CFG6 **11:30 am**

Formation of Quasi-regular Quantum Dots with Post-growth Thermal Annealing and Their Optical Characteristics in InGaN/GaN Quantum Wells

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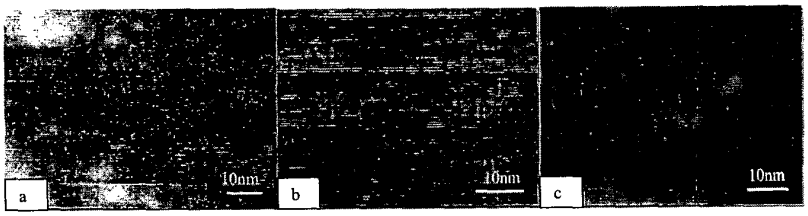
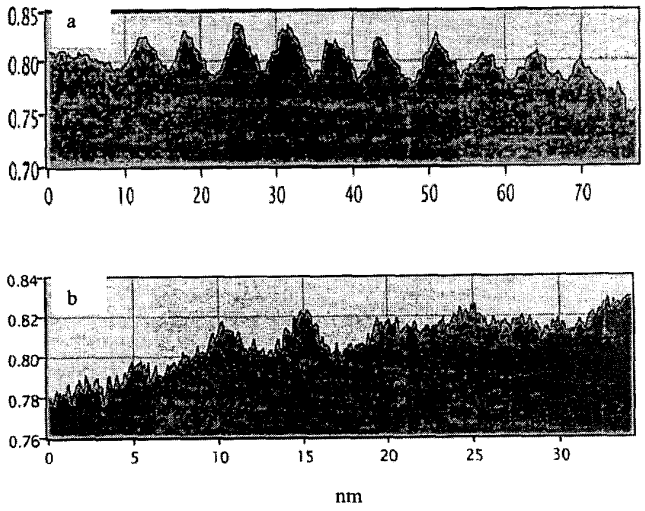
Quantum-dot (QD)-like structures have been observed in InGaN/GaN quantum wells (QWs). Such structures are formed because of the large lattice mismatch between InN and GaN. With high-resolution transmission electron microscopy (HRTEM), randomly distributed clusters of indium aggregation and phase-separated InN were observed. The cluster structures form potential minimums (called localized states) for trapping carriers for efficient photon emission. Such indium-aggregated distributions are basically located in the QW layers; however, they usually diffuse into barriers.[1] In InGaN compounds, post-growth thermal annealing (PGTA) processes for changing cluster structures and their photon emission properties were reported.[2] In this paper, we report the formation of quasi-regular QDs from randomly distributed indium-aggregated clusters after PGTA of an InGaN/GaN QW sample. It was found that with PGTA temperature at 900°C, indium distribution was better confined in the QW layers and quasi-regular QDs were formed. However, the regular structure disappeared when the PGTA temperature was 950°C. The optical measurements showed quite consistent trends of blue shift and spectral width variation.

The MOCVD-grown InGaN/GaN QW sample consisted of ten periods of InGaN QWs with 3.5/10 nm for wells/barriers. The growth temperatures were 1010 and 720°C for GaN and InGaN, respectively. The designated indium content was about 20%. As-grown samples were thermally annealed with temperature ranging from 800 to 950°C in nitrogen ambient for 30 min. Fig. 1 shows the HRTEM bright field images of the (a) as grown, (b) 900°C-annealed and (c) 950°C-annealed samples. The diffusive InGaN/GaN QW interfaces can be clearly seen in the as grown sample. The indium-rich clusters are irregularly dispersed and extended into the GaN barriers. Increasing the temperature leads to a better confinement of indium-rich clusters near InGaN QWs, as shown in Fig. 1(b). The average size of the indium-rich clusters becomes smaller after PGTA. The size homogeneity of QDs was also improved. Very fine indium-rich QDs (2–5 nm) were regularly dispersed inside the InGaN QWs after PGTA at 900°C. However, further increase of temperature to 950°C leads to a highly irregular structure (see Fig. 1(c)). A line scan of energy filter TEM along a QW in the sample of 900°C annealing is shown in Fig. 2(a). Quasi-regularly arrayed QDs with nearly the same indium concentration can be observed. Another line scan along a QW in the sample of 950°C annealing is shown in Fig. 2(b). The irregular distribution of compositional fluctuation can be observed. The formation of quasi-regular QD upon PGTA may arise from the following mechanism. High temperature annealing facilitates the movement of constituent atoms and interface reconstruction, which lead to sphere-like, energetically more stable indium-rich clusters. The fact that the clusters became smaller after PGTA can be attributed to the entropy-driven effect. Thermal energy at 900°C is sufficient to drive the system to a state of lower potential energy with a quasi-regular structure. When the temperature reached 950°C, the higher temperature caused coarsening of indium-rich clusters with the sizes exceeding the QW width. Such a process destroyed the QW structure.



