國科會專題研究結案報告

氮化鎵系列化合物光電及材料特性研究

主持人：楊志忠 國立台灣大學光電所

NSC 90-2112-M-002-052

執行期限：九十年八月一日至九十一年十月三十一日

中文摘要：

本年研究中，我們展示了 1) 在氮化銦鎵/氮化鎵量子井中量子點的形成，2) 在氮化銦鎵/氮化鎵量子井中銦聚集顆粒內載子動態變化，3) 光學與材料之特性隨不同氮化銦鎵/氮化鎵量子井厚度之變化，4) 熱處理對光學與材料之特性的影響。

Abstract:

We have demonstrated 1) the formation of quantum dots in InGaN/GaN quantum well structures, 2) carrier dynamics mechanisms in aggregated structures in InGaN/GaN quantum well samples, 3) optical and material properties of InGaN/GaN quantum well structures of different quantum well widths, and 4) thermal annealing effects on InGaN/GaN quantum well structures.

Summary:

We have shown TRPL measurement results with varying parameters of temperature, PL photon energy, excitation photon energy and excitation power in three InGaN/GaN quantum well samples of the same geometry but different nominal indium contents. With the excitation photon energy below the barrier potential level, multiple-component PL intensity decays were observed for PL photon energy larger than a certain value when sample temperature was fixed and for sample temperature higher than a certain level when the relative position of photon energy with respect to the PL peak was fixed. Also, near the PL spectral peak delayed slow rise of PL intensity could be observed. The early-stage decays and the delayed slow rises were interpreted as the results of carrier transport from relatively weaker localized states into stronger localized states. The process of carrier transport was enhanced with a certain amount of thermal energy. However, beyond a certain level non-radiative recombination dominated. With the excitation photon energy at the barrier potential level, the observed TRPL results were similar except that the extended decay times were generally shorter. In addition, the argument of the free excitons behavior of the three samples at high temperatures is consistent with previously reported HRTEM results. Among the three samples, with higher indium contents more strongly localized states exist and thus enhanced carrier transport activities occur.

Also, we have shown the dependencies of optical and material properties of thermally annealed InGaN/GaN QW samples on well width. In each sample of different QW widths, the results of temperature variations of PL spectral peak, integrated PL intensity and PL decay time showed consistent trends in varying annealing temperature. Different variation trends upon thermal annealing in different samples were also consistent with the results of HRTEM images. Generally speaking, thermal annealing at 800 ℃ of a narrow QW width (2 nm) structure led to regularly distributed QDs and improved optical quality. On the other hand, thermal annealing at 800 ℃ of a sample of larger QW width (4 nm) did not show QD formation. In this situation, even higher local strains might exist around QWs. Also, its optical quality was degraded.

Meanwhile, we have demonstrated the micro-structure variations upon post-growth thermal annealing at different temperatures

of InGaN/GaN QW structures of different QW widths. The HRTEM images showed that in a sample with a small QW width (2 nm), thermal annealing tended to form QDs of larger sizes (3-5 nm) such that arrayed QDs covered the designated QWs. In this situation, strain might be relaxed and quantum-confined Stark effect (QCSE) was reduced, leading to a higher radiative efficiency. Also, with the formed QD structures, the stronger carrier localization effect might make a significant contribution to the enhanced radiative efficiency. On the contrary, in a sample with a large well width (4 nm), thermal annealing tended to make the QW boundaries clearer. This process was even more significant when thermal annealing took place at a higher temperature (900 ℃). With the dominating QW structures, QCSE played the key role and the radiative efficiency was degraded. For a sample with the QW width in between (3 nm), the aforementioned QD and QW effects were supposed to mix.

Journal Publications:

