REVERSIBLE CHANGE OF SUPERCONDUCTING TRANSITION TEMPERATURE OF U_6Fe INDUCED BY NEUTRON IRRADIATION

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The change of T_c of superconductors upon disordering of the crystal lattice was investigated by many workers using films condensed at helium temperature [1, 2]. A theoretical analysis, similar to that carried out by McMillan assumed independence of the electron state density N(0) of the degree of disorder, leads to the conclusion that T_c of "amorphous" films should be higher than in the bulk material, owing to the softening of the phonon spectrum, as is indeed observed in a number of superconductors [3].

Later investigations of films of certain transition metals have shown, however, that the character of the variation of T_c of different materials upon disordering is not the same. Thus, Strongin [4] observed a large rise of T_c in Mo films, whereas in the case of disordered niobium films T_c was greatly lowered. These facts indicate that the mechanism of variation of T_c upon disordering of the crystal lattice is more complicated than assumed by McMillan, and that in many cases T_c may be strongly influenced not only by the change of the phonon spectrum, but also by the change of N(0).

It is therefore of interest to investigate the effect of disordering on T_c of bulky superconductors, for in this case the determination of the phonon spectrum and of N(0) is a simpler problem than in the case of films. A convenient material for such an investigation is the superconducting intermetallic compound U_6Fe, the crystal structure of which is strongly damaged by neutron bombardment. We present in this communication data on the variation of T_c of U_6Fe samples following neutron bombardment and following a subsequent annealing.

The superconductivity of the compound U_6Fe with T_c = 3.9°K was observed by Chandrasekhar and Hulm in 1958 [5]. X-ray structure investigations of this

