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DISLOCATION SWEEPING OF DEFECTS IN NEUTRON- AND ELECTRON-IRRADIATED NIOBIUM*

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The glide of dislocations in a [441]-oriented Nb single crystal irradiated at 325 K with 5.5×10^{21} neutrons/m^2 (E > 0.1 MeV) is shown in Fig. 1 for increasing time of tensile elongation (2×10^{-4} mm/s) in the High Voltage Electron Microscope at Argonne National Laboratory. The dimensions of the tensile specimen in the guage length were approximately 2 mm x 0.5 mm x 0.0001 mm. An electron energy of 900 keV was used during the simultaneous deformation and TEM observation.

A high density of aligned loops formed close to the intersection of the gliding dislocation with the specimen surfaces during the initial 45 s of deformation and TEM observation; the aligned loops are seen most clearly in Figs. 1e and 1g. These loops were identified to be interstitial in nature from their black-white contrast (Fig. 1g). The formation of these loops is attributed to dislocation "sweeping" of interstitial point defects produced by electron displacement. A similar alignment of loops was observed to form in specimens that were not previously irradiated with neutrons. In traversing the field of view shown in Fig. 1, dislocation A removed one defect cluster at the location indicated by the vertical arrow in Figs. 1b through 1g (the cluster is present in Figs. 1b through 1e and absent in Fig. 1f). Dislocation B traversed the field of view in < 0.01 s; the motion consisted of an avalanche of dislocations gliding on closely spaced, parallel planes. The "bowing-out" interaction of dislocation C with defect clusters can be clearly observed in Fig. 1d. However, the glide of dislocation C within the field of view did not result in cluster removal.

The average diameter and number density of defect clusters in the as-irradiated specimen were ~22 nm and $\sim 10^{21}/m^3$, respectively. During the ~5-minute period of TEM observaton, the average diameter of the loops increased to ~40 nm (e.g., compare the encircled clusters in Figs. 1b and 1f). The number density of defect clusters did not appear to increase during exposure of the specimen to the 900-keV electron beam. The threshold energy for atomic displacement in Nb by an electron is 24 eV.[1] Thus Frenkel pairs are created in Nb for electron energies $\gtrsim$ 650 keV.[1] Single vacancies do not undergo long-range migration in Nb at temperatures much below 620 K.[2] Therefore, the growth of the loops in Fig. 1 is attributed to the diffusion of self-interstitial atoms produced by electron displacement and their entrapment at interstitial defect clusters produced by the neutron irradiation. We did not observe shrinkage of the clusters in the neutron-irradiated specimen, which would

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be expected if the clusters consisted of vacancy defects.

In the case of Nb specimens irradiated with a relatively low fluence of neutrons ($\sim10^{22}$ neutrons/m^2) resulting in small defect clusters (~20 nm diameter), the primary mechanism for removal of the clusters by the gliding dislocations was the "sweeping" of the clusters along with the gliding dislocations. In contrast to the point defects (Fig. 1g), there appeared to be no transport of the defect clusters (neutron-produced) to the upper or lower pecimen surfaces.

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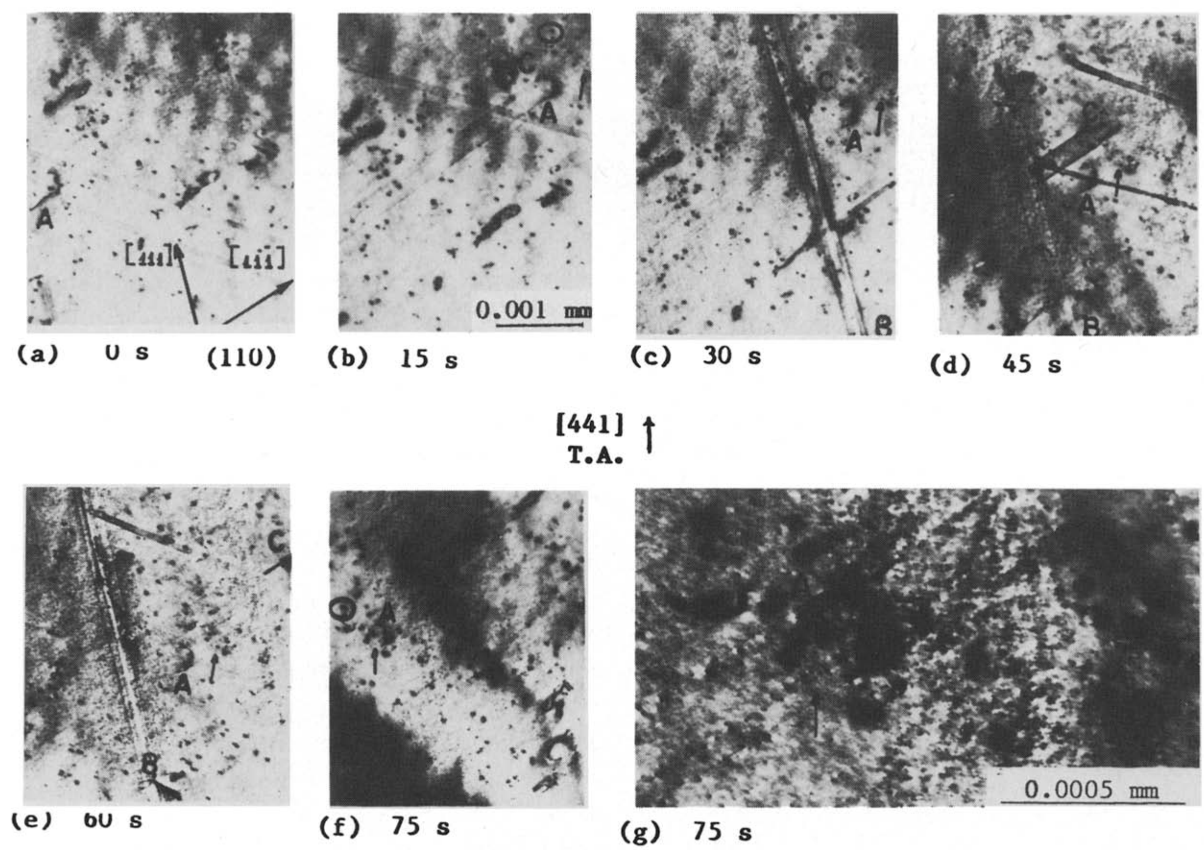

Fig. 1. In-situ deformation (2×10^{-4} mm/s) of a Nb single crystal with [441] tensile axis during 900-keV HVEM observation.