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Improved optical properties of a-plane InGaN/GaN multiple quantum wells with gradient-stages MQW structure

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1. Introduction

Group III-nitride-based material had been widely employed in the optoelectronic devices in recent years.[1] However, the wurtzite nitrite material has strong piezoelectric and spontaneous polarizations along the c axis, which results in obvious quantum-confined Stark effect.[2] The nonpolar nitrides, which have the crystal structure with c axis lying parallel to the multiple quantum well (MQWs), hence attract great interest for their absence of polarization field in the past few years.[3] Different groups had demonstrated the absence of polarization-related internal electric fields in nonpolar (Al,Ga,In)N QWs, grown along a- and m-directions and also fabricated the nonpolar a-plane and m-plane light-emitting diodes with polarization-free MQWs. However, the nonpolar GaN devices have been suffered by the high threading dislocation (TDs) problem (10^{10} cm^{-2}) and rough surface due to the planar anisotropic nature of growth mode. Therefore, the growth of high-quality MQWs as an active region of light-emitting diodes and laser diodes, is critical for the development of nonpolar III–N-based optoelectronic devices. To fabricate the green light LED, it is well known that the crystal quality of a-plane InGaN\GaN MQW became worse when increasing the Indium composition in the active region [4].

This paper had further improved the crystal quality of a-plane InGaN\GaN MQW structure by implanting gradient-stage MQW structure between undoped-GaN and active region. This modification can both improve the crystal quality and enhance the Indium-doping efficiency in InGaN\GaN MQW active region. The optical properties of a-plane InGaN\GaN MQW with gradient-stage MQW consisted of different pairs were investigated and reported in this paper.

2. Experiment procedure

All samples were grown on r-plane sapphire substrates by metalorganic chemical vapor deposition (MOCVD) system. During the growth, trimethylgallium (TMGa), trimethylindium (TMIn) and ammonia (NH3) were used as the gallium, indium and nitrogen sources, respectively. The growth procedures of all samples are described as follows: The sapphire substrates were heated at 1180 ℃ with hydrogen for removing the surface contamination. First, a AlN nucleation layer was grown on the substrate at 1100 ℃ before the deposition of 1-μm-thick undoped GaN layer. We grew N pairs of gradient-stage InGaN/GaN MQWs structure consisted a set of 3-nm-thick InGaN well layer and 7-nm-thick Si-doped GaN barrier layers. Then, 5 pairs of InGaN/GaN MQW structure as the active region were deposited with nitrogen at 780 ℃, as shown in Fig. 1.

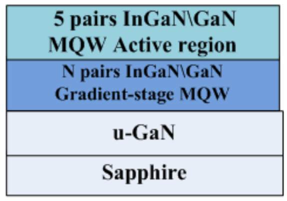

Fig. 1. The scheme diagram of a-plane InGaN/GaN MQWs with gradient-stage MQWs structure.

Three samples with N pairs (N=5, 8, and 11) gradient-stage MQWs structure were fabricated, respectively. To fabricate the gradient-stage MQWs, the gradient Indium (In) composition were grown by controlling flow rate of In source. Noted that the flow of In source was linear increasing during the growth of gradient-stage MQW, as shown in Fig.2. The sample without gradient-stage InGaN\GaN MQW structure (N=0) was also grown as the reference sample.

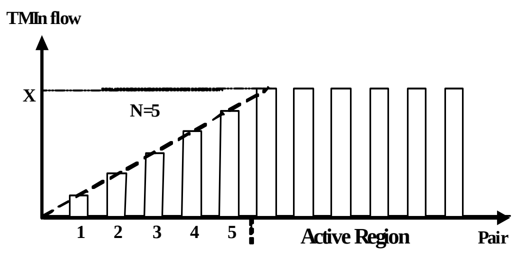

Fig. 2. The illustration of flow rate for controlling the In composition during the growth of N pairs gradient-stage MQW structure. (N=5)

To know the optical properties of a-plane InGaN\GaN MQW with the gradient-stage MQW structure, we used room temperature (RT) μ-photoluminescence (μ-PL) measurement (He-Cd Laser at 325nm) and high-resolution X-ray diffraction (HRXRD, Bede D1 System) to verify the crystal quality and Indium composition in MQW active region.

