Extended Abstracts of the 1999 International Conference on Solid State Devices and Materials, Tokyo, 1999, pp. 198–199

Comparison of Optical Properties in GaN/AlGaN and InGaN/AlGaN Single Quantum Wells

Shigefusa Chichibu, Takahiro Deguchi[1], Akiko Setoguchi[a], Mutsumi Sugiyama[a], Hisayuki Nakanishi[2], Takayuki Sota[1], Takashi Mukai[3] and Shuji Nakamura[3]

Institute of Applied Physics, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8573, Japan
Phone and Fax: +81-298-53-5289 e-mail: chichibu@ims.tsukuba.ac.jp
[1]Department of Electrical, Electronics, and Computer Engineering, Waseda University, Shinjuku, Tokyo 169-8555, Japan
[2]Department of Electrical Engineering, Science University of Tokyo, 2641 Yamazaki, Noda, Chiba 278-8510, Japan
[3]Department of Research and Development, Nichia Chemical Industries Ltd., 491 Oka, Kaminaka, Anan, Tokushima 774-8601, Japan

1. Introduction

Major developments of III-nitride semiconductors [1-3] have led to the commercial production of quantum well (QW) structure blue/green light emitting diodes (LEDs) [2] and to the sample forwarding of laser diodes (LDs) [2] lased at 400 nm with lifetimes more than 10,000 hours. InGaN alloys have attracted great interest since they serve as active regions of bright UV, blue, green, and amber single quantum well (SQW) LEDs and multi-quantum well (MQW) LDs. Despite the fact that InGaN is exclusively used as an active region of these devices, emission mechanisms of InGaN bulk materials and QW structures are not yet fully understood.

In this work, fundamental electronic modulations in strained AlGaN/GaN and AlGaN/InGaN SQWs are treated to explore the reason why InGaN devices emit bright luminescences in spite of the large threading dislocation (TD) density up to 10^{10} cm^{-2}.

2. Experiments

The measured samples were (a) 5-nm-thick GaN SQW with $Al_{0.15}Ga_{0.85}N$ barriers doped with Si or Mg grown on thick $Al_{0.1}Ga_{0.9}N$:Si layer and (b) 5.5-nm-thick In-doped GaN (InGaN) UV-SQW LED structure [4] that were grown on thick n-GaN:Si layer. They were grown on sapphire substrates by two-flow MOCVD technique [2].

In measuring the photoluminescence (PL) spectra, the 325 nm line of a cw He-Cd laser was used as an excitation source. The PL signal was dispersed by a 67-cm focal length grating monochromator and was detected by the photomultiplier. The accuracy and resolution of the system was 0.5 and 2 meV, respectively, at a wavelength of 350 nm. The He-Cd laser was also used as a pump light for photoreflectance (PR) measurements. PR spectra were taken in near-normal reflection angle. All measurements were carried out from 10 K to RT.

3. Results and Discussion

Effects of the internal electric field, F, across the QW, which is a sum of the fields due to spontaneous and piezoelectric polarizations and pn junction field, on the quantized energy levels are described to show how F changes them. Indeed F causes the redshift of the QW resonance energy through the quantum confined Stark effect (QCSE). Even under such high F stronger than 500 kV/cm, a 5-nm-thick GaN SQW [sample (a)] exhibited a clear excitonic absorption peak at 10 K and even at room

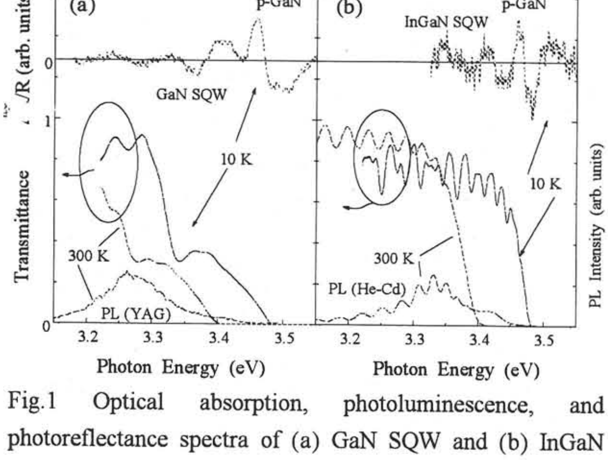

Fig.1 Optical absorption, photoluminescence, and photoreflectance spectra of (a) GaN SQW and (b) InGaN SQW structures with AlGaN barriers.

