JOURNAL OF MATERIALS SCIENCE LETTERS 12 (1993) 53–55

Temperature dependence of deep-level photoluminescence in $Ga_{0.5}In_{0.5}P$ epilayers grown by metal–organic chemical vapour deposition

JIALONG ZHAO, YING GAO
Changchun Institute of Physics, Chinese Academy of Sciences, Changchun 130021, People's Republic of China

TIANGU GU, M. SUTTON
Department of Physics, Centre for the Physics of Materials, McGill University, Montreal, Quebec, Canada H3A 2T8

JIACHANG LIANG*
Department of Basic Sciences, Civil Aviation Institute of China, Tianjin 300300, People's Republic of China

The ternary alloy $Ga_xIn_{1-x}P$ grown lattice matched to GaAs has attracted much attention because of its usefulness in optoelectronics and electronic devices. Various epitaxial techniques are utilized to grow high-purity, good-quality materials. The characteristics of these layers have been studied by transmission electron microscopy [1, 2], photoluminescence [3–5], Raman scattering [1, 6], electroreflectance [7] and picosecond absorption dynamics [8]. Deep levels in the epitaxial layers, which could have an important influence on the electrical and optical characteristics of the layers, have received little attention, although the persistent photoconductivity [9] and deep-level transient spectroscopy [10] in $Ga_{0.49}In_{0.51}P$ layers were reported recently.

In this work we studied the near-infrared photoluminescence (NIPL) related to deep levels present in $Ga_{0.5}In_{0.5}P$ epilayers grown on GaAs substrate by metal–organic chemical vapour deposition (MOCVD) with respect to temperature variations, observed three peaks with energies of 1.17, 0.99 and 0.85 eV, and identified that the 1.17 eV PL emission can be explained well by the recombination of the donor–acceptor pair (DAP), composed of a carbon donor on gallium sublattice site and the next-nearest neighbour gallium vacancy acceptor. Finally, the characteristics of the 1.17 eV emission are discussed using a configuration co-ordinate model.

The $Ga_{0.5}In_{0.5}P$ epilayer, 2 μm thick, used in the experiment was grown on the semi-insulating (1 0 0) GaAs substrate by MOCVD, misoriented 3–5° towards one of the (1 1 0) directions at a growth temperature of 700 °C with a group V/III ratio of 30. The lattice mismatch between the $Ga_{0.5}In_{0.5}P$ layer and GaAs substrate was less than ±0.1%. The layer was not intentionally doped. The temperature-dependent NIPL spectra of $Ga_{0.5}In_{0.5}P$ layer were measured with an ordinary grating monochromator and detected by a liquid-nitrogen-cooled germanium detector using a conventional lock-in technique. Luminescence was excited with the 632.8 nm line of an He–Ne laser under proper excitation conditions.

*Author to whom all correspondence should be addressed.

Fig. 1 shows the NIPL spectra of the $Ga_{0.5}In_{0.5}P$ layer as a function of temperature at an excitation intensity of about 0.1 W cm^{-2}. As shown in Fig. 1, the NIPL spectrum at 77 K can be fitted adequately by a sum of three Gaussian-type curves, where three peaks are labelled A, B and C, respectively. The three peak energies are 1.17, 0.99 and 0.85 eV, respectively. At T = 77–150 K the NIPL spectra are