1. Yung-Chen Cheng, Shih-Wei Feng, En-Chiang Lin, C. C. Yang, Cheng-Hua Tseng, Chen Hsu and Kung-Jeng Ma, "Quantum Dot Formation in InGaN/GaN Quantum Well Structures with Silicon Doping and Its Implication in the Mechanisms of Radiative Efficiency Improvement," accepted by Physica Status Solidi (b).
2. Yi-Yin Chung, Yen-Sheng Lin, Shih-Wei Feng, Yung-Chen Cheng, En-Chiang Lin, C. C. Yang, Kung-Jen Ma, Hui-Wen Chuang, Cheng-Ta Kuo and Jian-Shihn Tsang, "Quantum Well Width Dependencies of Post-growth Thermal Annealing Effects of InGaN/GaN Quantum Wells," revised for publication in J. Applied Physics.
3. Yen-Sheng Lin, Chih-Chiang Yan, Cheng Hsu, Kung-Jen Ma, Yi-Yin Chung, Shih-Wei Feng, Yung-Chen Cheng, En-Chiang Lin, C. C. Yang, Cheng-Ta Kuo, and Jian-Shihn Tsang, "A Microstructure Study of Post-growth thermally Annealed InGaN/GaN Quantum Well Structures of Various Well Widths," accepted for publication J. Crystal Growth.
4. Yung-Chen Cheng, Chern-Hua Tseng, Chen Hsu, Kung-Jen Ma, Shih-Wei Feng, En-Chiang Lin, C. C. Yang and Jenn-Inn Chyi, "Mechanisms for Photon Emission Enhancement with Silicon Doping in InGaN/GaN Quantum Well Structures," accepted for publication in J. Electronic Materials.
5. Yi-Yin Chung, Shih-Wei Feng, Yung-Chen Cheng, C. C. Yang, Yen-Sheng Lin, Kung-Jeng Ma, Hui-Wen Chuang, Cheng-Ta Kuo, and Jian-Shihn Tsang, "Optical and Material Characteristics of InGaN/GaN Quantum Well Structures with Embedded Quantum Dots," SPIE Proceeding, Vol. 4913, 2002.
6. Yen-Sheng Lin, Kung-Jen Ma, Cheng Hsu, Yi-Yin Chung, Chih-Wen Liu, Shih-Wei Feng, Yung-Chen Cheng, C. C. Yang, Hui-Wen Chuang, Cheng-Ta Kuo, Jian-Shihn Tsang, Thomas E. Weirich and Joachim Mayer, "Formation of Quantum dots with Post-growth Thermal Annealing of InGaN/GaN Quantum Wells," SPIE Proceeding, Vol. 4913, 2002. **(invited)**
7. S. Miasojedovas, S. Juršėnas, G. Kurilčik, A. Žukauskas, Shih-Wei Feng, C. C. Yang, Hui-Wen Chuang, Cheng-Ta Kuo, and Jian-Shihn Tsang, "Luminescence of Localized Excitons in InGaN/GaN Multiple Quantum Wells," accepted for publication in Physica Status Solidi (b).
8. Yi-Yin Chung, Shih-Wei Feng, Yung-Chen Cheng, En-Chiang Lin, C. C. Yang, Yen-Sheng Lin, Kung-Jeng Ma, Hui-Wen Chuang, Cheng-Ta Kuo, and Jian-Shihn Tsang, "Thermal Annealing Effects of InGaN/GaN Multiple Quantum Well Structures with Different Quantum Well Widths," accepted for publication in Physica Status Solidi (b).
9. Yen-Sheng Lin, Kung-Jen Ma, Cheng Hsu, Yi-Yin Chung, Chih-Wen Liu, Shih-Wei Feng, Yung-Chen Cheng, C. C. Yang, Hui-Wen Chuang, Cheng-Ta Kuo, Jian-Shihn Tsang, Thomas E. Weirich and

Joachim Mayer, "Quantum dot Formation with Post-growth Thermal Annealing of InGaN/GaN Quantum Wells," accepted for publication in Physica Status Solidi (b).