[a] on leave from Department of Electrical Engineering, Science University of Tokyo, 2641 Yamazaki, Noda, Chiba 278-8510, Japan

temperature (RT), as shown in Fig. 1(a). The observation of the excitonic absorption supports our hypothesis that quantum confinement is enough provided that QW rhickness L is smaller than the three dimensional free exciton Bohr radius a_B [5]. Despite this fact, spontaneous emission intensity of the GaN SQW is very low. The structure does not exhibit stimulated emission. Indeed the PL spectrum of GaN/AlGaN in Fig. 1(a) was taken under high excitation condition using 3rd harmonic of YAG laser. This poor luminescence proiperty may be due to short lifetime of carriers in GaN owing to defects or impurities [6] combined with the QCSE.

Conversely, slightly In-alloyed GaN SQW [sample (b)] exhibited bright UV emission even under low excitation condition using cw He-Cd laser and showed the stimulated emission from the sample edge under high excitation at RT. These findings clearly indicate that alloying or doping of In changes drastically the electronic structure of GaN [7]. It is interesting to note that the energy of the QW resonance structure in sample (b) is higher than that of sample (a) despite that the original bandgap of InGaN [sample (b)] is smaller than that of GaN [sample (a)]. The result implies that F in the InGaN SQW grown on thick GaN base is smaller than that in the GaN SQW grown on thick AlGaN base layer.

In addition, effective in-plane localization of the QW excitons in quantum disk size potential minima, which are produced by nonrandom alloy potential fluctuation enhanced by the large bowing parameter and F, has been found to play an important role to produce efficient emission in InGaN alloys [5,8]. Therefore it seems that doping of In in GaN may produce some effective bypass for the QW excitons into radiative recombination. From the fact that even bulk InGaN emits bright emission against the piezoelectric field exists in it, effective localization [8] of excitons and carriers, especially holes [9], is considered to serve as the bypass.

4. Conclusion

In summary, doping or alloying of In in GaN SQW was shown to prevent carriers from being trapped into nonradiative pathways to improve the luminescence intensity. From the fact that piezoelectric QCSE only separates the e-h pair in the QW, the improvement is considered to be due to generation of some bypass by the In-doping.

References

[1] For a review, see S. Strite and H. Morkoc, J. Vac. Sci. Technol. B **10**, 1237 (1992), and references cited therein.

[2] summarized in S. Nakamura and G. Fasol, The Blue Laser Diode (Springer-Verlag, Berlin, 1997).

[3] I. Akasaki and H. Amano, Jpn. J. Appl. Phys. **36**, 5393 (1997).

[4] T. Mukai, M. Yamada and S. Nakamura, Jpn. J. Appl. Phys. **37**, L1358 (1998).

[5] S. Chichibu, T. Sota, K. Wada, S. DenBaars and S. Nakamura, Mat. Res. Soc. Internet J. Nitride Semicond. Res. **4S1**, G2.7 (1999).

[6] S. Chichibu, H. Marchand, M. S.Minski, S.Keller, P.Fini, J. Ibbetson, S. Fleischer, J. Speck, J. Bowers, E. Hu, U. Mishra, S. DenBaars, T. Deguchi, T. Sota, and S. Nakamura, Appl. Phys. Lett. **74**, 1460 (1999).

[7] Y. Narukawa, Y. Kawakami, Sh. Fujita, and S. Nakamura, Phys. Rev. B **59**, 10283 (1999).

[8] S. Chichibu, T. Azuhata, T. Sota and S. Nakamura, Appl. Phys. Lett. **69**, 4188 (1996).

[9] L. Bellaiche, T. Mattila, L. Wang, S. Wei and A. Zunger, Appl. Phys. Lett. **74**, 1842 (1999).