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STUDIES OF STRUCTURAL DAMAGE IN HIGH-T_c SUPERCONDUCTORS BY HIGH-ENERGY HEAVY-ION IRRADIATION

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ABSTRACT

The results of studies of structural damage by high-energy (MeV) Si^{+13}, Cu^{+18}, Ag^{+21}, and Au^{+24} ions, using transmission electron microscopy techniques, revealed that the size of the damaged area (amorphous) is strongly dependent on: 1) the stopping power [dE/dx (keV/nm)] of the irradiating ions, 2) the thermal diffusivity of the crystal, 3) the degree of oxygenation, in the case of $YBa_2Cu_3O_{7-\delta}$, and 4) the direction of the ion beam with respect to the crystallographic axis.

INTRODUCTION

Recently a number of studies [1-4] of the effects of high-energy heavy ion irradiation on the properties of high-T_c cuprates have been reported. One of the most interesting and important findings of the studies is the fact that in general the critical current densities of the oxides are significantly increased, even at high temperatures and magnetic fields. These increases are attributed to the formation of latent tracks of amorphised non-superconducting columns through the thickness of the specimens[1-5] A number of the articles[1-3,6] have documented the evidence for the amorphised columnar damage in the crystalline lattice of the oxides obtained by high resolution transmission electron microscopy (HREM). However, the factors controlling the size and areal density of the columns as a function of the fluence, as well as the shape of the damaged areas, have not been reported. Here, we report a brief summary of the results of an extensive study, using electron microscopy techniques of the damage and of the physical conditions of the specimens which resulted in variations of the damage.

EXPERIMENTAL PROCEDURE

For this study, we irradiated $YBa_2Cu_3O_{7-\delta}$ (123) with Si^{+13}, Cu^{+18}, Ag^{+21}, and Au^{+24} ions, and the energy of each ion and its linear energy transfer rate for Y(123) and Bi(2223) are listed in Table I. Irradiation was performed on prethinned TEM specimens or on thin films. Since the depth of the penetration for all of the ions is significantly greater than the specimen thickness, we can assume that no applicable energy loss was experienced by the ions passing through the specimens.

RESULTS

In the following, we summarize the observed results on the damage:

(1) The shape and the size of the damaged areas depend on the crystallographic orientation relative to the beam direction. When the beam is perpendicular to the c-axis, the sizes are greater and the shapes are more oval than when it is perpendicular to the a-b plane.

(2) The areal density as a function of fluence and the size of the damage increased with the energy deposition rate, dE/dx (Fig. 1).

(3) The threshold energy for the production of amorphous columns increased and the size of the damage decreased with the oxygenation level of Y(123) (Fig. 2). Also pre-existing structural defects enhanced the possibility of the damage formation.

(4) Some of the above observed phenomena are shown to be qualitatively described by a thermal spike model where the thermal diffusivity plays an important role in determining the size and shape of the columns.

Table I. The energy and the charge state of various ions used in the present study and the estimated linear energy transfer rates for $YBa_2Cu_3O_{7-\delta}$ and $Bi_2Sr_2Ca_2Cu_x$ (denoted by *).

Ion	Au^{+24}	Ag^{+21}	Cu^{+18}	Si^{+13}
Energy (MeV)	300	276	236	182
Energy Loss (KeV/Å)	3.48 3.18*	2.38 2.18*	1.34 1.24*	0.38 0.25*

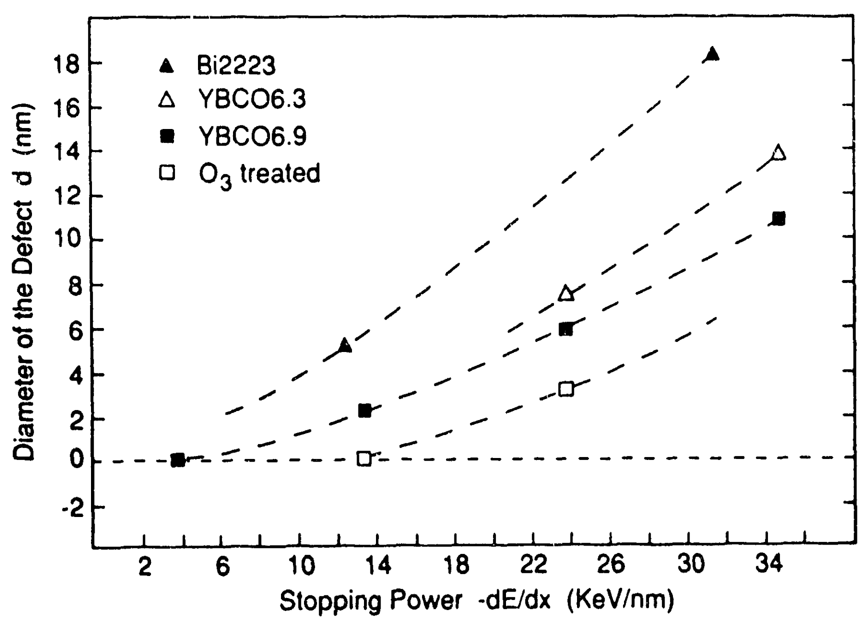

Fig. 1. The size of the amorphised areas as a function of the energy deposition rate dE/dx for Y(123) with various oxygen levels.