CFG6 Fig. 1. HRTEM images of the (a) as-grown, (b) 900°C-annealed and (c) 950°C-annealed samples.



CFG6 Fig. 2. Energy filter TEM line scan results along QW of (a) 900°C-annealed and (b) 950°C-annealed samples.

References

1. Y.S. Lin, K.J. Ma, C. Hsu, S.W. Feng, Y.C. Cheng, C.C. Liao, C.C. Yang, C.C. Chuo, C.M. Lee, and J.I. Chyi, "Dependence of composition fluctuation on indium content in InGaN/GaN multiple quantum wells," Appl. Phys. Lett. 77, 2988 (2000).
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CFG7 **11:45 am**

Bleaching Dynamics of Resonantly Excited Excitons in GaN Thin Films at Room Temperature

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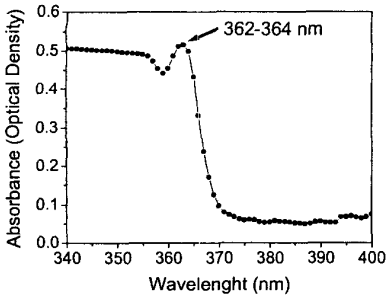
GaN-based semiconductors have received an ever-increasing interest for optoelectronic applications in the blue and ultraviolet spectral region. It is well known that optical properties near the band-edge are dominated by the many-body Coulomb correlation, or the dynamics of excitons. At room temperature, through interaction with longitudinal optical phonons, ionization of excitons plays an important role among various carrier dynamics. Exciton ionizations with time constant of a few hundred femtoseconds have been observed in semiconductor quantum wells at room temperature.[1,2] Through optical absorption measurement, exciton ionization has also

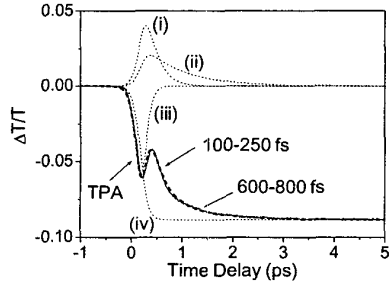


CFG7 **Fig. 1.** Absorption spectrum for unintentionally doped 2.5 μm GaN thin film. A strong exciton resonance around 363 nm is observed.

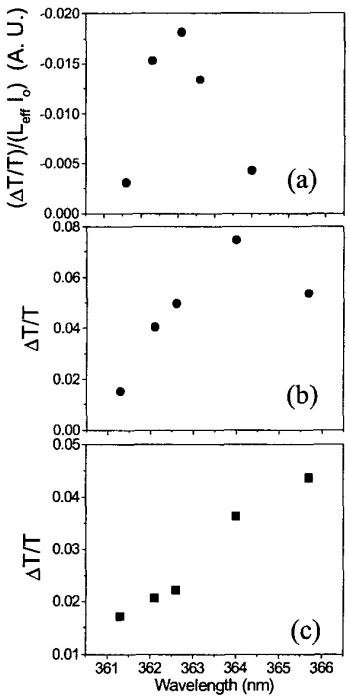
been observed in GaN epilayers up to room temperature.[3] By using transmission-type pump-probe measurement[4] around the exciton transition energy, we report, to our knowledge, the first direct measurement of exciton ionization process in wurzite GaN.