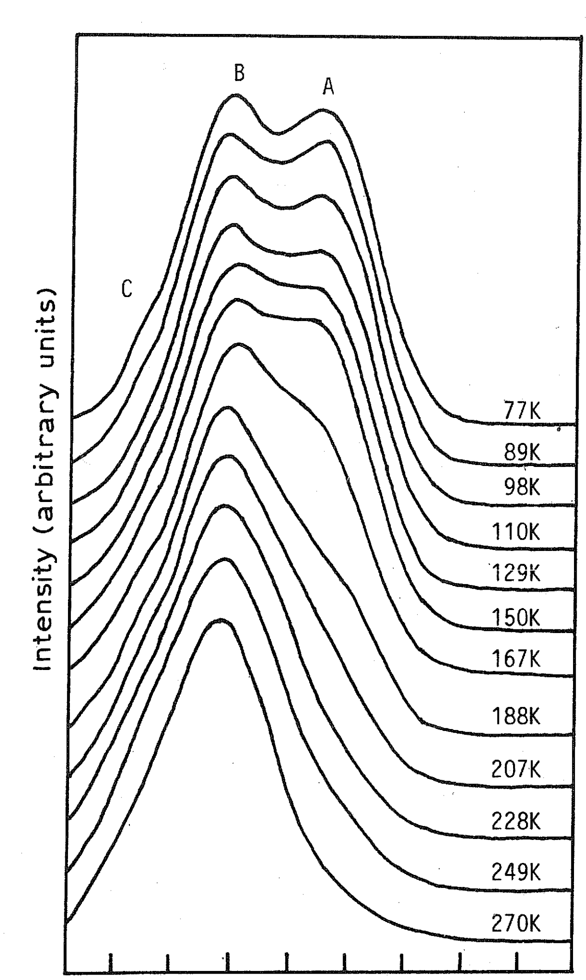

Figure 1 NIPL spectra of $Ga_{0.5}In_{0.5}P$ epilayer at different temperatures.

0261-8028

due mainly to peaks A and B, but at $T = 160–200$ K peak B becomes dominant. At temperatures above 200 K peak A disappears; that is, the 1.17 eV PL emission is quenched thermally.

The variation in the PL intensities with temperature for the 1.17 and 0.99 eV PL emissions in the $Ga_{0.5}In_{0.5}P$ layer are shown in Fig. 2. Using the above experimental data, the activation energy $\Delta E = 0.17$ eV for the thermal quenching process of 1.17 eV emission was obtained from

$$I = C \exp(\Delta E/kT) \quad (1)$$

where I is the PL intensity and C is a constant.

Fig. 3 shows the variation in the full width at half-maximum (FWHM) of the 1.17 and 0.99 eV PL emissions in the layer with the square root of the temperature. According to the configuration coordinate model [11], the theoretical temperature dependence of the FWHM, $W(T)$, is

$$W(T) = (8 \ln 2)^{1/2} S^{1/2} \hbar\omega [\coth(\hbar\omega/2kT)]^{1/2} \quad (2)$$

where $\hbar\omega$ is the longitudinal-phonon energy and S is the Huang–Rhys factor. Equation 2 is fitted to the experimental values in Fig. 3, and we obtained the values of $\hbar\omega = 31$ meV and $S = 5.3$ for 1.17 eV PL emission and $\hbar\omega = 32$ meV and $S = 5.7$ for 0.99 eV PL emission. The Huang–Rhys factor $S > 5$ indicates that in $Ga_{0.5}In_{0.5}P$ layer a strong electron–lattice coupling exists, which leads to the 1.17 eV PL emission having a very broad Gaussian lineshape (FWHM 0.17 eV at liquid-nitrogen temperature) without any fine structure [12]. The Frank–Condon shift (Δ_{FC}) is given by $S\hbar\omega = 0.16$ eV.

We studied the excitation intensity dependence of the 77 K NIPL spectra in the $Ga_{0.5}In_{0.5}P$ layer [13] and found that there are two strong peaks A and B, and one weak peak C, at low excitation intensity. With increasing excitation intensity, peak A becomes dominant, and peaks B and C disappear. A plot of the excitation intensity versus the NIPL intensity of peak A shows a linear relationship, whereas the NIPL intensities of peaks B and C appear to saturate gradually with increasing excitation intensity. Furthermore, the peak energy shifts per decade of the excitation intensity change for peaks A, B and C were 4, 9 and 10 meV, respectively.

