Electrical and Optical Characterization of $Al_xGa_{1-x}As$/GaAs *P-n* Junctions Grown via Liquid Phase Epitaxy

J. N. Laniog, K. M. A. N. Bautista, M. G. Patricio, R. V. Sarmago, and A. A. Salvador
Condensed Matter Physics Laboratory, National Institute of Physics
University of the Philippines Diliman, 1101 Quezon City, Philippines
E-mail: jean.laniog@intel.com

INTRODUCTION

The $Al_xGa_{1-x}As$/GaAs heterostructure system is of prime importance for use in high-speed digital and electro-optic device applications. The compositional dependence of the bandgap energy of $Al_xGa_{1-x}As$ can be tailored to meet specific device requirements such as photon emission and detection. The 0.15% lattice parameter difference between GaAs and $Al_xGa_{1-x}As$ $(0 \leq x \leq 0)$ at 300 K ensures that the density of interface states is kept to a level that would not affect device performance. These two properties of $Al_xGa_{1-x}As$/GaAs alloy system make it one of the most technologically important semiconductors to date (Adachi, 1985).

Epitaxial layers of III-V semiconductors have well-controlled carrier recombination and transport properties, usually derived from the addition of particular dopants. Among the n-type dopants, tin (Sn) is attractive for n-type doping because of its low volatility and relatively low distribution coefficient. This characteristic is crucial to minimizing dopant losses during epitaxy. Zinc (Zn), on the other hand, is preferred for doping of bulk GaAs due to its high doping efficiency and uniformity. Moreover, Zn acceptors exhibit high electrical activity and show no evidence of autocompensation (Streetman, 1995). In this work, therefore, Sn and Zn were used as the *n*- and *p*-type impurities respectively.

This study aimed to fabricate $Al_xGa_{1-x}As$/GaAs *P-n* junctions using the Liquid Phase Epitaxy (LPE) technique. The growth parameters of the samples were correlated with their structural, electrical and optical properties.

METHODOLOGY

The epitaxial layers were grown on (100)-oriented GaAs substrates using the double-substrate equilibrium LPE technique (Laniog et al., 1999). Thermosolutal data were calculated based on the phase diagrams of the materials system involved. The structural properties of the grown layers were evaluated using X-ray diffraction (XRD). Hot probe technique and Hall measurements were used complementarily to determine the conduction type and the free carrier concentration of the epilayers at room temperature. Photoluminescence (PL) and Photocurrent (PC) measurements taken at 77K were also performed in order to probe the optical quality and confirm the *P-n* configuration of the samples.

RESULTS AND DISCUSSION

Table 1 summarizes the properties of the $Al_{0.3}Ga_{0.7}As$/GaAs *P-n* samples fabricated.

The current-voltage (I-V) curves of samples *F1* and *F2* are shown in Fig. 1. Under forward bias conditions, the turn-on voltage for both *P-n* samples is 1.50 ± 0.05 V corresponding to the GaAs energy gap. A higher current density is exhibited by sample

Table 1. Carrier concentration and thickness of the *n*- and *p*-doped epilayers

Sample	Thickness of *n*-GaAs layer	Electron concentration	Thickness of *P*-AlGaAs layer	Desired Hole concentration
F1	9.66 μm	1×10^{18} cm $^{-3}$	3.0 μm	1×10^{17} cm $^{-3}$
F2	12.1μm	1×10^{18} cm $^{-3}$	0.572μm	1×10^{18} cm $^{-3}$

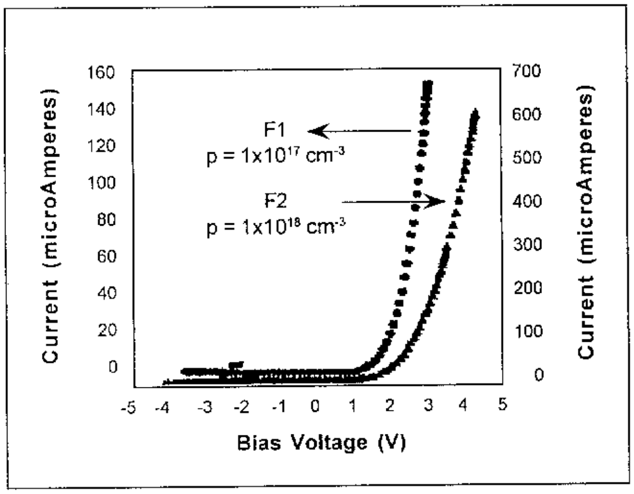

Fig.1. Current-voltage (I-V) plot of samples F1 and F2 consisting of a GaAs/Al$_x$Ga$_{1-x}$As *n-P* junction on a *n*-GaAs substrate

F2 owing to its higher hole concentration as compared to sample *F1*.

Fig. 2 features the PL spectra of the two units taken at liquid nitrogen (77 K) temperature. For sample *F1*, the luminescence peak around 1.819 eV observed is associated with a free-to-bound transition. This transition involves free electrons in the conduction band that recombine radiatively with the holes trapped on the acceptor states in the Al$_x$Ga$_{1-x}$As layer. The redshift observed for sample *F2* is attributed to the merging of the conduction and valence bands with the acceptor level.