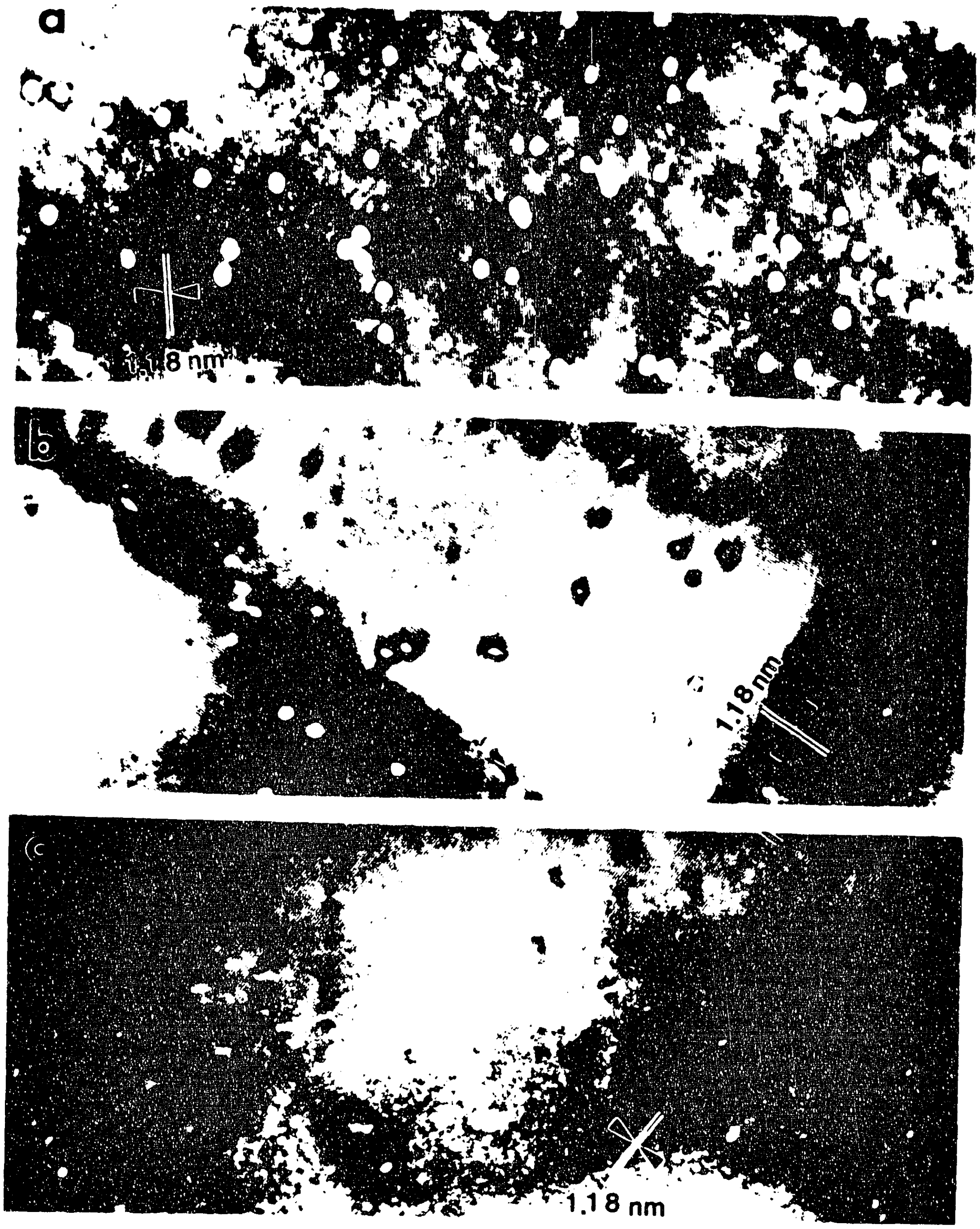

Fig. 2. Transmission electron micrographs showing the Ag^+ irradiation damages for $YBa_2Cu_3O_{7-\delta}$ with a) $\delta \sim 0.7$, b) $\delta \leq 0.1$, and c) $\delta = 0$.

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