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tron microscopy of the silicon samples and are indebted to R. R. Papania and H. D. Larson for their able technical assistance.

[1]G. R. Booker and R. Stickler, *J. Appl. Phys.* **33,** 3281 (1962).
[2]G. R. Booker and B. A. Unvala, *Phil. Mag.* **11,** 11 (1965).
[3]S. Mendelson, in *Single Crystal Films* (M. H. Francombe and H. Sato, Eds.), p. 251, Pergamon Press, Oxford, 1963.
[4]H. Widmer, *Appl. Phys. Letters* **5,** 108 (1964).
[5]R. N. Thomas and M. H. Francombe, *Appl. Phys. Letters* **11,** 108 (1967).
[6]T. N. Rhodin, in *The Use of Thin Films in Physical Investigations* (J. C. Anderson, Ed.), p. 187, Academic Press, London, 1966.

ROWS OF DISLOCATION LOOPS IN ALUMINIUM IRRADIATED BY ALUMINIUM IONS

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Single-crystal aluminium specimens, irradiated with 50-keV aluminium ions, contain dislocation loops that are arranged in regular rows along ⟨110⟩ directions.

The two most common techniques used to produce point defects in metals are quenching and irradiation with energetic particles. The former produces essentially only vacancies while the latter normally gives equal numbers of vacancies and interstitials. If, however, the irradiating particles are ions of the same elements as the target material these atoms will become interstitials if they come to rest in the target. This type of irradiation, therefore, produces more interstitials than vacancies, although the relative difference will in practice be negligible everywhere except in the region where the majority of the ions come to rest. This Letter reports experiments in which dislocation loops were produced in pure aluminium by irradiation with aluminium ions.

Single crystal aluminium specimens, thin enough to be examined by transmission electron microscopy, were irradiated with 50 keV aluminium ions. Crystals of nominal purity 99.9999%, and with surface normals oriented within 2° of either a ⟨110⟩ or a ⟨111⟩ direction were used. During each irradiation the ion beam was at right angles to the plane of the specimen to better than 1°. In all cases the specimen was examined in the electron microscope both before and after irradiation. Both types of crystal were irradiated at room temperature with fluxes in the range 1×10^{11}–1×10^{14} cm^{-2} sec^{-1} and doses from 6×10^{12} to 6×10^{14} cm^{-2}. For specimens of either orientation the irradiation is found to produce rows of dislocation loops parallel to ⟨110⟩ directions. At low magnification (see Fig. 1) these rows are quite easily distinguished. Higher magnifications (see Fig. 2) allow the individual loops to be resolved. Neither the spacing between the rows nor the regular spacing of individual loops within a row is dependent upon the dose, but the radii of the loops increase with dose. Within about 5000 Å of the edge the loop distribution differed from that observed in the rest of the specimen. The spacing between the rows fell to about half its normal value, and the overall loop density was approximately doubled. For the lowest flux, and with a dose of 6×10^{13} cm^{-2} the ⟨111⟩ specimens were found to contain isolated loops and no rows. Specimens of the ⟨111⟩ orientation were also irradiated at a nominal temperature of 78°K with fluxes in the range 1×10^{12}–1×10^{14}

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cm^{-2} sec^{-1} at a standard dose of 6×10^{14} cm^{-2}. The highest flux produced the rows of loops. For fluxes in the range $1 \times 10^{12}-1 \times 10^{13}$ cm^{-2}, however, no rows of loops were observed. This treatment was found to produce the complex tangles of dislocations which have been the characteristic observation of the related type of experiment in which a target of one element was irradiated with ions of a different element.[1] The actual temperature of the specimen during irradiation was not known. Heating effects would increase with irradiation flux, and this might explain why the highest flux produced a defect distribution which was more characteristic of the room temperature irradiations. To check that orientation is an important factor, polycrystalline specimens were irradiated under similar conditions. Individual grains, in which low index directions were not close to the direction of the ion beam, were examined and found to contain complex tangles of dislocations[1] and occasional isolated loops. No rows of loops were observed in these grains.

The appearance of rows of loops under certain conditions of ion irradiation has not been reported previously. The experiments described here involved two novel features in that the targets were both single crystals and of the same element as the irradiating ions. The observations indicate that specimen orientation is an important factor. Experiments are now in progress in which the target and the irradiating ions are of different elements to see whether the rows are still produced under such conditions. The fact that the rows of loops always lie along ⟨110⟩ directions is rather suggestive. Both focusing[2] and channeling[3] processes are known to be most favorable along these directions. The length of the rows is usually of the order of 5000 Å, however, whereas focusing is generally believed to occur over distances an order of magnitude smaller than this.[4] If each row is associated with a single directional event, therefore, focusing can be ruled out. Channeling on the other hand is thought to occur over distances as large as the lengths of the rows of loops. From determinations of the range distributions of 40 keV Na^{24} ions in aluminium,[5] one can make the rough