Fig. 1 shows the low-intensity absorption spectrum of GaN thin film used in our study. It is characterized by a strong resonant peak at energy 3.413 eV (363 nm) corresponding to the *A*-exciton,[5] and a relatively constant absorption above the bandgap 3.48 eV (356 nm). The experiments were performed using a standard transmission pump-probe technique with a UV pulse of width ~120 fs. Fig. 2 shows a typical measured probe transmission change $\Delta T/T$ of the nominally undoped GaN thin film versus probe delay with average photogenerated carrier density of 7×10^{17} cm^{-3} at room temperature. The pump/probe central photon energy is 3.42 eV (362.1 nm) corresponding to the *A*-exciton resonance. The solid line in Fig. 2 is the measured trace. The heavy dashed line is the convolution fitting result consisting of four kinds of carrier dynamics.[4] At zero time delay, a negative transmission decrease is recognized as the two-photon absorption (TPA) peak.

Fig. 3(a) shows the measured TPA absorption coefficient versus wavelength. The TPA exhibits an excitonic enhancement around 362 nm. After the TPA peak, a fast exponential decay time constant of 100–250 fs followed by a slow one of



CFG7 **Fig. 2.** Measured transient response of the unintentional doped GaN thin film at 362.1 nm. The solid line is probe transmission change. The heavy dashed line is fitting result with four fitting components: (i) fast exponential decay of time constant 100–250 fs, (ii) slow exponential decay of time constant 600–800 fs, (iii) TPA, and (iv) negative step function.



CFG7 **Fig. 3.** (a) Magnitude of the TPA component vs. laser excitation wavelength on unintentionally doped GaN thin film. (b) Magnitude of the fast time constant (200 fs) component vs laser excitation wavelength. (c) Magnitude of the slow time constant (750 fs) component vs laser excitation wavelength. The magnitudes are extracted under the same excited carrier density.

~700 fs can be extracted. The slow time constant was ascribed as the external thermalization time of the photoexcited electron-hole pairs into lattice temperature.[4] The fast decay time constant is interpreted as the ionization time of the resonantly created excitons. The wavelength dependences of these two time constants are plotted in Fig. 3(b) and (c), respectively. A resonance corresponding to the excitonic peak is observed for the fast time constant as shown in Fig. 3(b). However, the slow time constant does not possess a resonant feature. The delayed and prolonged thermalization time constant also indicates the ionization process of the resonantly excited excitons.

A pre-excitation experiment was also performed for comparison. The magnitude corresponding to the fast ionization time decreased significantly with respect to TPA and bandgap-renormalization terms. The weakening of this component can be ascribed to the suppression of exciton formation due to the large amount of the pre-injected background electron-hole plasma. Experimental measurements of strained and doped samples will be presented in the conference for further comparisons.

References

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CFH 10:15 am–12:00 pm
Room: 103

Applications of Ultrafast Optics

Keren Bergman, Tellium, Inc., USA, Presider

CFH1 **10:15 am**

Polarization Dynamics Induced by the "Virtual Excitation" of Spin-polarized Carriers: Applications to All-optical Polarization Switching

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Recently we have demonstrated an optically-addressed *coherent* polarization switch that is based on the near-resonant excitation of a *spin-polarized* population of "virtual excitons" in MQWs.[1] By taking advantage of the nonlinearities associated with a *virtual* carrier population, this near-resonant device exhibits a pulse-width-limited response; by operating near resonance it is capable of producing relatively large contrast ratios in thin samples; and finally, by generating a spin-polarized carrier population, the device produces a rotation of the signal polarization in unstrained MQWs. Here, we experimentally analyze the switching mechanisms by systematically performing spectrally and temporally resolved differential transmission measurements and by fully determining the polarization state of the transmitted signal as a function of time delay.

Our initial near-resonant spin switch measurements[1] were performed using the geometry shown schematically in the inset of Fig. 1. The 150 fs input signal pulses (from a Ti:saphire laser) were linearly s-polarized and were tuned below the heavy hole (hh) exciton as shown in the second inset. The control pulses were right circularly polarized, were spectrally narrowed by a pulse shaper, and were tuned below the hh resonance by ~23 meV to avoid resonant excitation. The signal beam was chopped, and the output signal that was passed by the analyzer was detected using a lock-in amplifier. Proof-of-principal measurements were performed at 100 K on a MQW sample consisting of 40 periods of 10-nm-wide GaAs wells alternating with 10-nm-thick $Al_{0.3}Ga_{0.7}As$ barriers. The switching performance is given by the open triangles in Fig. 1. The signal follows the shape of the cross correlation curve (not shown) and exhibits a pulse-width-limited switching time. A peak contrast ratio of ~140:1 is