F-Center Distribution and Electron Channeling in NaCl

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A rotating cylindrical crystal of NaCl was bombarded with 25-keV electrons. The optical density due to coloration was measured as a function of the angle of rotation. The optical density showed eight maxima corresponding to different angular positions of the crystal. The electron range was found to be longer along the ⟨100⟩ axes than along the ⟨110⟩ axes, and the magnitude of coloration had a lower value along the former axes.

INTRODUCTION

THE production of color centers by electron bombardment in crystals of alkali halides is well known. Among such centers, the F center is the most prominent and has attracted wide attention.[1] The energy[2,3] necessary to form an F center is derived from the electrons incident on the crystal. Thus, the incident electrons are expected to slow down in the crystalline medium. The energy loss per unit length (dE/dx), generally known as the stopping power of the medium, exhibits crystal-orientation dependence.[4] Such anisotropies are explained in terms of the channeling phenomenon, which has been studied in many cases.[5–9] But no similar observations have yet been reported for the energy loss of the incident electrons in NaCl-type crystals. It has been shown by Luntz and Bartram[10] that the stopping power should be a minimum along the ⟨100⟩ axial channels of NaI for heavy particles. Since NaI and NaCl are identical from the structural point of view, a study of the F-center distribution may reveal the crystal-orientation dependence of the stopping power.

EXPERIMENTS AND RESULTS

A cleaved rectangular block of NaCl single crystal (Harshaw) was turned down to a cylinder by a wet-cutting process, keeping the base rectangular for crystallographic reference. The cylindrical portion of the crystal was polished for the necessary optical measurements. The diameter of the crystal was 0.71 cm. The crystal was placed in the electron accelerator tube and rotated about its axis by an electric motor from outside. A 25-keV electron beam bombarded the rotating specimen at room temperature producing F centers uniformly over the entire cylindrical surface of the crystal. The beam current was 1.7 μA/cm^2, and the bombardment was continued for 10 min. The bombarded specimen was illuminated with a fine pencil (slit width 0.25 mm) of F light (465 mμ) perpendicular to a particular face of the crystal; and the intensity of the transmitted F light was measured by an RCA IP22 photomultiplier tube with conventional electronic circuits. The F absorption of the uncolored crystal was also tested to estimate the surface defects, if any. The experimental arrangement is shown in Fig. 1. The optical density due to coloration (saturated) was measured as a function of the angle of rotation, as shown in Fig. 2. The optical density was found to reach a saturation limit after 7.4 and 8.8 min of electron bombardment along the ⟨100⟩ and ⟨110⟩ directions, respectively. The average values of the optical densities along the face planes ({100}) and the diagonal planes ({110}) were 0.2215 and 0.2345, respectively.

The depth of coloration was measured by observing the change of the optical density on successive removal of surface layers of the crystal. The values determined were 18 μ along the ⟨100⟩ axes and 12 μ along the ⟨110⟩ axes. The number of F centers produced was calculated from Smakula's equation, which yielded the values 1.24 and 1.57×10^{15}/cm^2 along the ⟨100⟩ and ⟨110⟩ directions, respectively.

DISCUSSION

It may be seen in Fig. 2 that the optical density shows several maxima with respect to the angular position of the crystal. The angles correspond fairly well with

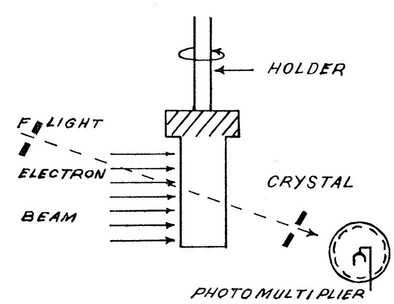

FIG. 1. Experimental arrangement for the electron bombardment and the optical-density measurement at room temperature.

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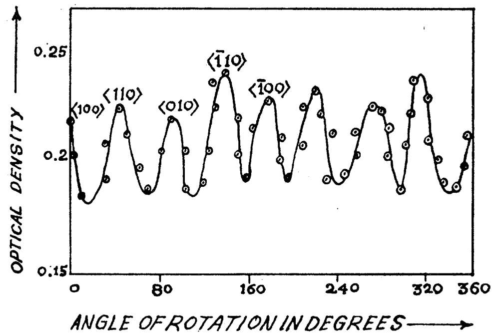

FIG. 2. Optical density plotted as a function of the angle of rotation. The angle was measured with respect to a ⟨100⟩ direction.

the acceptance angles for channeling of 25-keV electrons in NaCl crystal. The optical densities along ⟨100⟩ and along ⟨110⟩ are found to be unequal; there is also observed difference in the depth of coloration. The electrons have penetrated 18 μ deep along the ⟨100⟩ axes, forming F centers along the path, whereas along the ⟨110⟩ axes the penetration is only 12 μ. The average electron range has also been estimated from Bethe's equation, $dE/dx=(4\pi e^4N/mv^2)\ Z\log(mv^2/I)$, where e is electronic charge, N is the number of atoms per cc of the material, Z is the nuclear charge of the material, I is the excitation potential of NaCl, and m and v are the mass and velocity of the incident particle. The result is 3.7 mg/cm^2 or 15 μ for 25-keV electrons in NaCl. If the depth of coloration is considered as the electron range in this case, then the specific energy loss $-(1/\rho)dE/dx$ is 6.3 MeV cm^2/gm along a ⟨100⟩ axis, and 9 MeV cm^2/g along a ⟨110⟩ axis. For an energy loss of 1 eV cm^2/g (at 25 keV), the number of F centers produced would be 1 and 1.42×10^{11}/cc along the ⟨100⟩ and ⟨110⟩ directions respectively. Thus, the efficiency of F-center production is lower along the ⟨100⟩ direction, but the range is also much longer.

In Fig. 2, the low-level base coloration was found to have a small depth of penetration in the crystal. Practically, after the removal of a 1-μ-thick surface layer, the optical density was unmeasurable. It may also be observed that the optical density peaks are somewhat broad for channeling effects; such broadening may be due to the angular width (4°) of the F light incident on the surface of the crystal.

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