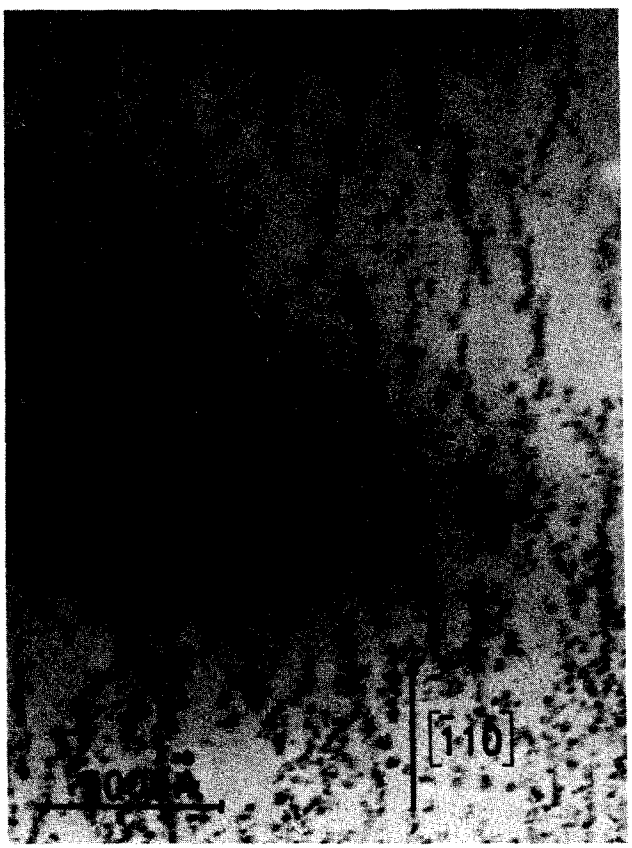

Fig. 1. An area of a ⟨111⟩ specimen irradiated at a flux of 1×10^{12} ions cm^{-2} sec^{-1} and a dose of 6×10^{14} ions cm^{-2}. The lower edge of the picture lies close to the edge of the specimen.

Fig. 2. Another area of the specimen shown in Fig. 1. Individual loops are resolved. This area is close to the edge of the specimen and the rows are more closely spaced.

estimate that the maximum range of aluminium ions in the ⟨110⟩ direction of an aluminium target is about 11000 Å. Approximately 5% of the ions would have ranges in excess of 5000 Å. The constant spacing between the rows, the constant spacing of individual loops within a row, and the constancy of the length of the rows, all for a range of different doses and fluxes, suggests that the rows are nucleated at an early stage during the irradiation. This too indicates a connection with channeling. Channeling of the irradiating ions will be most efficient when the crystal is still rather perfect and relatively free of irradiation damage.

The exact mechanism of the formation of the rows is not yet understood. Experiments aimed at determining whether the loops are of the vacancy or interstitial type are now in progress, and in addition irradiations are being carried out at 4°K in an effort to obtain a more clearly defined temperature dependence of the various effects.

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[1] P. B. Bowden and D. G. Brandon, *Phil. Mag.* **8,** 935 (1963).
[2] R. H. Silsbee, *J. Appl. Phys.* **28,** 1246 (1957).
[3] Chr. Lehmann and G. Leibfried, *J. Appl. Phys.* **34,** 2821 (1963).
[4] R. S. Nelson and M. W. Thompson, *Phil. Mag.* **7,** 1425 (1962).
[5] G. R. Piercy, M. McCargo, F. Brown and J. A. Davies, *Can. J. Phys.* **42,** 1176 (1964).

THE DIRECT ABSORPTION EDGE IN COVALENT SOLIDS*

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Comparative measurements of the absorption edge of *p*-type GaAs and compensated GaAs over a wide temperature range demonstrate that the shape of the edge in such materials is not dependent on phonon interactions, and is attributable to the state of charge of impurities in the material.

It is well known that fundamental optical absorption edges formed by direct band-to-band transitions should be characterized by the form $K(\hbar\omega - E_G)^{1/2}$ at photon energies $\hbar\omega$ close to the energy gap E_G. The constant K contains the matrix element, joint densities of states in the valence and conduction bands, etc. In practice, however, this form is almost never observed. Instead, the usual absorption edge does not have an abrupt threshold at E_G but a "tail" whose dependence on $\hbar\omega$ is very nearly exponential and which extends to energies below E_G. There have been numerous attempts to explain this phenomenon, most commonly by invoking phonon interactions.[1] The present Letter presents experimental evidence of a very direct nature showing that in predominantly covalent materials these exponential absorption edges are not related to phonons but rather to the state of charge of imperfections in the material.

The essential feature of the present experiments is the comparison of the absorption edge of ordinary, impure GaAs with the edge of similar, but compensated GaAs over a wide temperature range. The experimental considerations of consequence here were the very low stray light in the optical system and the thermal exchange gas surrounding the samples to establish stable and readily measurable sample temperatures.

The principle of these experiments is straightforward. If an ordinary, impure crystal is cooled sufficiently to freeze-out the free carriers, they will be recaptured by the fixed impurity centers from which they came and neutralize these centers. Such neutralization should reduce the absorption edge tails if the electric fields of the charged centers are responsible for the tails as has been proposed for covalent solids.[2] In Fig. 1 it is seen that this is indeed observed: The slope of the absorption edge increases monotonically as the temperature diminishes. (The shift in *position* represents the temperature dependence of the energy gap and is

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