Extended Abstracts of the 1999 International Conference on Solid State Devices and Materials, Tokyo, 1999, pp. 48-49

Effects of Strain on Highly-Mismatched AlGaN/GaN Multiple Quantum Wells

Norio Iizuka and Nobuo Suzuki

Advanced Discrete Semiconductor Technology Laboratory, Toshiba Corporation,
1, Komukai Toshiba-cho, Saiwai-ku, Kawasaki 210-8582, Japan
Phone: +81-44-549-2141 Fax: +81-44-520-1501 e-mail: nori.iizuka@toshiba.co.jp

1. Introduction

AlGaN/GaN multiple quantum wells (MQWs) have a focus of attention due to the possibility of their application to optical devices such as distributed Bragg reflector (DBR) mirrors [1], ultra violet (UV) light emitting diodes (LEDs) [2] and intersubband transition (ISBT) devices [3]. To achieve operations of LEDs and ISBT devices at short wavelength, it is necessary to reduce the well thickness in the MQWs. To grow MQWs with thin wells on GaN layers, one should consider the strain effects due to the lattice mismatch between the barrier and the well. The strain effects should be enhanced when the Al content and the barrier/well ratio are high. In the case of $Al_{0.65}Ga_{0.35}N$/GaN MQWs with narrow well thickness of 1.8-3.5 nm and the barrier thickness of 2.5 -3.1 nm, it was reported that the photoluminescence (PL) energy of the MQWs where the wells are unstrained is different from the PL energy of MQWs where the wells are strained because of the difference of piezoelectric field [4].

In this work, it is further investigated how the strain effects depend on the thicknesses of wells and barriers when the wells are thinner. A sharp PL spectrum from MQWs with the well thickness of 1.3 nm is reported at the wavelength as short as 314.4 nm.

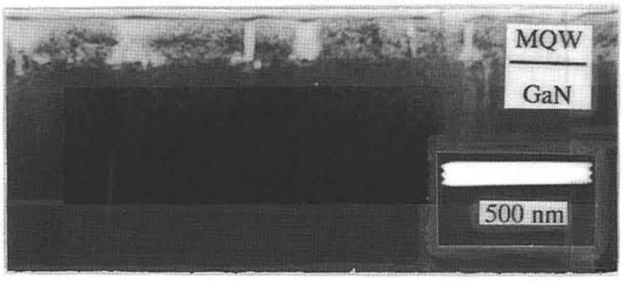
2. Experiments

Growths were carried out by an atmospheric pressure MOVPE. Each MQW structure was grown following an approximately 2-um-thick GaN layer on a (0001) sapphire. TMG (trymethilgallium), TMA (trymethylaluminum) and NH_3 (ammonia) were used as source gases. The growth temperature was approximately 1100°C. Al content was 0.65, and so the samples are assumed to be highly mismatched (1.6 %). All samples consisted of 30 quantum wells. Two groups of samples, group I and group II, were grown in different runs. In group I, the barrier thickness was set at 3.8 nm. The well thicknesses were 1.0 (sample A), 1.3 (B), 1.8 (C), 2.6 (D) and 3.1 nm (E). On the contrary, in group II, well thickness was set at 1.3 nm. The barrier thicknesses were set at 1.3 (sample F), 2.0 (G) and 2.8 nm (H). The samples were examined by an optical microscope, TEM (transmission electron microscopy) and PL. PL spectra were obtained by using SHG (second harmonic generation) of Ar laser (257 nm) at 77K.

