Anomalies in the superconducting transition in A-15 films with a periodic inhomogeneity

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An anomalous behavior of the superconducting transition has been observed in Nb_3Sn and Nb_3Ge films bombarded by He^+ ions with $E = 3$ MeV through grid masks with grid lines and apertures having characteristic dimensions of a few tens of microns. An explanation is proposed on the basis of the assumption that long-range stresses arise around disordered regions in the A-15 lattice.

The bombardment of Nb_3Sn is known to give rise to substantial local stresses and distortions of the crystal lattice.[1] There are also indications that the scale length of the spatial modulations of the lattice constant in neutron-bombarded polycrystalline Nb_3Sn is comparable to the grain size.[2]

In this letter we report a study of the effect of periodic inhomogeneities, deliberately produced by bombardment, on the transition temperatures T_c of superconductors with the A-15 structure.

The samples are Nb_3Sn and Nb_3Ge films deposited by a magnetron method on a substrate of sapphire or oxidized single-crystal silicon. The film thickness is 4000–8000 Å. All the samples have a homogeneous phase composition, identical temperatures $T_c = 17$–18 K, and a transition width $\Delta T = 0.2$–0.5 K.

The samples are bombarded on a Van de Graaf accelerator with 3-MeV helium ions. The beam current does not exceed 1.5 μA. The maximum bombardment dose is 2.12×10^{18} He/cm^2. The bombardment temperature is close to the temperature of liquid nitrogen. The size and period of the structure produced by the nonuniform bombardment vary with the particular mask used from 1 mm to several tens of microns. The size of the inhomogeneities is determined from the known parameters of the mask. The thickness of the mask exceeds the mean free path of the helium ions in the mask material; i.e., the regions of the matrix which are covered by the grid lines of the mask are not bombarded. That the mask is impenetrable at the grid lines to α particles, whose mean free path in the mask material is about 6 μm, was verified by bombarding a control sample covered with a 10-μm nickel foil (this thickness is half the thickness of the mask). After bombardment with a dose of 2.47×10^{17} He/cm^2, we found no changes of any sort in the superconducting-transition curve.

During bombardment of samples in a nonuniform manner through fine cells (the cell size was 60 μm, and the width of the grid lines was 40 μm) we observed an anomalous behavior of the superconducting transition. We used both inductive and resistive methods to study this behavior. After bombardment with a dose of 1×10^{18} He/cm^2, T_c decreased from 18 K to 3 K (Fig. 1). The final effect of the bombardment through the mask turned out to be the same as if the bombardment had been carried out continuously; in the case of continuous bombardment, the temperature of the

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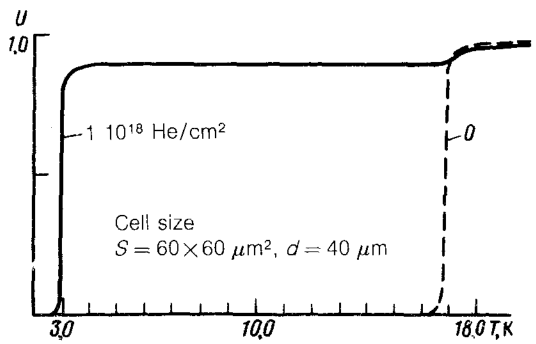

FIG. 1. Temperature dependence of the superconducting transition after bombardment of a sample with the dose of 1×10^{18} He/cm^2 for the case of a fine bombardment cell.

superconducting transition is known[3] to decrease throughout the volume of the sample. In other words, during bombardment through a fine grid, there is no shunting of the bombarded regions with a low transition temperature T_c by the regions of the film which are not bombarded. We did not observe this anomaly in samples bombarded through a large-cell mask, with scale dimensions of 0.5 and 0.3 mm for the apertures and the grid lines, respectively; the shunting of the bombarded regions by regions that are not bombarded does occur.

It is important to note that the fraction of the area of the film which is bombarded was approximately the same in the cases of the coarse and fine masks.