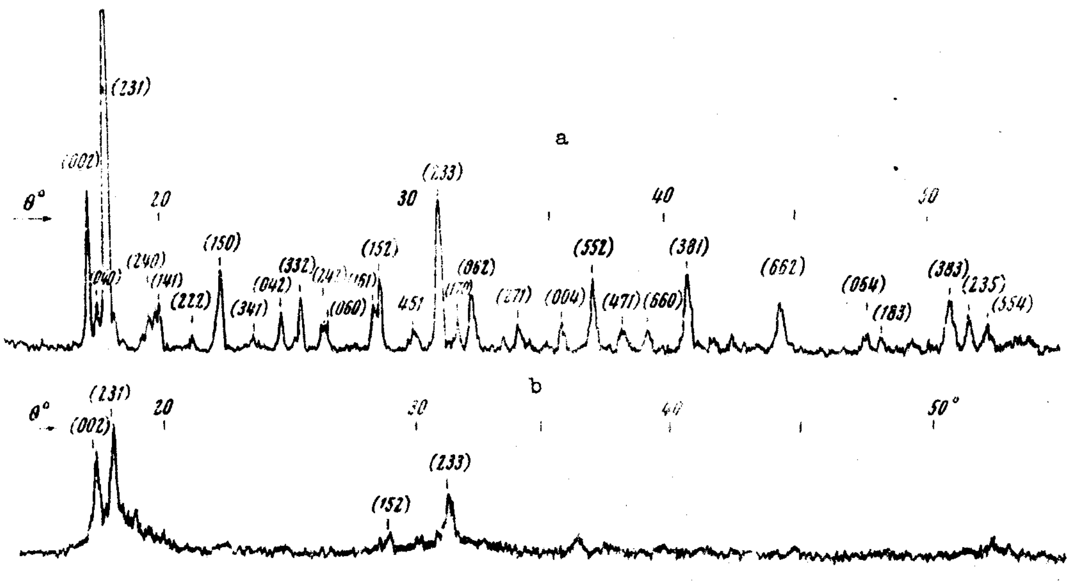

Fig. 1

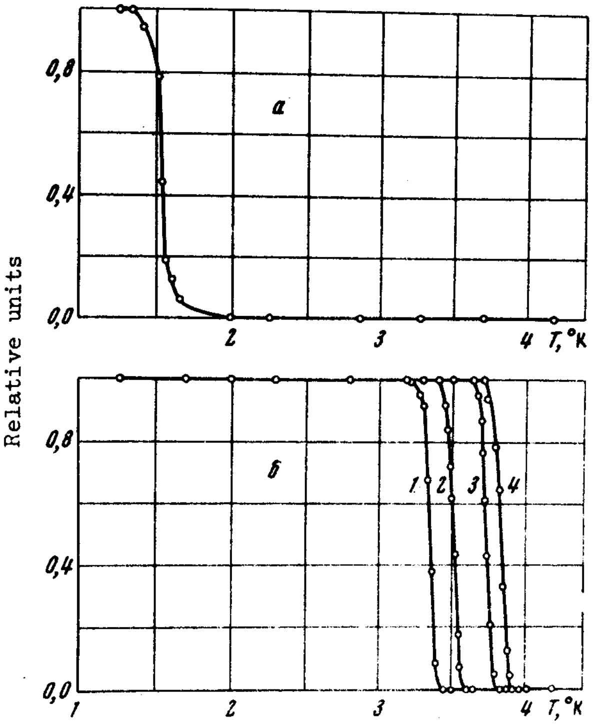

Fig. 2

compound are reported in [6]. Hill and Matthias [7] measured T_c of pseudobinary compounds produced by fusing, in different ratios, two neighboring members of the series U_6Mn, U_6Fe, U_6Co, and U_6Ni. They have shown that U_6Fe has the highest T_c of all the obtained samples. The critical temperature of the other samples decreased gradually with changing composition both in the direction of U_6Mn (T_c = 2.3°K) and in the direction of U_6Ni (T_c = 0.4°K).

These authors pointed out the existence of a correlation between T_c of the compounds of the aforementioned series and the average number of unbalanced electron spins per atom of the magnetic elements contained in the compound when these elements are in the metallic or alloyed state.

Bloch has shown that neutron irradiation of U_6Fe, up to the burning out of about 5×10^{-6} of the total number of uranium atoms, causes complete disappearance of the diffraction maxima on the x-ray pattern of the compound. This phenomenon was attributed to the transition of the compound into an "amorphous state" as a result of destruction of the crystal structure by the uranium fission fragments. Annealing at 450°C restored fully the diffraction pattern of the irradiated samples.

We prepared the initial U_6Fe samples by vacuum melting in an induction furnace and subsequent annealing at 790°C for 10 hours. The samples were irradiated at 60°C in a thermal-neutron flux 3×10^{12} neut/cm^{2}sec up to burnup of 4×10^{-6} of the total number of the uranium atoms.

The T_c of the U_6Fe samples was determined from the change of the inductance of a small coil with the sample placed in it, with the temperature lowered by pumping-off the helium. The ac bridge (R-571) operating at 1 kHz was balanced at 4.2°K. The change of the bridge output voltage when the sample became superconducting was registered with a cathode voltmeter (VK-7) as a function of T. For certain samples, T_c was determined from the change of the resistance with the aid of a low-resistance dc potentiometer (R-330). No significant differences were observed between the results obtained by the two indicated methods.

X-ray patterns of U_6Fe before and after irradiation are shown in Figs. 1a and 1b. The incomplete disappearance of the x-ray maxima can be attributed to partial reconstruction of the structure during the irradiation time, since the irradiation dose was perfectly sufficient to cause the entire material to go through the state of the thermal peak.

A plot of the superconducting transition of the irradiated U_6Fe is shown in Fig. 2a. We see that in this case T_c equals 1.6°K, i.e., it is decreased by an approximate factor 2.5 compared with the T_c initial U_6Fe; at the same time, the transition remains comparatively abrupt.

The irradiated samples were annealed in pure helium at temperatures from 350 to 500°C for 3 hours. The transition curves of the samples after annealing are shown in Fig. 2b. After annealing at 500°C, T_c reaches a value 3.9°K, i.e., it returns to its initial value observed for the original U_6Fe. The transitions remain relatively abrupt both after the intermediate and after the final annealing. A reconstruction of the crystal structure of the compound takes place simultaneously with the rise of T_c.

Disregarding the hypothesis of Matthias and Hill [7] that the superconductivity of compounds of the U_6Fe type is brought about by a special "magnetic" mechanism, a hypothesis insufficiently well founded at present, it must be assumed that the change of T_c upon "amorphization" of the U_6Fe should be due to the change of the phonon spectrum or of the electron density of states on the Fermi surface, or to both simultaneously. Since the softening of the phonon spectrum, which apparently should accompany the transition into a near-amorphous state, leads according to McMillan to a rise of T_c, it must be assumed that "amorphization" of U_6Fe is accompanied by a predominant lowering of N(0), just as in the case of the disordered Nb films employed by Strongin [4].

One cannot exclude, however, another explanation of the observed effect, connected with the change of the magnetic state of the iron atom upon destruction of the compound, an effect that can exert on T_c an influence similar to the influence of a paramagnetic impurity in a superconducting alloy. Thus, the mechanism responsible for the change of T_c of irradiated U_6Fe is not yet completely clear, and calls for further research.

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