Extended Abstracts of the 2000 International Conference on Solid State Devices and Materials, Sendai, 2000, pp. 526–527

D-9-5

DLTS, PL and CL Study of Dominant Deep Level and Its Removal in InGaP/GaAs Heterostructure Grown by TBP-Based GSMBE

Fumitaro Ishikawa, Atsushi Hirama and Hideki Hasegawa

Research Center for Interface Quantum Electronics and Graduate School of Electronics and Information Engineering, Hokkaido University, North-13, West-8, Sapporo 060-8628, JAPAN

TEL: +81-11-706-7171, FAX: +81-11-716-6004, e-mail: fumitaro@rciqe.hokudai.ac.jp

1. Introduction

Recently, the InGaP/GaAs heterostructure system is attracting keen attention as an alternative system to the more traditional AlGaAs/GaAs system, because devices such as HBTs as well as HEMTs and solar cells show higher reliability and performance with this system.

For mass-production of InGaP/GaAs heterostructure wafers, gas-source MBE (GSMBE) growth method using low toxic tertiarybutylphosphine (TBP) is extremely attractive as compared with MOVPE/MBE approaches using phosphine. Although electronic and optical quality of the crystal obtained previously by such a method was usually much inferior to those grown by phosphine-based methods, we have recently shown that equally high quality epitaxial InGaP layers can be grown after optimization of growth conditions [1].

As a next step, we have grown many InGaP/GaAs/InGaP quantum well (QW) structures to test the quality of InGaP/GaAs heterostructure interface grown by this method. However, our preliminary study showed that photoluminescence spectra from such QW structures tend to be dominated by a certain deep level-related luminescence near 1.7 eV.

The purpose of this paper is to carry out a systematic study on the dominant deep level at InGaP/GaAs heterostructure interface grown by TBP-Based GSMBE by deep level transient spectroscopy (DLTS), photoluminescence (PL) and cathode luminescence (CL) techniques and to try to remove it by growth optimization.

2. Experimental

Sample structures S1-S4 shown in **Fig.1** were used. DLTS study was made using the structure S1 having a thick Si-doped n-type InGaP layer ($n=1\times10^{17}$ cm^{-3}). PL and CL studies were made on structures S2-S4. In S4 (QW) samples, no intentional doping was made

All the samples were grown by GSMBE using TBP as the phosphorous source. TBP was decomposed to obtain P_2 beam by cracking at 800℃. As sources of In, Ga and As, metallic In, Ga and As were used. Growth was done under various TBP flow rates, F_{TBP} at a fixed substrate temperature of 480℃. The QWs were grown with various growth interruption time from 0 to 60 s at both of the bottom and top heterointerfaces of the GaAs QW layers.

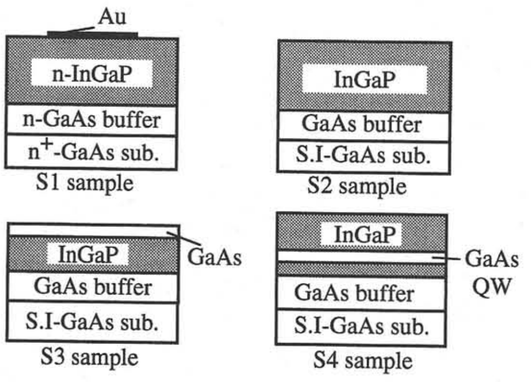

Fig.1 Sample structures.

3. Results and Discussion

InGaP layers grown under F_{TBP} higher than 4 sccm showed PL spectra consisting only of the band edge emissions at room temperature. As shown in **Fig.2**, its intensity increased remarkably with F_{TBP}. On the other hand, PL data from QW structures grown under F_{TBP} higher than 4 sccm showed unexpected appearance of a peak near 1.7 eV as shown in **Fig.3 (a)** and **(b)** by the peak "D".

In order to identify the origin of the peak "D" near 1.7 eV, knowledge of bulk deep levels are important. Thus, DLTS study was made on InGaP using the S1 sample. Five

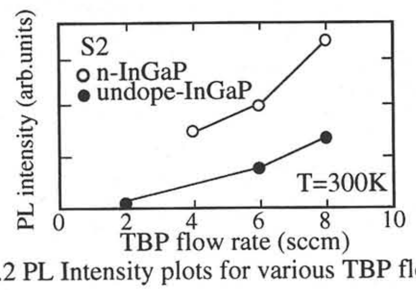

Fig.2 PL Intensity plots for various TBP flow rate.

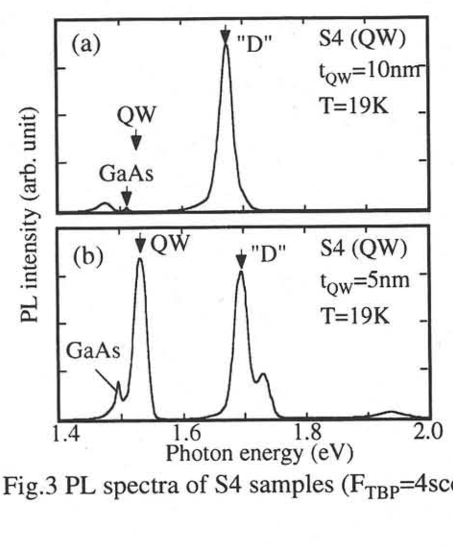

Fig.3 PL spectra of S4 samples (F_{TBP}=4sccm) .

broad peaks, A-E, were observed in the samples grown at small F_{TBP} values. Out of five peaks, four peaks, A-D, showed no bias dependence of the peak position, indicating that they are bulk electron traps. The so-called "signature plots" of these peaks A-D are shown in **Fig.4**. The data points seem to lie on the solid lines reported in the literature as originating from P-vacancy and their complexes. The peak D, reported to be due to P-vacancy, had the largest peak height. The energy distance of this level from the valence band maximum is about 1.7 eV, corresponding to "D" peak in PL. On the other hand, the high temperature broad peak E showed strong bias dependence. This seems to come from interface states at the Au/InGaP Schottky interface.

