. For the magnetization relaxation experiment the single crystal was cooled down in zero field. After the temperature is stabilized the field is increased at a rate of 10 mT/s until the maximum value of 1.5 Tesla is reached. After the field sweep is stopped the magnetic moment is measured every 0.05 seconds during typically 10 minutes. Both kinds of experiments have been performed at several temperatures between 4 K

and 83 K before and after irradiation with fast neutrons.

3 RESULTS

The critical current density, determined at a field of 1 Tesla from the magnetization curves, as a function of temperature is shown in Fig.1. We see clearly an enhancement of the critical current density especially at high temperatures. This is comparable to the results reported by others^{1,4}. The magnetization relaxation data are given in Fig.2 where the normalized relaxation rate $S = (1/M(t_0))(dM/d\ln t)$, is plotted as a function of temperature before and after irradiation. $M(t_0)$ is the magnetic moment of the sample at the time t_0 of the

FIGURE 1
The critical current density before and after irradiation

FIGURE 2
The normalized relaxation rate before and after irradiation

first datapoint ($t_0 \approx 0.05s$). Before the irradiation we see a normal relaxation behaviour which is comparable to other single crystals with a maximum at about 15 K and vanishing relaxation near T_c . On the other hand, after irradiation, S shows a plateau for $20 K \leq T \leq 50 K$. For $T > 50 K$, S is increasing and seems to diverge at $T = T_c$. For fluences lower than $2 \times 10^{21} m^{-2}$ we found that the plateau in S has an even wider range from -10 K to almost 60 K. The constancy of S can be explained in terms of collective pinning^{6,7} for which $S = [\nu \ln(t/t^*)]^{-1}$ if the pinning energy varies as $j^{-\nu}$ with current density. It is evident from the curves shown in Fig.2 that there is no universal behavior for S as claimed by Malozemoff and Fischer⁸. The temperature dependence of S depends strongly on the defect structure of a given sample. For $T > 50 K$ S is strongly enhanced although the critical current density is still a factor of 4 higher than before irradiation. To explain this, we assume, that although strong pinning centers are present, their density is not sufficient to compensate for the weakening of the pre-irradiation defect structure in the temperature regime close to the irreversibility line.

Acknowledgements

This work has been supported in part FWF, Wien, under contract No. 7970 and by the EC SCIENCE program, and the U.S. DOE-BES-MS #W-31-109-ENG-38.

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