The 1.17 eV PL emission with 0.17 eV FWHM, 200 K thermal quenching temperature, 4 meV peak energy shift per decade of the excitation intensity change, a strong electron–lattice coupling and linear relationships of excitation versus PL emission and PL FWHM have been carefully identified as a PL emission of DAP, composed of a carbon donor, the dominant impurity in $Ga_{0.5}In_{0.5}P$ layer grown by MOCVD [14], on a gallium sublattice site and gallium vacancy acceptor as the next-nearest neighbour [15]. This transition is denoted by $C_{Ga}–V_{Ga}$, where C_{Ga} represents the carbon donor on a gallium sublattice site and V_{Ga} the next-nearest neighbour gallium vacancy.

The 0.99 eV band is due to the transition from a level of the phosphorus vacancy to the valence band [16, 17], and the 0.85 eV PL emission is attributed to the transition from a hole trap to the valence band, where the hole trap is associated with structural defects created by the strain relaxation related to the lattice mismatch in the $Ga_{0.5}In_{0.5}P$ layer [18].

In conclusion, we have identified that the 1.17 eV PL emission in the NIPL spectra is a transition of DAP, composed of a carbon donor on gallium sublattice site and the next-nearest neighbour gallium vacancy acceptor in a GaInP layer grown on GaAs substrate by MOCVD. The emission was described in terms of the transition energy, the FWHM, the thermal quenching temperature, the lineshape and strong electron–lattice coupling. This work is the first study of NIPL as a function of temperature for a $Ga_{0.5}In_{0.5}P$ layer and the first identification of the DAP transition including gallium vacancies from this type of material. It is well

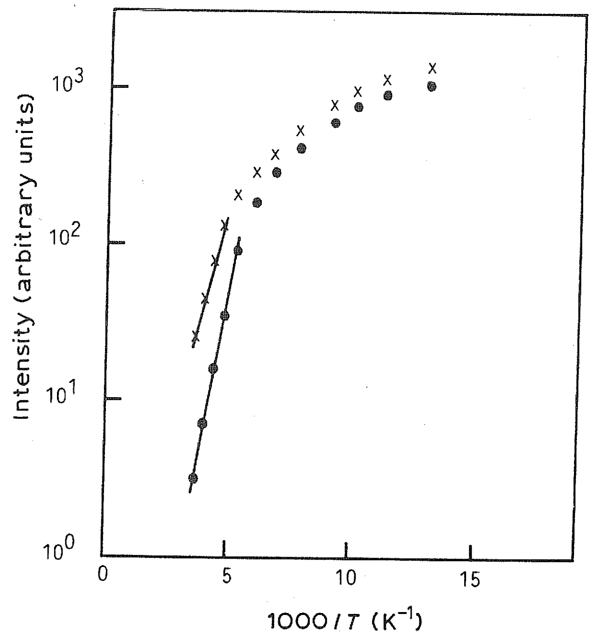

Figure 2 Temperature dependence of PL intensity for peaks (●) A and (×) B.

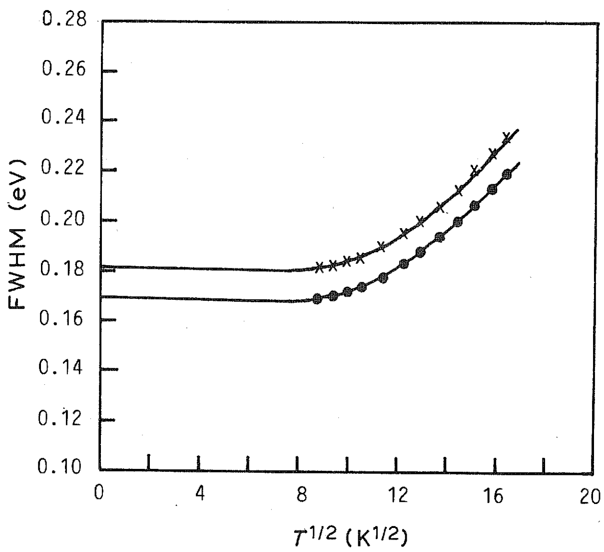

Figure 3 Variations in FWHM of peaks (●) A and (×) B with $T^{1/2}$.

known that gallium vacancies degrade the quality of this material, and thus it may be possible to improve further the quality of the $Ga_{0.5}In_{0.5}P$ layer by controlling the vacancies.

