Increase of the critical temperature due to low-temperature twinning of superconducting niobium

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The critical temperature T_c of niobium is observed to increase appreciably as a result of low-temperature twinning. The superconductivity near the twins is altered by dislocation plastic flow and warming of the strained samples. Data on the magnetic-field dependence of T_c are presented.

It was reported in Refs. 1–3 that twinning increases T_c in Sn, In, and Tl. Near an individual twinning boundary in Sn, T_c was observed to increase by 0.04 K.[1] In the neighborhood of several twins, T_c increased by 0.08 K.[2] A larger increase in T_c was obtained by pressing the microparticles together and by electric-spark treatment of bulk samples of Sn. Khlyustikov *et al.*,[3] attributed this increase to the appearance of a high density of twins and a weakening of the proximity effect. The results in Refs. 1–3 indicate that the superconducting properties are altered near twinning boundaries. It is of interest to study this phenomeon in different materials and under different twinning conditions.

An appreciable increase in the critical fields and in the trapped magnetic-flux density with low-temperature twinning was previously observed in Nb.[4] It was reported in Ref. 5 that H_{c2} increases in Nb bicrystals with a boundary close to the twinning boundary. In the present letter we study the effect of strain-induced twins on superconducting transitions in Nb near T_c.

Single-crystal Nb samples ($4\times4\times12$ mm), whose axis is oriented in nearly the same direction as the type $\langle 110\rangle$ axis, were strained by compression at $T\lesssim 8$ K at a rate of 200 μm/min. The deformation, which occurred in a jump-like manner, was determined by the twinning processes.[4] Each jump in the load resulted in the appearance of a group of intersecting twins with a typical interlayer width of $\sim$1–10 μm and a distance of $\sim$10–100 μm between twins. Superconducting transitions were detected from the penetration of magnetic flux into the sample. A current (37 Hz), which produced an alternating magnetic field with an amplitude of $\lesssim 1$ Oe, was passed through the transfer coil wound along the entire length of the sample. The amplified and detected signal from the pickup coil and the readings of a semiconducting thermometer attached to the samples being strained were recorded on an *x-y* plotter. The measurements were performed after the straining apparatus was switched off, as the samples were being warmed at a rate of $\lesssim 10^{-2}$ K/s. After the superconducting transition was recorded, the sample under study was cooled and again strained until the next set of measurements.

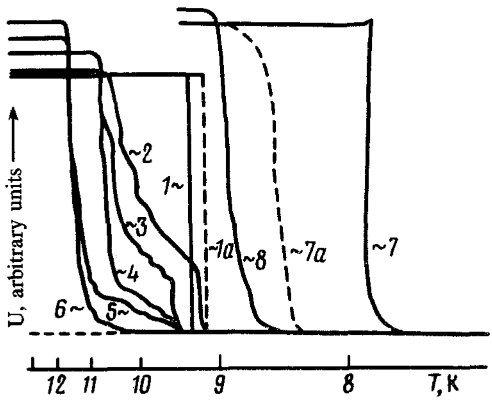

FIG. 1. Examples of superconducting transitions near T_c detected from signals U on the pickup coil on one of the samples. 1) Starting sample without load; 1a) with uniaxial compression under a load of 29 kg/mm^2; 2–6) after the 1-st, 2-nd, 7-th, 11-th, and 14-th jumps in the load (twinning events); 7) no load, after warming the deformed sample to 300 K over a period of two days; 7a) under a load of 85 kg/mm^2, 8) first jump in the load due to deformation after warming.

Figure 1 shows some of the signals recorded by the pickup coil of one of these samples. In the presence of low-temperature twinning of Nb, we see an appreciable shift in the superconducting transition toward higher critical temperatures T_c. The increase in T_{cm}, which corresponds to the center of the transitions, is as high as 2.2 K for a given sample. The shape of the recorded curves, especially during the initial stages of deformation, depends on the distribution of the twins along the length of the samples being deformed. This circumstance affects the curve of T_{cm} versus the degree of deformation ϵ. As ϵ is increased, T_{cm} shifts toward the upper transition temperatures. Some increase in T_c that accompanies the deformation can be due to the decrease in the distance between the twinning intercalculations (see, for example, Refs. 2 and 3). The results of studies of the dependences of T_{cm} and the width of the transition, ΔT, on ϵ for three samples are shown in Fig. 2. The observed increase in T_c

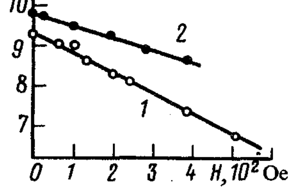

FIG. 2. The temperature T_{cm} (a), corresponding to the center of the superconducting transition, and the width of the transition ΔT (b) as a function of the degree of deformation ϵ due to twinning. The different symbols correspond to different samples. The broken lines indicate the transition width and the minimum and maximum transition temperatures.

