Redistribution of impurity sulfur atoms in nickel due to high-temperature electron irradiation

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A decrease of the residual electrical resistance in binary nickel–sulfur alloys has been observed experimentally as a result of high-temperature electron irradiation, which is attributed to redistribution of the impurity sulfur atoms in the bulk.

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The initial experiments using pure nickel[1] showed that the residual electrical resistance of nickel decreases as result of high-temperature electron irradiation. This effect was attributed[1] to redistribution of the residual impurities in the bulk of the irradiated material. It was natural to assume that the kinetics of the observed effect (the kinetics of stationary distribution of the impurities in the bulk of the sample) are determined by the interaction of the impurities with the radiation defects and with the dominant sinks in the sample. It is difficult to anlayze the composition of the investigated samples of pure nickel and to determine that impurity which interacts most efficiently with the flux of radiation defects. Therefore, the experiments described in this paper were carried out by using nickel–sulfur binary alloys.

The irradiation was carried out by using 5.5-MeV electrons and a beam with an intensity of 6.25×10^{13} e/cm^2·sec in a special thermostat in an atmosphere of highly purified helium with an oxygen content $\leqslant 10^{-10}$ vol.% at 625 K.

The polycrystalline and single-crystal samples were prepared from nickel single crystals with a room temperature to liquid-helium temperature resistance ratio of 600-900. The samples were subsequently saturated with elementary S^{35} by the diffusion method. The thickness of the samples was about 100 μm.

Before irradiation the samples were anealed in the thermostat at the irradiation temperature for 5 to 10 hours. The residual electrical resistance of the samples remained the same within the limits of the measurement errors.

Figure 1 shows the variation of the resistance of the single-crystal samples with pure nickel and with nickel–sulfur alloy as a function of the electron flux. As can be seen, the irradiation decreases the residual electrical resistance of the samples. There is, moreover, a definite correlation between the decreases of electrical resistance and the sulfur content in the samples: the higher is the sulfur concentration, the larger is the decrease of electrical resistance. The results of irradiation of the polycrystalline samples are analogous to those of the single-crystal samples. The radiometric measurements showed that the amount of sulfur in the samples after irradiation remained the same.

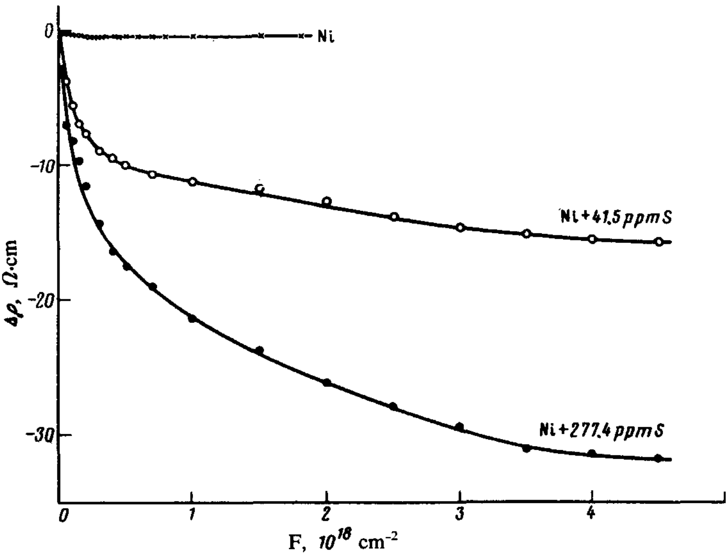

FIG. 1. Variation of the residual electrical resistivity of single-crystal samples of pure nickel and nickel–sulfur alloy as a function of the electron fluence.

After irradiation the samples were annealed at 900 K for 40 minutes, after which time their resistance was completely restored to its original value. A second irradiation of the same samples after annealing produced the same results as the first (Fig. 1).

The obtained data indicate that as a result of irradiation the impurity sulfur atoms are redistributed in the sample due to the flux of the radiation defects to the sinks[2] such as the external surface of the sample and the dislocations.

An estimate of the lower limit of the width of the sulfur-depleted zones near the surfaces and dislocations, which is based on the observed decrease of the resistance and on the assumption that the sulfur concentration in these zones is reduced to the level of the residual impurities in the original nickel, gives the value of 10^{-4} cm.

Using the coefficients of diffusion of sulfur into nickel at 900 K[3] and the homogenizing time of the irradiated samples at this temperature (40 min), we can estimate the average length of the diffusion path of sulfur in nickel during homogenization:

$$2(Dt)^{1/2} = 6\times10^{-5}\ \text{cm} \approx 10^{-4}\ \text{cm}\ .$$

A good agreement of these estimates indicates that the dislocations in the nickel single crystals are as efficient a sink as the external surfaces for the radiation defects which are responsible for redistribution of the impurities in nickel.

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