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# Triple Luminescence Peaks Observed in the InGaAsN/GaAs Single Quantum Well Grown by MOVPE

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## 1. Introduction

Dilute-nitride materials recently have drawn much of attentions due to their promising application in long-haul optical communication. However, the alloy composition fluctuation remains a serious issue in III-N-V alloys due to a very large electronegativity difference between nitrogen and arsenic. Several studies have reported the effects of nitrogen-clustering or compositional fluctuations in these epitaxial layers[1,2], which add complications to the controls of the laser emission wavelength and threshold-current density. Therefore, it's valuable to understand how the N and In are distributed in InGaAsN. In the present article, the triple luminescence peaks were observed by photoluminenscence measurements in the highly nitrogen incorporated $In_{0.33}Ga_{0.67}As_{0.978}N_{0.022}$ (33 Å)/ GaAs(439 Å) single quantum well. RTA treatments and temperature dependent PL measurements were also performed on the InGaAsN SQW to study its clustering nature.

## 2. Results and Discussion

As shown in Fig.1(a), the 300K PL measurement of as-grown InGaAsN SQW revealed only one peak, located at 0.947eV on the lower energy side and we denoted this peak as $P_L$. However, additional two peaks, namely, $P_M$ and $P_H$, were also identified on the higher energy side of 23K PL spectrum. The triple-peak phenomenon was also observed in the low temperature PL spectrum of the 550°C RTA-annealed samples, shown in Fig.1(b).

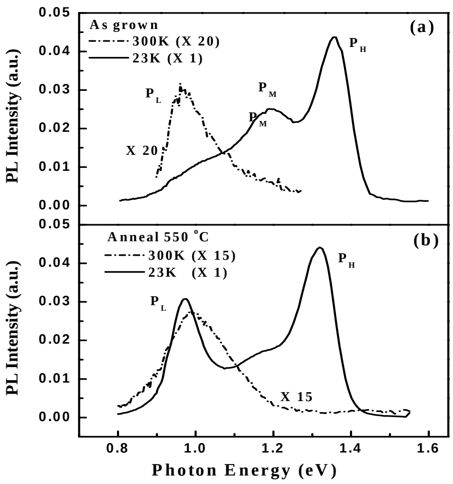


Fig. 1

In order to investigate the extraordinary optical properties, the 23K PL multiple spectra were obtained at different laser excitation powers for a 550°C RTA-annealed sample, as shown in Fig.2. Since the peak of $P_M$ was shrouded by the other two peaks, the intensity and position of $P_M$ could not be resolved accurately. Thus, the discussion here is mainly focused on the variations of $P_H$ and $P_L$ with respect to different excited powers. As shown in Fig.2(a), the peak emission energies of $P_L$ were shifted continuously toward higher energies in response to an increase in the laser excitation power. Furthermore, under low excitation conditions the peak intensities of both $P_H$ and $P_L$ increased linearly with the excitation power. However, the intensities of $P_L$ began to saturate as the excitation power continuingly increased. Fig. 2(b) shows the PL peak intensity as a function of laser excitation power. Obviously, the intensities of $P_L$ saturated at the laser excitation power greater than 200 mW, while those of $P_H$ still remained proportional to the excitation power. The blue-shift tendency and saturation behavior of $P_L$ altogether revealed the transition of $P_L$ was dominated by the nature of the relatively few states in the energy band.