Under F_{TBP} higher than 4-5 sccm, the peaks A-D were almost completely removed, suggesting that these peaks are related to defects produced by insufficient supply of phosphorous. Thus, PL intensity increase with F_{TBP} in **Fig.1** can be understood by reduction of bulk deep levels.

However, even grown under high F_{TBP} conditions, QWs showed a peak near 1.7 eV. This suggests that this peak comes from the defects lying in the vicinity of the heterointerface. A strong experimental evidence for this was obtained in the S3 samples where a GaAs thin layer was grown on a thick InGaP layer. This sample showed strong 1.7 eV peak in addition to the GaAs peak.

Further CL study on S2 sample has shown that peaks around 1.7 eV becomes visible in addition to the edge emission peak even in S2 samples, if the acceleration voltage of the electron beam, V_{acc}, was made sufficiently large. As an example, **Figure 5** shows the CL spectrum at 5 K of an S2 sample grown under F_{TBP}=8 sccm taken under

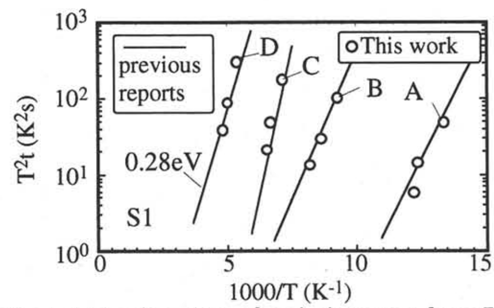

Fig.4 Arrhenius plots of emission rates from DLTS.

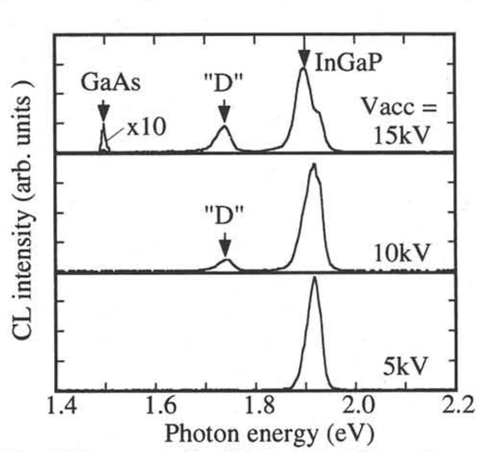

Fig.5 CL spectra for S2 sample (F_{TBP}=8sccm).

V_{acc} from 5 to 15 kV. At V_{acc}= 5 kV, only a peak near InGaP band edge was observed. On the other hand, At V_{acc} larger than 10 kV, additional peak "D" appeared near 1.7 eV, and its peak intensity increased with the increase of V_{acc}. Since higher values of V_{acc} result in deeper penetration of electrons, this result clearly indicates that the deep level responsible for the additional "D" peak is not distributed uniformly in the InGaP layer, but is localized in the vicinity of the InGaP/buffer GaAs interface down below.

A similar analysis was made on S4 QW samples, and led to a similar conclusion. The model for luminescence obtained in this study is shown in **Fig.6**. The most likely origin of the dominant trap peak near 1.7 eV is P-vacancy in InGaP formed near both of the GaAs/InGaP and InGaP/GaAs interfaces during long growth interruption for group-V switching

With this understanding, trials were made to grow QWs under large values of F_{TBP} and without growth interruption at the heterointerfaces. The resultant PL spectrum is shown in **Fig. 7**. Here, only intense and narrow PL peak corresponding to emission from the QW itself was observed. This is believed to be due to the suppression of the formation of P vacancies defects at heterointefaces.

References

[1] H. Sai et al., Jpn. J. Appl. Phys. **38,** 824 (1999).

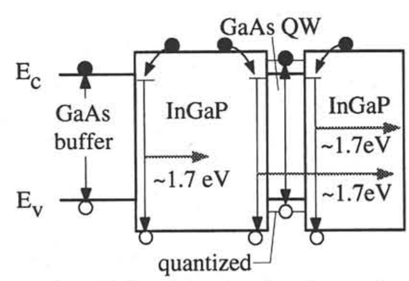

Fig.6 Considerable band structure

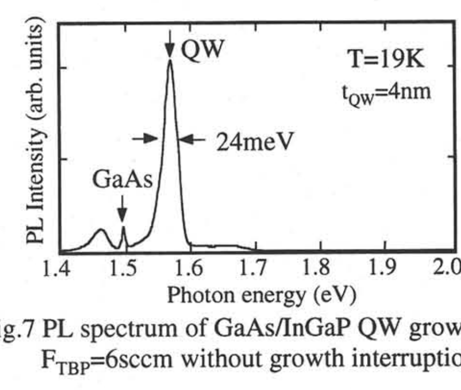

Fig.7 PL spectrum of GaAs/InGaP QW grown under F_{TBP}=6sccm without growth interruption.