EVOLUTION OF THE ELASTOPLASTIC BENDING OF WHISKER CRYSTALS OF NaCl DUE TO NANOSECOND EXPOSURE TO A HIGH-DENSITY ELECTRON BEAM

D. I. Vaisburd and A. A. Petrova

High-speed photography is used to study the evolution of the plastic bending of whisker crystals (WCs) of NaCl caused by nanosecond exposure to a pulsed high-density electron beam. The total time of irreversible bending of a WC, reckoned from the radiation pulse to attainment of the quasisteady state, is equal to 1.5–2.5 msec and nearly coincides with the characteristic relaxation time of the quasistatic thermoelastic mechanical stresses that develop due to the nonuniform distribution of the dose and the corresponding temperature through the thickness of the specimen. These stresses relax when the temperature distribution is equalized by heat conduction. There is an induction period of 0.3–0.6 msec between the radiation pulse and the beginning of intensive bending, this period being much longer than the period of the thermoelastic bending vibrations. One interesting result of the study is that the bending is nonmonotonic.

Introduction

The resistance of whisker crystals (WCs) of NaCl to brittle fracture and plastic deformation induced by exposure to a pulsed high-density electron beam of nanosecond duration was first studied in [1]. The following are the main findings from the large volume of new data obtained in [1].

1. A single powerful pulse of radiation from an electron beam causes a substantial portion of WC specimens to undergo severe plastic deformation: the specimens are irreversibly bent, and the bending is always toward the incoming beam. This would seem to suggest that the pressure exerted by the beam bends the specimen. However, calculations show that beam pressure is negligible compared to the thermoelastic stresses that are created. If the bent specimen is turned so that its convex side faces the beam and is again exposed to a pulse of radiation, it straightens and then bends in the opposite direction.

2. There is intense competition between brittle cleavage and plastic bending. This competition is clearly seen by comparing three groups of specimens. The first group was not subjected to preliminary deformation and did not undergo noticeable bending as a result of irradiation. It had the lowest value of the mean threshold of brittle fracture for the NaCl whisker crystals: $\Phi_{\text{int}} = 21 \mu\text{C/cm}^2 \times \text{pulse}$. However, this value was still an order of magnitude greater than the mean threshold for the normal NaCl crystals. The latter were not predeformed but were severely bent by the radiation. The mean threshold for brittle fracture in this case was twice as great as for the specimens of the first group: $\Phi_{\text{int}} = 40 \mu\text{C/cm}^2$. Finally, the third group was subjected to severe deformation and was severely bent by the radiation. It had the highest mean threshold for brittle fracture: $\Phi_{\text{int}} > 40 \mu\text{C/cm}^2$. Some of the specimens could not be fractured even at the maximum beam current densities that could be achieved on the accelerator.

Thus, it was found that whisker crystals undergo severe plastic bending by a nanosecond pulse of radiation from a dense beam of electrons. One other intensive process associated with relaxation of the mechanical stresses created by the radiation was also observed in pure form — severe plastic deformation connected with the creation and slip of dislocations. This process quite rapidly reduces the thermoelastic stresses that develop in the specimen during irradiation and lowers the resulting stress to a value below the threshold for the movement of cracks, thus preventing brittle fracture [1].

However, the dynamics of the bending phenomenon over time were not studied. Neither the time over which plastic bending occurred nor its average rate were known.

The goal of this investigation is to develop an experimental method and study the dynamics of the plastic bending of WCs over time.

1. Experimental Method

This study is a continuation of [1, 2]. We are examining the dynamics of the elastoplastic bending of NaCl whisker crystals in real time after exposure to a nanosecond pulse of radiation from a dense electron beam. The dynamics of the bending of the crystals were studied by using a high-speed optical camera.

Figure 1 presents a block diagram of the experimental unit: 1) small electronic accelerator with a maximum beam current density of 4 kA/cm², 2) experimental vacuum chamber, 3) high-speed photographic unit VFU-1, 4) synchronization circuit, 5) vacuum system, 6) specimen (whisker crystal with a crystal holder), 7) flash lamp. The NaCl whisker crystal was placed in the experimental vacuum chamber on a special needle holder and was secured to the holder at one end (cantilever attachment). The flash lamp was installed in the chamber to illuminate the specimen during the filming. An airtight seal was created between the chamber and the electron accelerator. The image of the specimen was transmitted by the optical channel to the input of high-speed camera VFU-1, which produced a frame-by-frame film record of the specimen. The synchronization circuit ordered the times of operation of the accelerator, flash lamp, and the VFU camera. The specimen, illuminated by the flash lamp, was exposed to a dense electron beam for several nanoseconds. After being irradiated, it began to slowly deform, and the VFU camera filmed the deformation process frame by frame. The results obtained from filming with different experimental parameters served as the primary source of information on the plastic bending of the WCs by nanosecond pulses of radiation from the dense electron beam.

2. Experimental Results

A typical time sequence of the film frames was presented in [2]. This sequence reflects the dynamics of the plastic bending of NaCl whisker crystals after exposure to a pulse of radiation from an electron beam with an integral dose of 39 μ/cm². Measurements were made on predeformed specimens, which have a higher concentration of dislocations and dislocation sources than undeformed WCs [2]. The following results were obtained from an analysis of sequences of frames recording the geometry of the whisker crystals at different moments of time after irradiation.

1. The time dependence of the deflection of the free (unsecured) end of the WC from the initial position \( h(t) \) during bending is shown in Fig. 2. It has both a large-scale and a small-scale (fine) structure.