3. Result and discussion

The structure features of InGaN\GaN MQWs are very important for device performance of LEDs, for instance, indium composition and interface. Fig. 3 shows the omega-2theta scan of XRD spectrum of a-plane InGaN/GaN MQW with N pairs gradient-stage MQWs. When the N increased, the peak shape of a-plane InGaN/GaN MQWs became more clearly. It shows that the quality of the interface between InGaN and GaN was improved by implanting the gradient-stage MQW. Noted that indium composition in the inserted gradient-stage MQW is always smaller than that in the active region and larger than that of GaN buffer. Thus, the gradient-stage MQWs play an appropriate heterolayers between undoped-GaN and active region. So, when the N increased, it means the lattice mismatch between buffer layer and the active region increased smoothly, resulting in better crystal quality of the interface between InGaN\GaN MQW active region.

Therefore, the XRD measurement was also performed on the a-plane MQW samples to examine the well width and identify the indium composition. The indium composition of the QWs was obtained around 18.8 %, and the well and barrier thickness was estimated to be 42 and 143 Å, respectively, for the MQWs active region with 11 pairs gradient-stage MQWs structure grown on the a-plane GaN template.

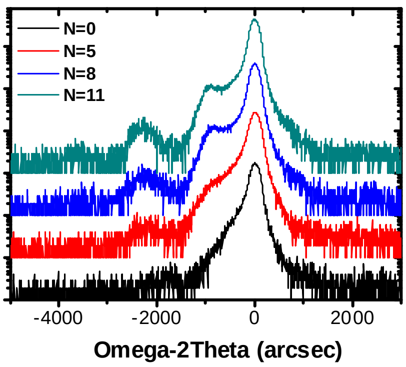

Fig. 3. The Omega-2theta scan of HRXRD spectra of a-plane InGaN/GaN MQWs with N pairs gradient-stage MQWs.

Fig. 4(a) shows the μ-PL spectrum of a-plane InGaN/GaN MQWs with N pairs gradient-stage MQWs at 300K. When the N increased, it was easy for Indium to diffuse in MQWs, leading to higher PL peak wavelength and narrower full width at half maximum (FWHM). The PL peak energy and emission intensity at room temperature were also plotted in Fig. 4(b). As the N increased, the main PL peak is red-shift from 2.59 to 2.48 eV. The PL intensity rose quickly with the 11 pairs of gradient-stage MQWs, which could be due to the better crystal quality with less defect formation. It was found that the better interface between InGaN\GaN MQW active region also can enhance the In-doped efficiency in InGaN\GaN MQWs active region because of the lattice mismatch induced piezoelectric field was reduced by implanting the gradient-stage MQWs with gradual change the lattice constant from GaN buffer to the active region. To verify the strain relaxation, the measurement by Raman is underway.

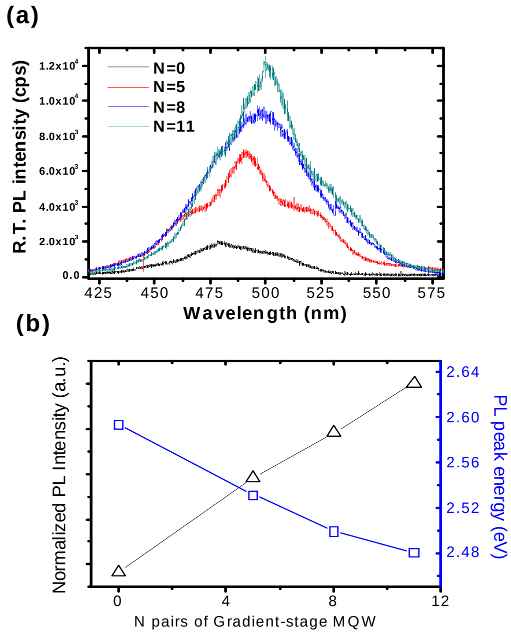

Fig. 4 (a) Room temperature μ-PL spectra of a-plane InGaN/GaN MQWs with N pairs gradient-stage MQWs (b) Normalized PL peak energy and emission intensity plotted as a function of N pairs gradient-stage MQWs.

3. Conclusions

In this paper, the crystal quality of a-plane InGaN\GaN MQWs was further improved by implanting the gradient-stage MQWs before the active region. The a-palne InGaN\GaN MQWs with N (N=0, 5, 8, and 11) pairs of gradient-stage MQWs structure was also investigated. The omega-2theta scan by XRD shows the crystal quality was improved when the number of pairs increased. The PL peak energy was red-shift and the intensity increased when the N increased. This results show that when the lattice mismatch induced piezoelectric field might be reduced when the lattice constant was changed smoothly by implanting the gradient-stage MQWs structure.

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