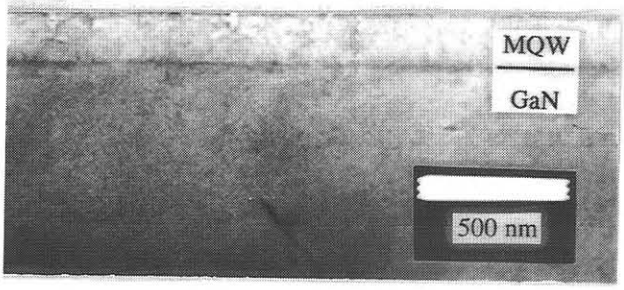
3. Results and discussions

For samples of group I, cracks across MQWs were observed only on samples D and E. The cracks are supposed to be caused by the difference in the thermal expansion coefficient between the MQWs and the underlying GaN layer. Since samples D and E have lower average Al composition, the difference of the thermal expansion coefficient should be smaller in these samples. Thus, one would suppose that they would be the last ones to have cracks. The result, however, was the opposite. TEM images of samples B and D shown in Fig.1(a) and (b), respectively, reveal the reason. In both figures, MQWs and the underlying layer are seen. White segments penetrating the MQWs are the areas where the lattice is disordered. It is found that sample B has more lattice disordered areas in the MQWs. Although a TEM image is not shown here, sample A has many disordered areas too. These results suggest that the disordered areas play a role of a buffer for the energy which produces cracks.

In Fig. 2, PL spectra of group I samples are shown. The peaks around the wavelength of 357 nm are from GaN layers which are grown beneath the MQWs. Single peaks are observed for samples A, D and E, whereas double peaks are observed for sample B, and sample C seems to have two peaks which overlap each other. In Fig.3, energies of these peaks are plotted as a function of well thickness. Calculated energies are also plotted for the cases when the well and the barrier are assumed to be unstrained, respectively. This figure suggests that the peaks of sample D and E and the lower peaks of sample B and C have the same origin and the higher energy peaks of sample B and C and the peak of sample A have a different origin. The lower energy peaks agree with the calculated energies when the barrier is



(a)



(b)

Fig.1 TEM photographs for samples (a) B and (b) D. White portions in the MQW layers are where the lattices are disordered. In sample B, more disordered regions are seen.

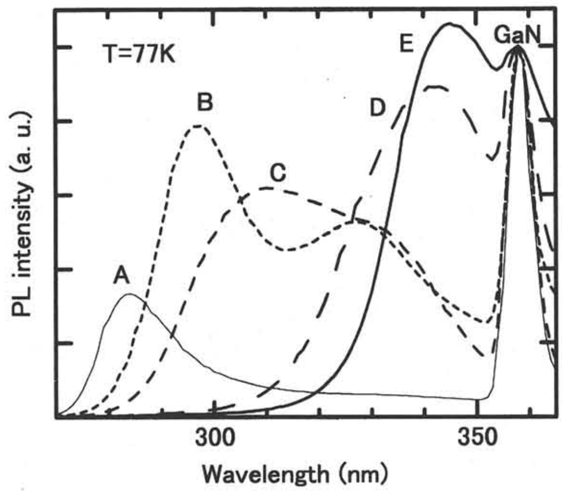


Fig. 2 PL spectra of $Al_{0.65}Ga_{0.35}N$/GaN MQWs with the well thickness of (A) 1.0, (B) 1.3, (C), 1.8, (D), 2.6 and (E) 3.1 nm. The peaks at 357 nm are from the underlying GaN layers.

assumed to be strained. And for the wider-well samples, only the lower energy peak is observed. Thus, they are considered to originate from the quantized levels when the MQWs are lattice-matched with the underlying GaN layer. It is speculated that the higher energy peak is related to the strain in the wells because it is found in the narrower-well samples, in which the MQWs are likely to relax and lattice-matched with the barrier. Figure 3 indicates that the experimental results are close to the calculated value for the case in which barriers are unstrained. From the result that samples B and C have two peaks, it is considered that in these samples two kinds of state or region co-exist; one is the area where the well is unstrained and the other is the region where the well is strained.

In Fig.4, PL spectra of group II are shown. The peak wavelengths of sample F and G are similar whereas the peak of sample H is at shorter wavelength of 304.8 nm. Sample H, however, is considered to be relaxed because the PL spectrum is broad (FWHM = 216 meV). With sample F, which has the thinnest barriers and accordingly less strained structure, the narrowest spectrum (FWHM = 93 meV) is obtained at the wavelength as short as 314.4 nm. The peak of sample F is smaller than that of sample G. This may be attributed to the thin barriers which lead to weak confinement of electrons in the wells. With thinner barriers, the peak would be smaller.

