Annealing of defects in plastically deformed ^{4}He crystals

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The activation energy for diffusion of dislocations in deformed ^{4}He crystals, grown under a pressure of 31 atm, coincides with the activation energy of vacancies in specimens with the same density, as well as with the characteristic activation energy of ^{3}He impurity atoms and charges in the region of thermally activated motion.

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Previously we reported[1] that bending of perfect hcp ^{4}He crystals at $T \leqslant 0.45$ K leads to a many-fold decrease in the coefficient of thermal conductivity $\kappa(T)$. Judging from the magnitude and temperature dependence of the thermal conductivity of the deformed crystal, the additional resistance $W_g = \kappa_g^{-1} - \kappa_u^{-1}$ (κ_u, κ_g are the thermal conductivities of the starting and deformed specimen) is due primarily to scattering of phonons by dislocations produced by bending. The measurements have shown that the deformed crystals are annealed well: in order for the thermal conductivity of the deformed specimen to return to the starting value κ_u over a time $\cong 10$ min, it is sufficient to heat the specimen to a temperature $T_0 = 0.6 - 0.8\ T_{\text{melt}}$. The time required for complete annealing of bending-induced defects increases rapidly with decreasing temperature. It is natural to assume that W_g is proportional to the density of induced defects. For this reason, the study of the dependence of W_g on the annealing time at different temperatures permits judging the temperature dependence of the mobility of newly induced dislocations.

In this paper we present the results of measurements of the time dependence of the additional thermal resistance $W_g(t)$ at different annealing temperatures. The experiments were performed on specimens consisting of pure ^{4}He, grown at a constant pressure of 31 atm in a thin-walled metallic capillary with inner diameter 1.8 mm and length 15 cm, bent on a template with radius $\cong 5$ cm. The construction of the apparatus is described in detail in Ref. 1.

The procedure for performing the measurements consisted of the following. First, we measured the thermal conductivity of the starting specimen κ_u over a wide temperature range; then we deformed the specimens (bending and unbending at $T \leqslant 0.40$ K) and measured the quantity W_g at $T = 0.403$ K as a function of the annealing time of the specimen at fixed temperature T_{ann}. We performed the annealing at several temperatures, $T_{\text{ann}} = 0.45$ K, $T_{\text{ann}} = 0.475$ K, $T_{\text{ann}} = 0.50$ K, $T_{\text{ann}} = 0.55$ K, $T_{\text{ann}} = 0.62$ K. In order to ensure identical starting density of induced defects, after a series of measurements at fixed T_{ann}, we annealed the specimen at 1.5 K and again deformed it at $T \leqslant 0.40$ K.

The curves of the relative thermal resistance $W_g(t)/W_g(0)$ for fixed T_{ann} are

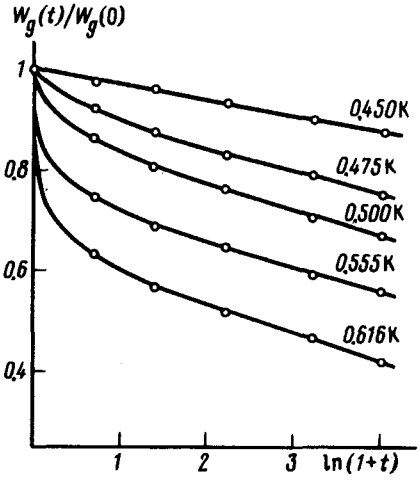

FIG. 1. The relative thermal resistance as a function of holding time at different annealing temperatures.

shown in Fig. 1 as a function of time (the holding time t is measured in minutes). The quantity $W_g(0) = \kappa_g^{-1}(0) - \kappa_u^{-1}$, where $\kappa_g(0)$ is the thermal conductivity at $T = 0.403$ K, measured immediately after deformation before annealing. It turned out that the experimental results are well described by a function of the form

$$W_g(t)/W_g(0) = 1 - A \ln\left(1 + \frac{t}{\tau}\right)$$

used in describing recovery phenomena in deformed crystals,[2] where A is a constant, and τ is the relaxation time which depends on the temperature T_{ann}. It is evident from

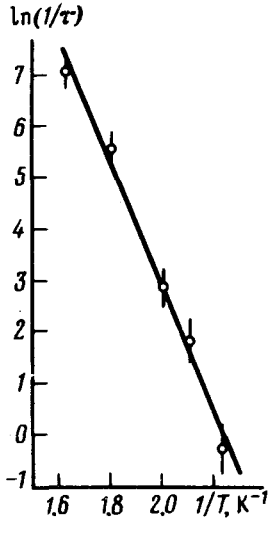

FIG. 2. ln $(1/\tau)$ as a function of $1/T$.

Fig. 1 that as the temperature increases the rate of annealing increases rapidly. Assuming that the diffusion of dislocations is thermally activated, i.e., $\tau \sim \exp(\Delta / T)$, it is possible to estimate the magnitude of the activation energy Δ from the known $\tau(T)$.

Figure 2 shows $\ln(1/\tau)$ as a function of $1/T$. It is evident that the experimental points lie satisfactorily along a straight line. The activation energy Δ, calculated from the slope of the straight line, is 11.6 ± 1.5 K. The average value of the activation energy calculated from measurements on four specimens was 12 ± 2 K.

The values obtained for the activation energy of diffusion of dislocations in hcp ^{4}He coincide with the activation energy of vacancies and characteristic activation energies of impurity ^{3}He atoms and charges in the region of thermally activated motion (see, for example, Ref. 3).

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[1]A. A. Levchenko and L. P. Mezhov-Deglin, Zh. Eksp. Teor. Fiz. **82**, 278 (1982) [Sov. Phys. JETP **55**, 166 (1982)].
[2]A. Kh. Cottrel, Dislokatsii i plasticheskoe techenie v kristallakh (Dislocations and Plastic Flow in Crystals), Metallurgizdat, Moscow, 1958.
[3]V. B. Shikin, Usp. Fiz. Nauk **121**, 457 (1977) [Sov. Phys. Usp. **20**, 226 (1977)].

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