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A FIELD-EMISSION ION MICROSCOPE INVESTIGATION OF TUNGSTEN IRRADIATED WITH 240 MeV ELECTRONS

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Radiation damage in crystals irradiated with high-energy electrons was studied with a field-emission ion microscope. It was found that microcavities of 10 Å diameter were produced by irradiation at room temperature. The concentration of interstitial atoms in the samples which received an integral radiation dose of 10^{16} electrons/cm^2 was $\sim 5 \times 10^{17}$ cm^{-3}.

RADIATION damage in crystals irradiated with α particles,[1] neutrons,[2] and accelerated atoms[3] has been investigated using field-emission ion microscopy, by which a resolution of the order of a lattice parameter can be achieved. There have been several investigations, using low-resolution methods,[4,5] of the damage in tungsten irradiated with electrons of energies up to 5 MeV. It was therefore of interest to study the damage produced by bombardment with high-energy electrons using a high-resolution method. Tungsten wires, 0.05 mm in diameter, were irradiated with a beam of electrons of 240 MeV extracted from the linear accelerator described in[6].

During irradiation, the temperature of the tungsten did not rise above 40°C. The integral radiation dose ranged from 5×10^{15} to 2×10^{16} electrons/cm^2 in different experiments and the intensity ranged from 0.3 to 1.3×10^{13} electrons $\cdot$ cm$^{-2} \cdot$ sec^{-1}. After irradiation, the wires were stored at room temperature for 7 to 15 days. Needle-like samples were prepared from irradiated and unirradiated wires, and these samples were investigated with a field-emission ion microscope. (The method used in the preparation and investigation of these samples has been described in[7].)

Two types of defect were observed in the irradiated samples: microcavities A and "interstitial atoms" B.

The figure (case a) shows one of five frames recorded during successive stages of the stripping of (211) atomic layers by an electric field from the surface of an irradiated tungsten point. This series of frames showed that the depth of the microcavities was six interplanar [211] distances, i.e., about 10Å. The dimensions of the microcavities in the plane of the frame were also 10 Å. Thus, the volume of the microcavities A were equivalent to about 100 atoms.

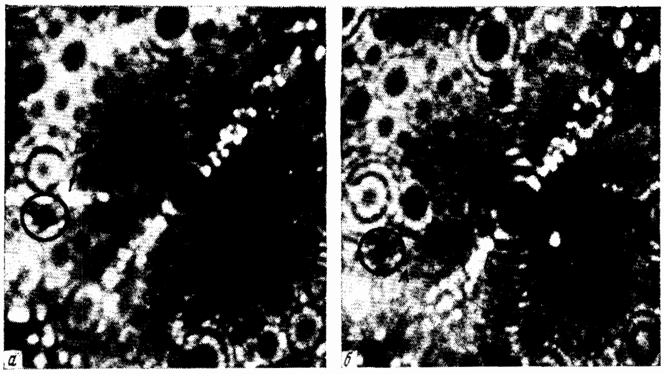

Image of a tungsten sample obtained using helium ions: a – after electron irradiation; b – after evaporation of five (211) atomic layers. A microcavity A and the interstitial atoms B can be seen on the left near the (211) face.

The interstitial atoms B can be seen in the figure as bright spots against a general background. In case a, they are located at distances of 30–40 Å from a microcavity, while in case b they are at distances of ≈150 Å. The presence of other interstitial atoms could not be established definitely from these frames because some bright reflections at the peripheries of the frames could not be attributed with certainty to type B defects.

These observations suggest that A is a defect similar to a displacement spike. The high concentration of interstitial atoms near a microcavity (at a distance of up to 200 Å) can be explained by the fact that interstital atoms migrate away from a spike in the form of dynamic crowdions and they settle preferentially along the closest packing direction [111] (cf. figure). A calculation, based on the treatment of Seitz and Koehler[8] and on the assumption that the electron energy is considerably greater than the rest mass, shows that the average energy transferred to an atom is 476 eV and that the total cross section for the displacement of tungsten atoms is $\sigma = 89$ b; the average value of the total number of displacements per one primary knocked out atom is $\bar{\nu} = 5$. The threshold displacement energy is assumed to be $E_d = 50$ eV.[3] The observed concentration of interstitial atoms ($N = 5 \times 10^{17}$ cm^{-3}) is in satisfactory agreement with the calculated values of σ and $\bar{\nu}$.

The value $\nu \geq 10^2$ (representing 10^2 atoms knocked out from an A microcavity) corresponds to a primary atom energy of 5×10^3 eV. For such collisions, $\sigma = 0.9$ b, which is also close to the frequency of appearance of type A defects in the experiments described here. Photographic and visual observations indicated that there were many more defects resembling small pores but because of the difficulties in identification of these defects, we were unable to calculate their number or determine their volume. We found practically no pores of volume larger than type A defects, which was evidently due to the limited dimensions of each of the samples and the low probability of the transfer, in a single collision, of an energy considerably higher than 10^4 eV.

A series of field-emission ion photomicrographs showed also the presence of single vacancies but the determination of their concentration was difficult because vacancies could be identified with certainty only in those cases when they were near the points of emergence of poles of fully resolved faces. The change in the number of vacancies in a material subjected to a radiation dose of 10^{16} cm^{-2} was of the order of magnitude of the concentration of vacancies in an unirradiated material.

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