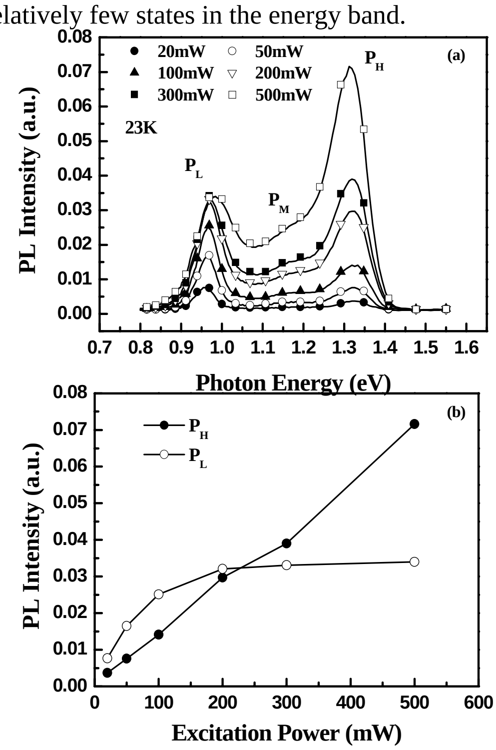


Fig. 2

Figure 3 shows the 23K PL spectra of the InGaAsN/GaAs SQW for as-grown sample and RTA-annealed samples at temperatures of 550, 600 and 650°C for 15 seconds. The intensities of $P_L$ increased and peak emission wavelength blue-shifted with increasing annealing temperatures; the very phenomena were commonly observed in the dilute-nitride materials and were reported in several articles [3,4]. In addition, the peak emission energies of $P_H$ remained unchanged irrespective of annealing temperature, shown in the inset of Fig.3. Since the blue-shift observed in PL spectra could be due to the transformation of local N configuration, the invariant peak position of $P_H$ after thermal treatments implied that the responsible transition was non-nitrogen related. By comparing the peak energy shifts of $P_H$ and $P_L$, it was reasonable to conclude that regions with nearly zero and heavy nitrogen incorporations are responsible for the transitions of $P_H$ and clustering-induced $P_L$, respectively.

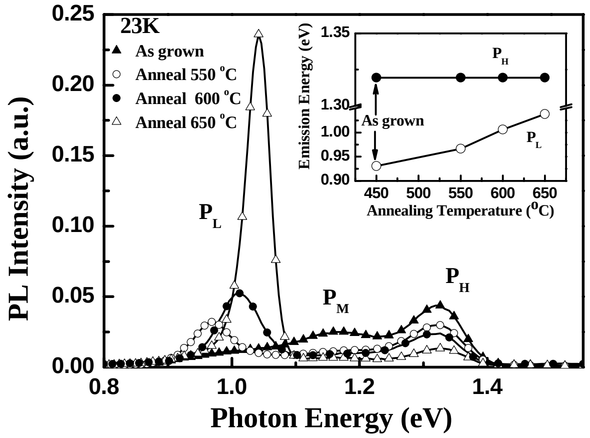


Fig. 3

Figure 4 depicts the temperature-dependent PL spectra of InGaAsN/GaAs SQW after 550°C RTA annealing. the intensity of both $P_H$ and $P_L$ decreased with increasing temperatures. The intensity of $P_H$ decreased faster than that of $P_L$, and finally vanished at room temperature. As of result only one peak, $P_L$, was observed in the PL spectrum. A reasonable explanation for this strange optical property could be attributed to a defect state existed in the GaAs barrier, although carriers were mostly trapped in the QW layer. Under ideal situation, it is logical to state that the carrier recombination only occurs in the quantum well, but not in the GaAs barrier layer. However, Vening *et al.*[5] concluded instead that defects created during the barrier layer growth are responsible for the thermal quenching of InGaAs/AlGaAs QW's PL efficiency. Recently, T. K. Ng *et al.*[6] have similarly reported the photoluminescence quenching mechanisms associated with InGaAsN/GaAs quantum well grown by solid-source MBE. They employed a dual-activation energy (DAE) model to fit on the profile of integrated PL intensity versus temperature. To our estimation a larger activation energy of $E_a$ = 35.3 meV is required to thermally excite the carriers from the well to a defect state of GaAs barrier, which is responsible for a significant PL quenching effect at temperatures above ~120K, which is demonstrated on the inset of Fig.4. Hence, in our case we believe the thermal quenching effect is a predominant mechanism to explain why $P_H$ vanishes at elevated temperatures.

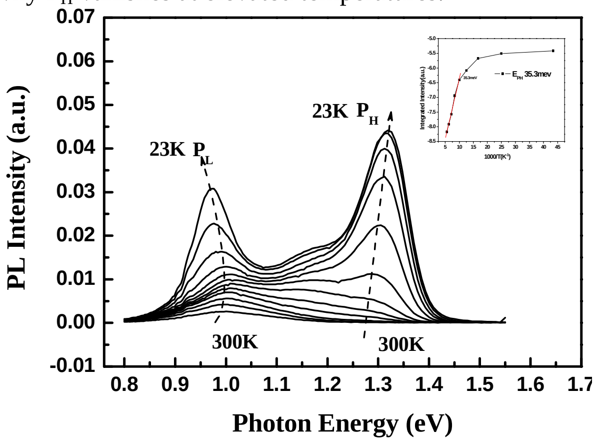


Fig. 4

## 3. Conclusions

In summary, the PL measurements under different temperatures and excitation powers were conducted to reveal the clustering nature of InGaAsN SQW. Our studies have suggested that the regions with high and nearly-zero nitrogen incorporation are primarily responsible for the clustering-induced and non-clustering related emission peaks as identified by the PL measurements, respectively. In addition, we believe the eventual disappearance of non-clustering related peak at room temperature could likely be attributed to the thermal quenching effect.

## Acknowledgements

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