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B—2—5 Comparison of Defect Formation in InGaAsP/InP and GaAlAs/GaAs

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InGaAsP/InP and GaAlAs/GaAs are used as materials for optical devices in optical fiber communication systems. The reliability of devices which are fabricated from these materials have been studied extensively, and it has been proved that InGaAsP/InP is more reliable than GaAlAs/GaAs in concern with lives of diodes. However, the difference in defect formation between InGaAsP/InP and GaAlAs/GaAs has not been understood until now. The purpose of this work is to clarify the mechanism of defect formation in these two materials, by the investigation of defects in the diodes under carrier injection and those in heavily doped as-grown crystals, with TEM, SEM, and EDX(energy dispersive x-ray spectroscopic) experiments.

In InGaAsP/InP DH LED's, all of the dark defects that were observed in the light emitting region were proved to have been induced before carrier injection. The origins of the dark defects consisted of stacking faults, misfit dislocations, precipitates, and mechanical damages. These defects did not develop under the carrier injection. The generation of dark region was observed only in the diode applied with large current pulse($\gtrsim$100 kA/cm^2). The dark region corresponded to amorphous regions of the matrix or small grain-like structures(Fig. 1), and did not correspond to structural defects such as dislocations or their loops.

In GaAlAs DH LED's, however, $\langle 100 \rangle$ and $\langle 110 \rangle$ DLD's were generated under carrier injection. The $\langle 100 \rangle$ DLD's were proved to be associated with interstitial type dislocation dipoles generated by climb process. The $\langle 110 \rangle$ DLD's corresponded to glide-dislocations. $\langle 110 \rangle$ or $\langle 1\bar{1}0 \rangle$ DLD's(cross-hatched) were also observed in the diodes degraded by the injection of pulsed large current. The DLD's were associated with dislocation bands consisting of high density of straight dislocations and threading dislocations(Fig. 2).

In the characterization of heavily doped InGaAsP LPE layers(λ_{PL}=1.3μm) with Zn, Cd, Sn, or Te, no dislocation(or faulted) loops were observed, although heavy doping in the compound semicondutors, in general, induces various crystal defects such as dislocation loops and faulted loops due to the segregation of impurities. Only precipitates were observed in heavily doped InGaAsP LPE layers, as shown in Fig. 3. On the other hand, faulted loops were observed in heavily Ge-doped $Ga_{0.9}Al_{0.1}As$ LPE layers with carrier concentration of more than 1 x $10^{18}cm^{-3}$ (Fig. 4). These loops were determined to be interstitial type Frank loops with Burgers vectors of the type a/3$\langle 111 \rangle$.

Defect formation during operation and defect structures in heavily doped LPE layer in InGaAsP/InP and GaAlAs/GaAs are summarized in Table I.

The generation of faulted loops could be well explained by the following sequence : i) segregation of impurities, ii) nucleation of supersaturated interstitials of the host atoms, iii) condensation of the interstitials at some nucleation centers, iv) formation of micro-loops by the relaxation of the stress localized at these nucleation centers(glide process), and v) development of faulted or unfaulted loops from the micro-loops by climb process.

Therefore, the faulted loops can be generated by the combination of glide and climb process. No faulted loops were observed in heavily doped InGaAsP layers. This fact suggests the difficulty in the occurrence of glide and climb process in the InGaAsP/InP material.

Large Peierls stress and formation energy for a jog, and strong interaction between point defects and dislocations are considered to be the main reasons for the difficulty in glide and climb processes in InGaAsP/InP material.

In summary, defect formation under carrier injection and that by heavy doping in InGaAsP/InP and GaAlAs/GaAs crystals were systematically clarified. The difference in the occurrence of glide and climb process between these materials could be well explained by considering the generation of faulted loops in heavily doped crystals.

Figure 1. Degraded area corresponding to dark region in InGaAsP/InP DH LED degraded by pulsed large current(TEM).

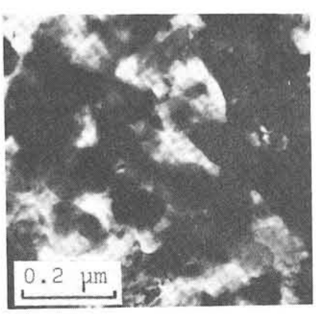

Figure 2. Dislocation bands corresponding to cross-hatched ⟨110⟩ DLD's in GaAlAs DH LED degraded by pulsed large current(TEM).

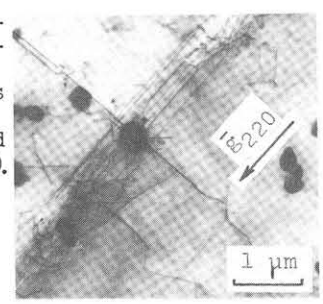

Figure 3. Precipitates in heavily Sn-doped LPE InGaAsP layer(TEM).

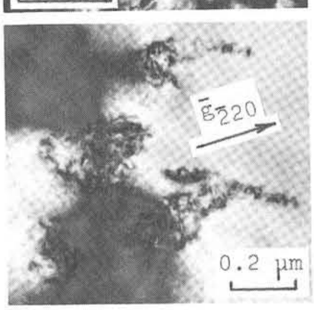

Figure 4. Faulted loops in heavily Ge-doped LPE $Ga_{0.9}Al_{0.1}As$ layer (TEM).

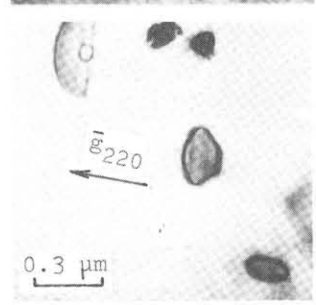

Table I. Easiness of defect formation and defect structures.

Material	Defect formation under carrier injection: Glide process	Defect formation under carrier injection: Climb process	Defect structures in heavily doped crystal
InGaAsP/InP	difficult	difficult	precipitates (no structural defects)
GaAlAs/GaAs	easy	easy	faulted loops