Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp629-630

Shallow Carrier Trap Levels in GaAsN Investigated by Photoluminescence

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Abstract

Shallow carrier trap levels in $GaAs_{1-x}N_x$ epi-layers are investigated by photoluminescence in 4.2 – 300K. There are 3 emissions in PL spectra of near-band-edge of GaAsN based on peak decomvolution. The existence of these peaks is evidence of carrier localization at near-band-edge. We clarified the energy levels of the peak on low energy side and its intensity of this peak increase with increasing N composition up to x = 0.0038. This behavior is similar to degradation of electrical property. This carrier trap center may act as scattering center in GaAsN. We determined band gap energy by photoreflectance technique.

1. Introduction

InGaAsN has been regarded as a promising material for ultra high efficiency tandem solar cells because its band gap energy (Eg) can be achieved 1.0 eV with lattice matched to Ge and GaAs [1]. It can be achieved more than 40% conversion efficiency. However, electrical properties of current (In)GaAsN are poor. One of the candidates of poor electron mobility is due to these N related shallow defects [2,3]. "*S-shape*" behavior in temperature dependence of photoluminescence suggested that there are some shallow level in near-band-edge of GaAsN [4,5]. However, these trap levels were not understood yet. It is needed to clarify energy levels and these effects on electrical property. The near-band-edge PL spectra of GaAsN grown by chemical beam epitaxy (CBE) were observed consist of several peaks. In this study, we discussed and clarified the energy levels and the origins of each peak near the band edge in GaAsN by analysis of the temperature and the excitation power dependence.

2. Experiment

GaAsN films were grown on a semi insulated GaAs (001) substrates by CBE. GaAsN layer was embedded between 400 nm thick GaAs buffer layer and 20 nm thick GaAs cap layer. They avoid surface recombination in PL. Triethylgallium ((C2H5)3Ga: TEGa = 0.02 sccm), trisdimethylaminoarsenic ([(CH3)N]3As: TDMAAs = 1.0 sccm) and monomethylhydrazene (H3N2CH3: MMHy = 4 sccm) were used as Ga, As and N precursor, respectively. N composition was determined by X-ray diffraction. We performed PL measurement in 4.2 – 300 K using a solid state laser pumped by laser diode as excitation. The luminescence was dispersed by 0.75m a single monochrometer and detected by photomultiplier cooled at -70°C. To measure band gap energy, we used photoreflectance (PR) technique with a halogen lamp and the 488 nm line of an Argon ion laser serving as probe and pump beams, respectively.

3. Results and discussion

Temperature dependence of the near-band-edge PL spectra of $GaAs_{0.9977}N_{0.0023}$ epi-layer grown by CBE are shown in Fig. 1. There are several emissions in PL spectra of near-band-edge. These PL spectra was decomvoluted several Gaussian functions and it is shown in Fig. 2. We conclude that there are 3 energy levels from fitting results. These results indicate there are different 3 emission processes. We labeled these 3 peaks as P1, P2 and P3 from high energy side.

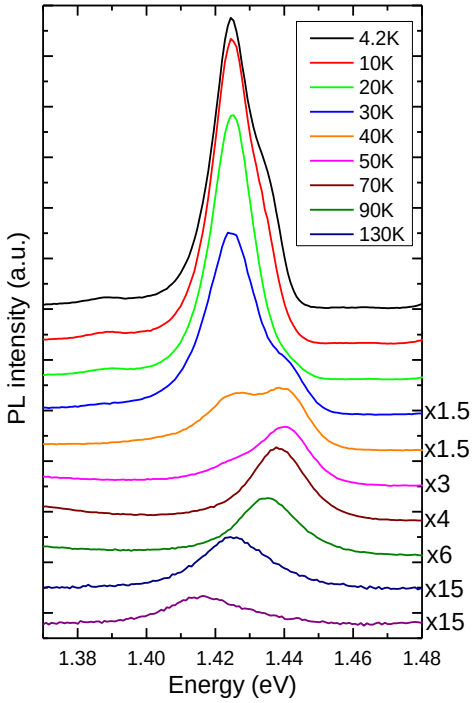

Fig. 1. Temperature dependence of PL spectra of $GaAs_{0.9977}N_{0.0023}$ grown by CBE.