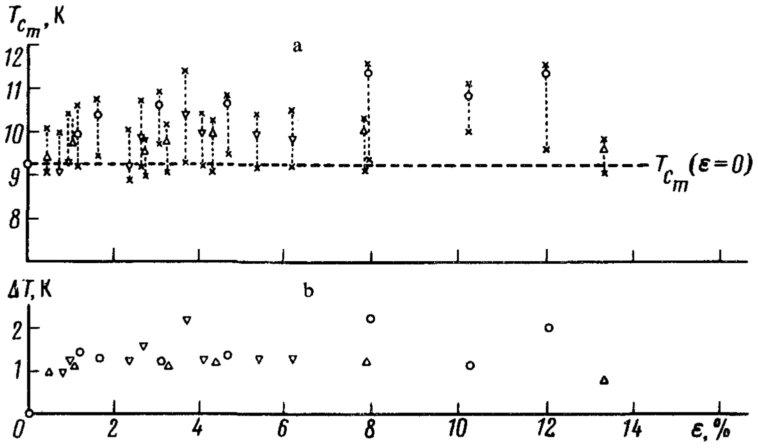

FIG. 3. Dependence of T_{cm} on the external magnetic field H. 1) Starting sample; 2) after deformation by twinning, $\epsilon \gtrsim 6\%$.

accompanied by twinning is in qualitative agreement with the results of Ref. 6, in which electrical-resistance measurements were used to detect an increase in T_c as a result of twisting-induced deformation of vanadium and niobium samples at low temperature.

When different samples were deformed, the degree to which T_c increased as a result of twinning was found to be different (see Fig. 2a, for example). Twins tend to have a weaker effect on T_c for samples with a more pronounced dislocation plastic flow that accompanies twinning (up to 30% of the total deformation). We carried out experiments in which the samples were warmed to 30–50 K and deformed plastically after twinning. In this case, T_{cm} dropped below T_c of the starting samples. The influence of the twins decreased when the samples were deformed plastically at higher temperatures before the twinning at low temperature occurred. The superconducting transitions were displaced toward lower values of T_c when the deformed samples were warmed. Even rapid warming to 300 K led to an appreciable drop in T_c. After resting the deformed samples at 300 K for two days, for example, T_c dropped to a much lower level than T_c of the undeformed samples (see Fig. 1). The effect produced by warming decreased when its duration and temperature were reduced. These results, taken collectively (see also Ref. 6), indicate that the processes leading to relaxation of the structure and the stress near twins can change substantially the superconducting properties of twins.

Studies have shown that uniaxial compression has an effect on T_c (Fig. 1), depending on the structural state of the loaded samples. The accuracy of these data will be improved in future experiments.

We studied the effect of an external magnetic field on superconducting transitions of the starting and deformed samples near T_c. The results of the corresponding measurements for one of the samples in a magnetic field for oriented parallel to the deformation axis are shown in Fig. 3. For the undeformed samples, the results of the measurements agree well with the data in the literature[7] for dH_c/dT of Nb. The slope of the plot of T_c versus H is observed to decrease due to twinning, which corresponds to an increase in dH_c/dT near T_c. For example, from the data in Fig. 3 it may be concluded that dH_c/dT increases with twinning by a factor of approximately 1.7. This could be associated with the corresponding increase in H_c near twins, in agreement with the results of Ref. 4.

Our studies show that the critical parameters of superconducting Nb increase appreciably with low-temperature twinning and that this increase is attained when the average density of the deformation twins in the samples is small (less than 5% of their volume). The observed change in the superconducting properties can be attributed to a special, localized, superconducting state in the vicinity of twins and, in particular, to twinning boundaries. A change in the properties of samples containing deformation twins produced as a result of low-temperature annealing and dislocation plastic flow shows that the stress relaxation and the structure of the twins and their boundaries are dominant factors in the existence of this peculiar superconducting state.

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