10. Shih-Wei Feng, Yung-Chen Cheng, Yi-Yin Chung, En-Chiang Lin, C. C. Yang, Chih-Chiang Yan, Yen-Sheng Lin, Cheng Hsu, Kung-Jen Ma and H. X. Jiang, "Strong Green Luminescence in Quaternary InAlGaN Thin Films," accepted for publication in Applied Physics Letters.
11. Shih-Wei Feng, Yung-Chen Cheng, Yi-Yin Chung, C. C. Yang, Yen-Sheng Lin, Cheng Hsu, Kung-Jen Ma, and Jen-Inn Chyi, "Impact of Localized States on the Recombination Dynamics in InGaN/GaN Quantum Well Structures," J. Applied Physics, Vol. 92, No. 8, pp. 4441-4448, October 2002.
12. Yen-Sheng Lin, Kung-Jen Ma, C. C. Yang, and Thomas E. Weirich, "Effects of Post-Growth Thermal Annealing on the Indium Aggregated Structures in InGaN/GaN Quantum Wells," J. Crystal Growth, Vol. 242, pp. 35-40, 2002.
13. Shih-Wei Feng, Yi-Yin Chung, Chih-Wen Liu, Yung-Chen Cheng, C. C. Yang, Ming-Hua Mao, Yen-Sheng Lin, Kung-Jen Ma, Jen-Inn Chyi, "Multiple-component Photoluminescence Decay Caused by Carrier Transport in InGaN/GaN Quantum Wells with Indium Aggregation Structures," Applied Physics Letters, Vol. 80, No. 23, pp. 4375-4377, 2002.
14. Yen-Sheng Lin, Kung-Jen Ma, Cheng Hsu, Yi-Yin Chung, Chih-Wen Liu, Shih-Wei Feng, Yung-Chen Cheng, Ming-Hua Mao, C. C. Yang, Hui-Wen Chuang, Cheng-ta Kuo, Jian-Shihn Tsang, and Thomas E. Weirich, "Quasi-regular Quantum-dot-like Structure Formation with Post-growth Thermal Annealing in InGaN/GaN Quantum Wells," Applied Physics Letters, Vol. 80, No. 14, pp. 2571-2573, 2002.
15. Shih-Wei Feng, Chi-Chih Liao, C. C. Yang, Yen-Sheng Lin, Kung-Jeng Ma, Chin-An Chang, E-Tsou Wu, Fung-Jei Lai, Chang-Cheng Chuo, Chia-Ming Lee, and Jen-Inn Chyi, "Comparison of Photoluminescence Properties Between MBE and MOCVD Grown InGaN/GaN Multiple Quantum Well Structures," J. Chinese Institute of Electrical Engineering, Vol. 9, No. 2, pp. 103-108, 2002.
16. Yen-Sheng Lin, Kung-Jeng Ma, Shih-Wei Feng, Chi-Chih Liao, C. C. Yang, Chang-Cheng Chuo, Chia-Ming Lee, and Jen-Inn Chyi, "Compositional Inhomogeneities in InGaN/GaN Quantum Wells Studied with High Resolution Transmission Electron Microscopy," J. Chinese Institute of Electrical Engineering, Vol. 9, No. 2, pp. 121-126, 2002.
17. Shih-Wei Feng, Chin-Yi Tsai, Yung-Chen Cheng, Chi-Chih Liao, C. C. Yang, Yen-Sheng Lin, Kung-Jeng Ma, and Jen-Inn Chyi, "Temperature Dependence of Phonon-Replica Transitions in InGaN/GaN Quantum Well Structures," Optical and Quantum Electronics, December 2002.
18. Shih-Wei Feng, Yung-Chen Cheng, Yi-Yin Chung, Chih-Wen Liu, Ming-Hua Mao, C. C. Yang, Yen-Sheng Lin, Kung-Jeng Ma, and Jen-Inn Chyi, "Dynamics Carrier Relaxation in InGaN/GaN Multiple Quantum Well Structures," SPIE Proceedings Vol. 4643, 2002.
19. Yung-Chen Cheng, Chi-Chih Liao, Shih-Wei Feng, C. C. Yang, Yen-Sheng Lin, Kung-Jeng Ma, and Jen-Inn Chyi, "Activation of p-type GaN with Irradiation of the Second-harmonics of a Q-switched Nd:YAG Laser," Physica Status Solidi (b), Vol. 228, No. 2, pp. 357-360, 2001.
20. Shih-Wei Feng, Yung-Chen Cheng,, Chi-Chih Liao, Yi-Yin Chung, Chih-Wen Liu, C. C. Yang, Yen-Sheng Lin, Kung-Jeng Ma, and Jen-Inn Chyi, "Two-Component Photoluminescence Decay in InGaN/GaN Multiple Quantum Well Structures," accepted for publication in Physica Status Solidi (b), Vol. 228, No. 1, pp. 121-124, 2001.

21. Shih-Wei Feng, Yung-Chen Cheng, Yi-Yin Chung, Chih-Wen Liu, C. C. Yang, Yen-Sheng Lin, Kung-Jeng Ma, and Jen-Inn Chyi, "Carrier Dynamics in InGaN/GaN Multiple Quantum Wells," SPIE Proceedings, Volume 4594, 2001.