To determine the distinctive features of the nonuniform bombardment, we carried out an experiment in which each of the samples was cut into two identical parts, which were then bombarded simultaneously, one part covered by a mask with fine cells. A typical result is shown in Figs. 2 and 3. We see that, in contrast with the shift of the transition toward a lower temperature which is ordinarily observed during uniform bombardment, the nonuniform bombardment gives rise to a second transition, with $T_{c_1} < T_{c_0}$ (Fig. 2). With increasing bombardment dose, the relative amplitude of the second transition increases, and the temperature at which it begins decreases, approaching a value which corresponds approximately to the saturation value of T_c for Nb_3Sn. On the basis of this behavior it can be suggested that during nonuniform bombardment of Nb_3Sn and Nb_3Ge films, the high concentration of radiation-induced

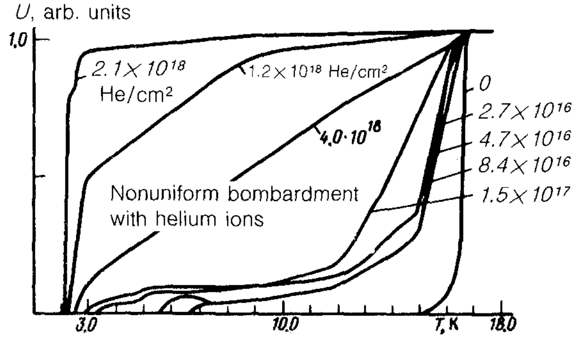

FIG. 2. Temperature dependence of the superconducting transition after nonuniform bombardment of a sample with helium ions.

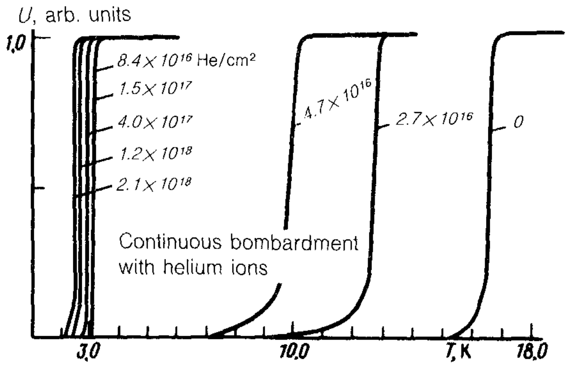

FIG. 3. Temperature dependence of the superconducting transition after continuous bombardment of a sample with helium ions.

defects produced in the bombarded regions causes substantial local distortions of the lattice. Under certain conditions, these distortions can propagate quite far, causing changes in the physical properties in regions not affected by the bombardment.

The reason for this long-range nature of the distortions that arise may lie in the following circumstances: First, the stress relaxation that occurs near a spherical dilatation source in the model of an elastic continuum is "slow" $(1/r^2)$. Second, the elastic moduli in A-15 compounds have several distinctive features, which lead to a metastability of the crystal lattice of this class of compounds. It may be that the formation of defects or the appearance of a local strain disrupts the symmetry in close-lying coordination spheres. As this process propagates further on, it can in principle cause changes in the local properties near the disordered zones over distances greater than the coherence length ξ. This length serves as a scale dimension in the Pande model,[4] which has been proposed to explain the degradation of the superconducting transition temperature in compounds with the A-15 structure during bombardment.

These experimental results suggest the following hypothesis to explain the degradation of the superconducting transition temperature in high-temperature A-15 compounds: The disordered regions of small dimensions create stresses in their vicinity and thereby change the local value of T_c in a volume which is significantly larger than the volume of the disordered region itself. As was stated earlier, the distortions in the A-15 lattice propagate over greater distances than has previously been assumed.

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[1]I. V. Voronova, N. N. Mikhailov, G. V. Sotnikov, and V. Yu. Zaikin, Proceedings of the International Discussion Meeting on Radiation Effects on Superconductivity, Argonne, Illinois, June 1977, p. 13.
[2]C. S. Pande, Solid State Commun. **37**, 753 (1981).
[3]N. N. Mikhaĭlov, V. A. Somenkov, G. V. Sotnikov, and A. S. Tokarev, VANT Ser. Obshch. Yad. Fiz. No. 2/23, 17 (1983).
[4]C. S. Pande, Phys. Status Solidi A **52**, 687 (1979).

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