Optimum design of silicon doping for emission enhancement of InGaN/GaN quantum well light-emitting devices

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Abstract: InGaN/GaN quantum well samples of various silicon doping conditions, including doping layers and concentrations, are compared in nano-structures and emission characteristics for design optimization. The best performance of barrier-doped samples originates from stronger carrier localization.

OCIS codes: (250.5230) Photoluminescence; (160.6000) Semiconductors, including MQW

Although silicon doping in InGaN/GaN quantum wells (QWs) has been widely used in fabricating high performance light emitting devices, its mechanisms for enhancing emission efficiency are still unclear such that optimum design is still difficult. In this study, we compare the nano-structure and optical characteristics between InGaN/GaN QW samples of different doping conditions. Such comparisons provide us the clues of the mechanisms and hence the guidelines for device design. Totally 10 InGaN/GaN QW samples with different doping conditions were prepared for comparisons. The variations of doping layer, nominal indium content and doping concentration lead to various comparisons.

All samples consisted of five QW periods, with 2.5 nm in well width and 7.5 nm in barrier width. Figs. 1(a) and (b) show the temperature-dependent variations of PL spectral peak and normalized integrated PL intensity, respectively, of three samples. The three samples are un-doped, well-doped and barrier-doped, denoted with HU, HW, and HB, respectively, with doping concentration of silicon at 5 x 10^{18} cm^{-3}. The nominal indium contents of the three samples are the same at around 20 %. From part (a), one can see the blue shift of sample HB when compared with samples HU and HW. Only sample HU shows a clear S-shape behavior. As shown in Fig. 1(b), the radiative efficiency of sample HB is higher than those of the other two samples. Barrier-doped samples always result in higher optical quality.

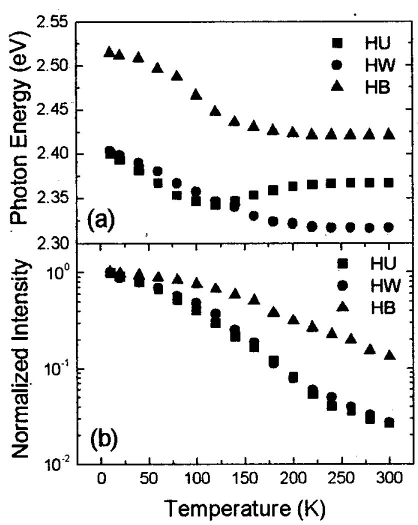

Fig. 1 (a) Temperature-dependent PL spectral peak positions, and (b) integrated PL intensities of the three samples.

Fig. 2 shows the CL images of the three samples. In samples HU and HW, the sharp sub-micron bright light spots correspond to the indium-rich clusters. The background distributions of contrast correspond to slowly varying potential fluctuations in the two samples. One can clearly see that slightly more indium-rich clusters but significantly stronger potential fluctuation exist in sample HW. This observation is consistent with the results of high-resolution TEM images. Compared with samples HU and HW, the CL image of sample HB shows even sharper bright spots and an even stronger potential fluctuation. In particular, more discrete-like potential distribution is speculated in sample HB. In other words, distributions of island-like structures exist around the QW layers.

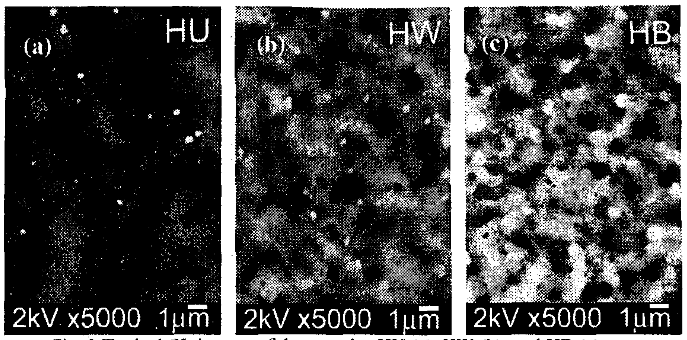

Fig. 2 Typical CL images of the samples HU (a), HW (b), and HB (c).

Carrier localization and quantum-confined Stark effect (QCSE) are the two major mechanisms for explaining the aforementioned S-shape behavior. However, it is still unclear which one dominates. With the results above, one can speculate that upon silicon doping in wells or barriers, the QCSE is reduced, due to strain relaxation and/or carrier screening, and the S-shape behavior disappears. This argument actually implies that the usually observed S-shape behavior can be dominated by the QCSE. On the other hand, carrier localization can be the key to the blue shift and radiative efficiency improvement, particularly in the barrier-doped sample. The similar nano-structures of samples HU and HW explain well their close PL spectral peak positions, particularly below 150 K, and their close integrated PL intensity curves. The stronger carrier confinement in sample HB does result in higher radiative efficiency. This result may imply that carrier localization is more effective in improving radiative efficiency.

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