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Ge-doping behavior in $Al_xGa_{1-x}As$ grown by LPE

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Germanium (Ge) is expected as an amphoteric dopant in GaAs and $Al_xGa_{1-x}As$ as is the case with silicon[1]. Though Ge has been commonly used as a p-type dopant in $Al_xGa_{1-x}As$, its behavior as a donor impurity has not been reported. We found for the first time that Ge behaves as an n-type dopant in $Al_xGa_{1-x}As$ grown by LPE when the alloy composition x and the atom fraction of Ge in the melt X^l_{Ge} are properly chosen.

Ge-doped $Al_xGa_{1-x}As$ layers were grown on n-type GaAs substrates using a conventional slide-boat. The growth temperature was 800°C with a cooling rate of 0.3°C/min. The alloy composition was varied from 0 to 0.8 at a constant X^l_{Ge} of 0.19 or 0.48 at.%. The carrier concentration in grown layers was measured by the C-V method and the results were shown in Fig. 1. The photoluminescence (PL) spectra were also measured at 4K by Ar^+-laser excitation and the typical result was shown in Fig. 2.

From Fig. 1, it can be seen that Ge behaves as a p-type dopant in the alloy for low X value and the hole concentration decreases markedly with the increase of X even if X^l_{Ge} is kept constant, and finally it behaves as an n-type dopant above a critical composition X_c. The value X_c increases with X^l_{Ge}. By use of this behavior of Ge, p-n heterojunction which was composed of p-$Al_{0.05}Ga_{0.95}As$ and n-$Al_{0.7}Ga_{0.3}As$ was made by doping Ge alone and observed by SEM, as shown in Fig. 3.

Two PL peaks due to Ge-doping were observed except an edge emission as shown in Fig. 2. They correspond to deep and shallow impurity levels, as shown in Fig. 4. The former represents the acceptor level, as reported previously[2,3]. The latter, observed for the first time in our study, is considered to be related with the donor level because the ratio of the latter PL intensity to the former increases with X.

References

1) W. J. Johnson et al.; J. Appl. Phys. 44 (1973) 1311.

2) K. Kaneko et al.; J. Appl Phys. 51 (1980) 6337.

3) V. Swaminathan et al.; J. Appl. Phys. 53 (1982) 5163.

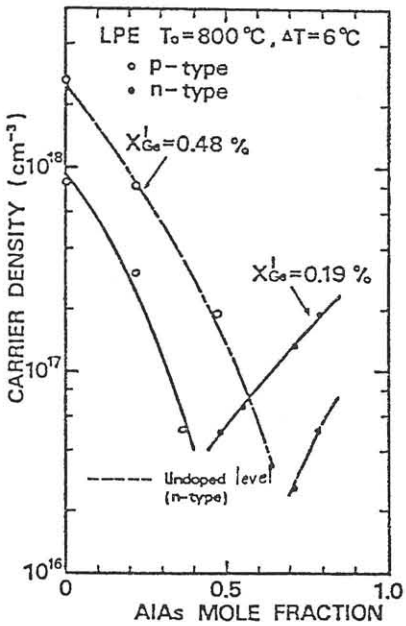

Fig. 1 Carrier concentration in Ge-doped $Al_xGa_{1-x}As$ LPE layers as a function of AlAs mole fraction.

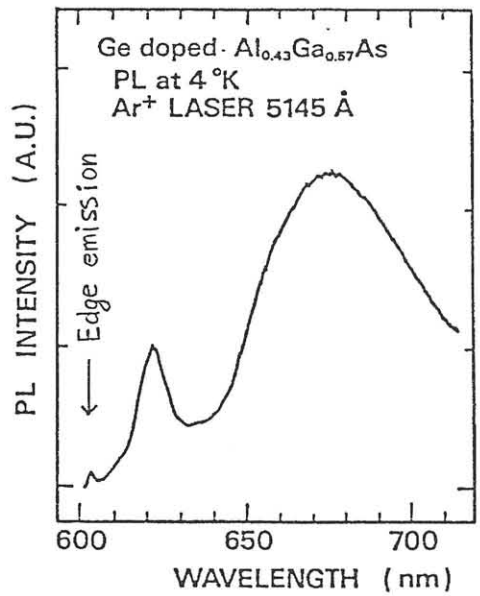

Fig. 2 PL spectrum of Ge-doped $Al_xGa_{1-x}As$ LPE layer.

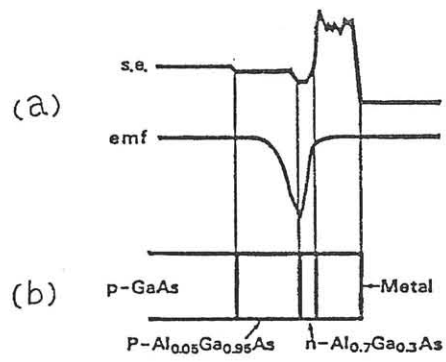

Fig. 3 SEM observation of Ge-doped p-n heterojunction. The upper figure, (a), shows a secondary electron signal (se) and a electromotive force one (emf), and the lower one, (b), is the cross-section of the p-n heterojunction.

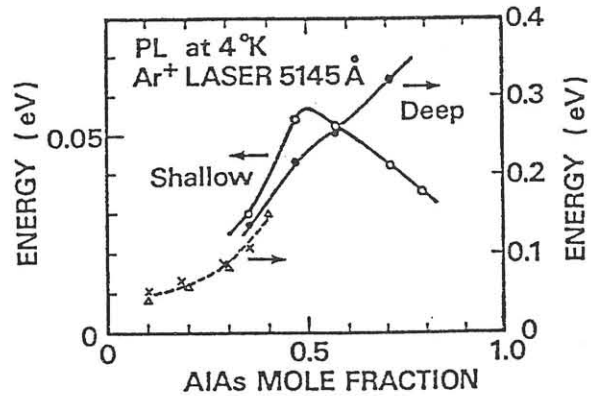

Fig. 4 Energy levels of PL peaks from band edge as a funciton of AlAs mole fraction. Δ: Ref. 2, X: Ref. 3