Acknowledgements

This work was supported by the National Natural Science Foundation and the Laboratory of Excited State Processes, Changchun Institute of Physics, Chinese Academy of Sciences.

References

1. M. KONDOW, H. KAKIBAYASHI, S. MINAGAWA, Y. INOUE, T. NISHINO and Y. HAMAKAWA, *Appl. Phys. Lett.* **53** (1988) 2053.
2. O. UEDA, M. TAKECHI and J. KOMENO, *ibid.* **54** (1989) 2312.
3. M. KONDOW, S. MINAGAWA, Y. INOUE, T. NISHINO and Y. HAMAKAWA. *ibid.* **54** (1989) 1760.
4. M. C. DELONG, P. C. TAYLOR and J. M. OLSON, *ibid.* **57** (1990) 620.
5. J. E. FOUQUET, V. M. ROBBINS, S. J. ROSNER and O. BLUM, *ibid.* **57** (1990) 1566.
6. A. GOMYO, T. SUZUKI, K. KOBAYASHI, S. KAWATA, I. HINO and T. YUASA, *ibid.* **50** (1987) 673.
7. T. NISHINO, Y. INOUE, Y. HAMAKAMA, M. KONDOW and S. MINAGAWA, *ibid.* **53** (1988) 583.
8. P. THIAGARAJAN, J. F. SCHMERGE, C. S. MENONI, M. MARCONI, O. E. MARTINEZ, J. J. ROCCA, M. J. HAFICH, H. Y. LEE and G. Y. ROBINSON, *ibid.* **59** (1991) 90.
9. S. B. AMOR, L. DMOWSKI, J. C. PORTAL, N. J. PULSFORD, R. J. NICHOLAS, J. SINGLETON and M. RAZEGHI, *J. Appl. Phys.* **65** (1989) 2756.
10. S. L. FENG, J. C. BOURGOIN, F. OMNES and M. RAZEGHI, *Appl. Phys. Lett.* **59** (1991) 941.
11. C. C. KLICK and J. H. SCHULMAN, in "Solid state physics", Vol. 5, edited by F. Seitz and D. Turnbull (Academic Press, New York, 1957) p. 100.
12. P. W. YU, *Phys. Rev.* **B42** (1990) 11 889.
13. Y. GAO, J. L. ZHO, X. Y. LIU, X. A. SU, T. G. GU, M. SUTTON and J. C. LIANG, *J. Mater. Sci. Lett.* in press.
14. K. H. GOETZ, D. BIMBERG, H. JUGENSEN, J. SELDERS, A. V. SOLOMONOV, G. F. GLINSKI and M. RAZEGHI, *J. Appl. Phys.* **54** (1983) 4543.
15. E. W. WILLIAMS, *Phys. Rev.* **168** (1968) 922.
16. J. E. FOUQUET, R. R. SAXENA and G. A. PATTERSON, *IEEE J. Quantum Elec.* **QE-25** (1989) 1025.
17. H. TEMKIN, B. V. DUTT and W. A. BONNER, *Appl. Phys. Lett.* **38** (1981) 431.
18. J. F. CHEN, J. C. CHEN, Y. S. LEE, Y. W. CHOI, K. XIE, P. L. LIU, W. A. ANDERSON and C. R. WIE, *J. Appl. Phys.* **67** (1990) 3711.

Received 21 January
and accepted 24 July 1992