4. Conclusions

The crystalline quality and the optical properties were investigated for the MQWs with various well and barrier thicknesses. In the samples with narrow wells and thick barriers, the formation of cracks is suppressed due to the increase of disordered areas. Two kinds of region co-exist in the wells; one is strained and the other is unstrained, which leads to the double peaks in the PL spectrum. With a thinner well sample, the wells are completely relaxed and the PL spectrum shows a single but broad peak. By reducing the barrier thickness, the wells are kept unstrained. With a sample with the well thickness of 1.3 nm and the barrier thickness of 1.3 nm, a sharp PL peak was observed at the wavelength as short as 314.4 nm.

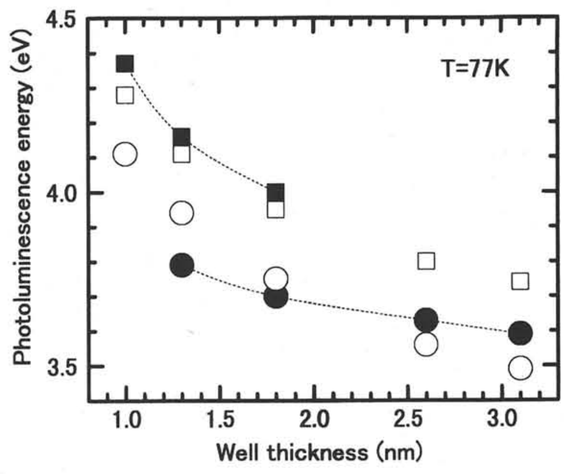


Fig.3 PL peak energy vs well thickness. Solid circles and rectangles are experimental results. Open circles and rectangles are calculated results for the case in which the barrier is strained and the case in which the well is strained, respectively.

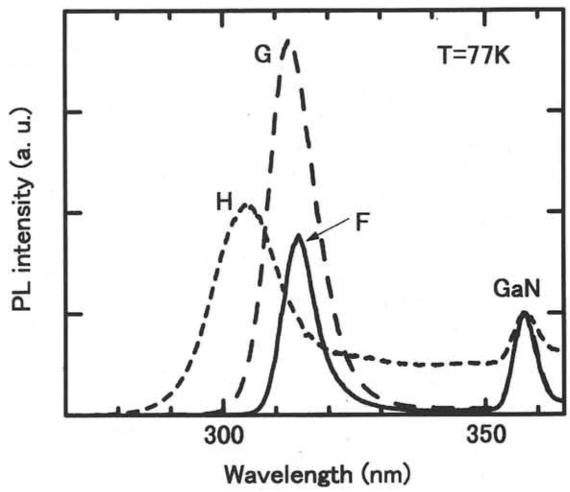


Fig. 4 PL spectra of $Al_{0.65}Ga_{0.35}N$/GaN MQWs with the barrier thickness of (F) 1.3, (G) 2.0, (H) 2.8 nm. All well thicknesses are 1.3 nm. The peaks around 357 nm are from the underlying GaN layers.

Acknowledgments

The authors would like to thank Dr. Matsumoto for TEM observation and Dr. R. A. Hogg for the calculation of the energy of the quantized levels.

References

[1] Y. Someya and Y. Arakawa, Appl. Phys. Lett., **73**, 3653 (1998)

[2] J. Han, M. H. Crawford, R. J. Shul, J. J. Figiel, M. Banas, L. Zhang, Y. K. Song, H. Zhou and A. V. Nurmikko, Appl. Phys. Lett. **73**, 1688 (1998)

[3] N. Iizuka and N. Suzuki, The 25th International Symposium on Compound Semiconductors, Fr1B-1 (1998)

[4] R. A. Hogg, C. E. Norman, A. J. Shields, M. Pepper and N. Iizuka, The 9th International Conference on Modulated Semiconductor Structures, P03 (1999)