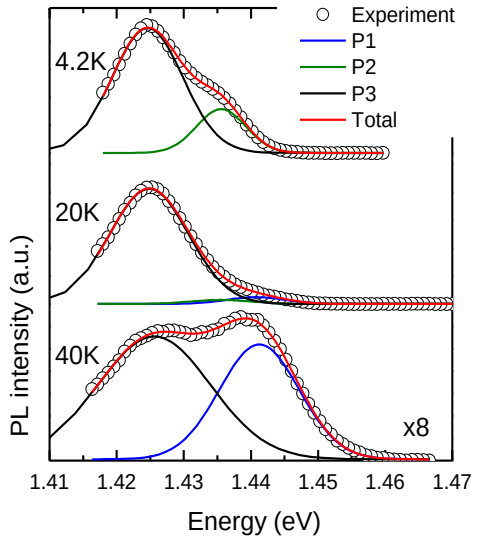

Fig. 2. Fitting results of near-band-edge of PL spectra of $GaAs_{0.9977}N_{0.0023}$

Figure 3 shows the temperature dependence of energy of each peak. Energy of P2 and P3 is 6 meV and 17 meV lower than that of P1 independently temperature. The energy of P1 is good agreement with band gap energy which is determined by PR (see Fig. 3). Hence, P1 is band to band transition. One of the candidates of origin of P2 is free exciton because binding energy is estimated to 5.5 – 7 meV by reported effective mass of GaAsN [6,7]. However, origin of P3 still is not clear.

The integrated intensity ratio of P2/(P1+P2+P3) (red dot) decrease with increasing N composition (see Fig. 4). If origin of P2 is free excition, it is reasonable results since N related defects increased with increasing N composition. In contrast, that of P3/(P1+P2+P3) increase. It might indicate density of states of P3 was increased with increasing N composition. On the other hand, energy of P3 blueshifted with the increasing excitation power. Origin of P3 is considered to be the transition between neutral donor - neutral acceptor pair (DAP) or overlapping of luminescence from a number of localized levels such as N-N pairs and higher order clusters. However, there is no report satisfying sum of ionization energy donor and acceptor.

4. Conclusion

We clarified there are 3 emissions in near-band-edge PL spectra of GaAsN. The origins of them were studied by analyzing temperature dependence of each peak for the first time. Furthermore, following possibilities were demonstrated: (i) P1 is from band to band transition, (ii) P2 is caused by free exciton or related shallow defects, and (iii) P3 originates from overlapping of individual emissions from a number of localized levels.

In particular, PL intensity of P3 increased with increasing N composition. This behavior is similar to degradation of electrical property of GaAsN. P3 might act as strong scattering center. Therefore, to clarify origin of P3 is

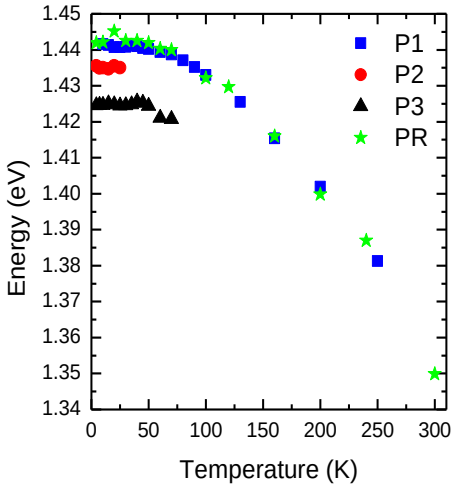

Fig. 3. Temperature dependence of the energy of each peak of $GaAs_{0.9977}N_{0.0023}$.

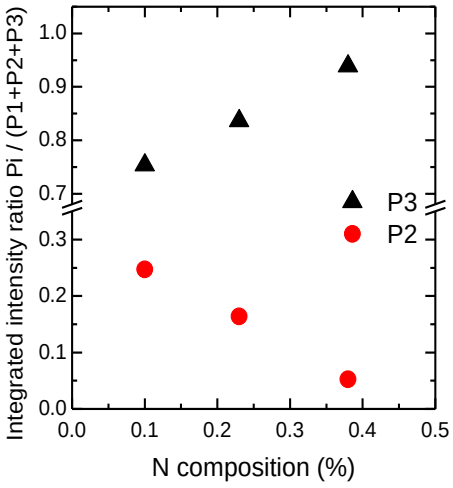

Fig. 4. Integrated intensity ratio of P2 (red dot) and P3 (closed triangle) depend on N composition at 4.2 K.

important to improve the crystal quality. However, more experiments are required to clarify the origin of P3.

Acknowledgements

Part of this work was supported by the New Energy Development Organization (NEDO) under the Ministry of Economy, Trade and Industry, Japan.

References

[1] D. J. Friedman *et al*., J. Cryst. Growth **195** (1998) 205
[2] S. Fahy *et al*., Appl. Phys. Lett. **83** (2003) 3731
[3] F. Ishikawa *et al*., Appl. Phys. Lett. **87** (2005) 262112
[4] H. Yaguchi, *et al*., phys. stat. sol. (b) **228** (2001) 273
[5] I.A. Buyanova, *et al*., Appl. Phys. Lett. 82 (2003) 3662
[6] W. Shan *et al*., Phys. Rev. Lett. **82** (1999) 1221
[7] F. Masia *et al*., Phys. Rev. B **73** (2006) 073201