Anisotropic-Defect Production in Compound Semiconductors by Electron Irradiation

In a recent Letter, Pons and Bourgoin[1] concluded that the main defects observed by deep-level transient spectroscopy (DLTS) in electron-irradiated GaAs ($E1$, $E2$, and $E3$)[2] are caused by As-atom displacements. This is in direct conflict with the interpretation of Lang, Logan, and Kimerling,[3] who had previously concluded that the displacements were of Ga atoms. Both used arguments based upon the anisotropy of defect production by high-energy electron irradiation.

Lang, Logan, and Kimerling had found that the damage production rate at 1 MeV was greater along the [111] Ga direction than the [111] As direction and concluded therefore that Ga displacements were involved. (The [111] Ga direction is the As to Ga molecule direction with an empty lattice space directly behind the Ga atom.) Pons and Bourgoin confirmed their observations at ~1 MeV but reported the surprising result that at lower electron energies, nearer damage threshold, the anisotropy reverses and that [111] As damage dominates, thus suggesting As displacements.

To my knowledge, the only detailed *microscopic* information available on anisotropy of displacement damage in a compound semiconductor is from earlier EPR studies of Frenkel pair formation in ZnSe.[4] There it was *known* that metal-atom displacement was involved and clear evidence of easy damage production in the [111] Zn direction even at 1.5 MeV was demonstrated. Lang, Logan, and Kimerling used this result in support of their original interpretation.[3] I have therefore reexamined my original data to see if it contains information that can help clear up this apparent discrepancy.

In Fig. 1, I show previously unpublished data where 1.5-MeV irradiation was alternated between the [111] Se and [111] Zn directions on a single ZnSe sample. The concentration of zinc displacement Frenkel pairs aligned along the [111] beam direction, $V'(\bar{1}\bar{1}\bar{1})$, and along the [11$\bar{1}$] direction, $V'(11\bar{1})$, were monitored directly by EPR. The strong anisotropy of damage rates for the differently oriented pairs clearly reflects the easy [111] Zn displacement.

To compare to the DLTS studies of Pons and Bourgoin[1] and Lang, Logan, and Kimerling,[3] however, we must estimate the *total* demage.

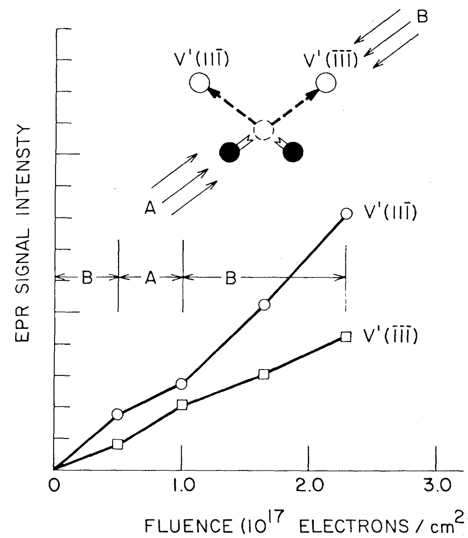

FIG. 1. Production of zinc-vacancy–zinc-interstitial Frenkel close pairs in ZnSe vs 1.5-MeV electron fluence at 20.4 K for two different beam directions: *A*, [111] Zn; *B*, [111] Se.

This can be obtained from the figure as $V'(\bar{1}\bar{1}\bar{1}) + 3V'(11\bar{1})$, the factor of 3 arising since there are also $V'(\bar{1}11)$ and $V'(1\bar{1}1)$, which are equivalent to $V'(11\bar{1})$ but are not being monitored. We find that the total damage rate (η) is indeed greater in the [111] Se direction

$$\eta_{[111]\,\mathrm{Se}} \cong 1.5\eta_{[111]\,\mathrm{Zn}}.$$

These results therefore confirm the interpretation of Pons and Bourgoin that at these high energies the total damage rate is greater in the "hard-displacement" direction. The *individual* atom displacements, as monitored directly by EPR, still reflect the easy-displacement directions, however.

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