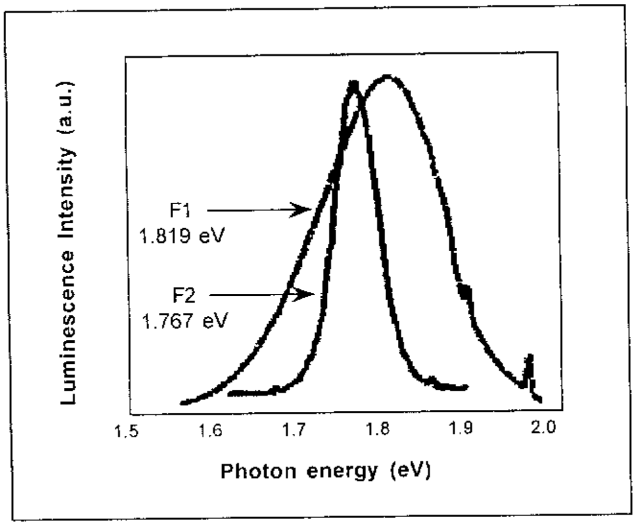

Fig.2. PL spectra of F1 and F2 samples taken at 77K

Figs. 3a and 3b show the photocurrent signal of the GaAs/ Al$_x$Ga$_{1-x}$As *P-n* junction. The photocurrent peak occurring at 1.375 eV corresponds to the energy gap of the GaAs layer. Appearing on Fig. 3b is a small broad hump in the Al$_x$Ga$_{1-x}$As spectra which also lies within the vicinity of the Al$_{0.3}$Ga$_{0.7}$As energy gap. The photoconductivity observed is a direct evidence of the *P-n* configuration of the sample since the built-in electric field in the space-charge region (SCR) is responsible for this phenomenon.

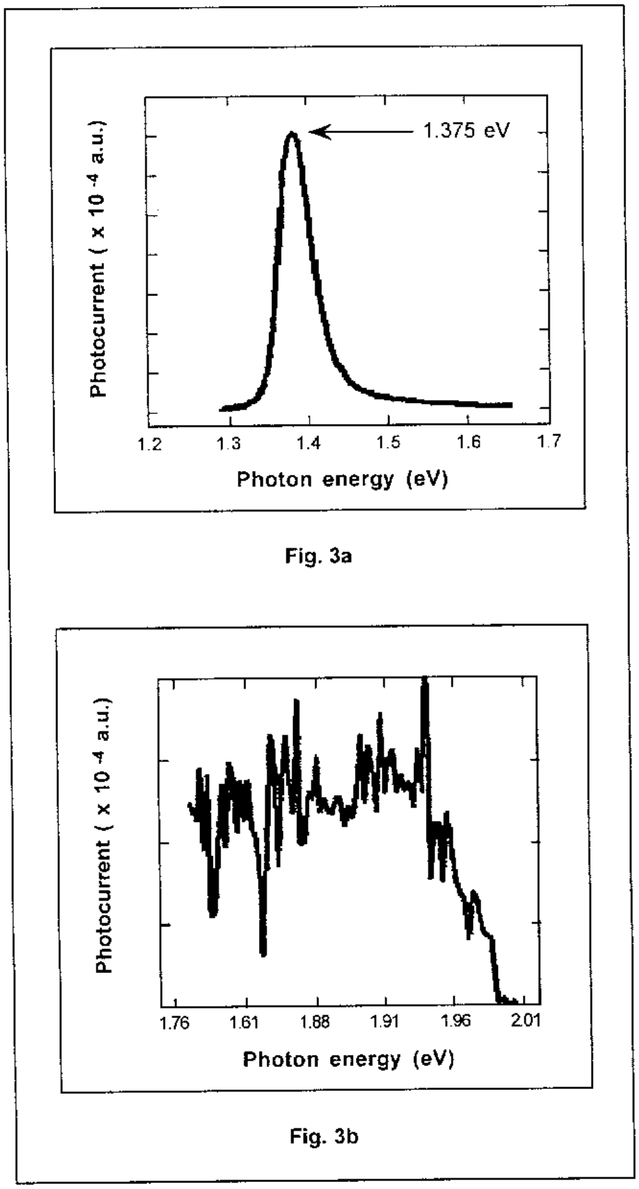

Fig. 3a

Fig. 3b

Fig. 3. Photocurrent of the GaAs/ Al$_x$Ga$_{1-x}$As p-n junction. 3a: Photocurrent peak corresponding to the energy gap of GaAs; 3b. Enlarged photocurrent signal at photon energies near the Al$_x$Ga$_{1-x}$As band gap

The two orders-of-magnitude discrepancy in the photocurrent values between *n*-GaAs and *P*-$Al_{0.3}Ga_{0.7}As$ is attributed to the thickness of the $Al_{0.3}Ga_{0.7}As$ layer. The *P-n* sample was illuminated with photons of energy $\hbar\omega$ on the $Al_xGa_{1-x}As$ side. Photons with energies less than the $Al_xGa_{1-x}As$ energy gap ($\hbar\omega < E_g'$) are transmitted and reach the GaAs layer at the junction. If they have energies greater than the GaAs energy gap, photon absorption takes place. Electrons from the valence band may be promoted to the conduction band, leaving a free hole. Due to the presence of the built-in electric field in the SCR, these photogenerated carriers within a diffusion length are swept down and contribute to photoconduction. On the other hand, when photon $\hbar\omega \geq E_g'$, most of the absorption occurs on the surface of the thicker $Al_{0.3}Ga_{0.7}As$ layer. The photogenerated holes and electrons may recombine radiatively or nonradiatively on the surface. This, therefore, greatly diminish probabilities of photoconductivity.

CONCLUSION

We have succeeded in fabricating $Al_{0.3}Ga_{0.7}As/GaAs$ *P-n* junctions with a $V_{turn\text{-}on} = 1.50 \pm 0.05$ V using the LPE technique. PL measurements at 77K revealed high radiative efficiency with a band-to-band transition around 1.819 eV. The redshift observed in the case of sample *F2* is due to the increase in hole concentration. The photocurrent results further confirm the *P-n* configuration of the samples.

REFERENCES

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