Cubic InGaN/GaN Multiple Quantum Wells and AlGaN/GaN Bragg Reflectors for Green Resonant Cavity LED

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High quality cubic InGaN/GaN multi-quantum wells (MQWs) were grown with clearly resolved superlattice peaks in high resolution X-ray diffraction. We show that during a growth interruption between InGaN well and GaN barrier growth, In atoms segregated at the InGaN surface can evaporate. This procedure results in room temperature photoluminescence (PL) emission with full width at half maximum (FWHM) of 240meV. Distributed c-AlGaN/GaN Bragg reflectors (DBR) which consist of 15 layer stacks have a maximum reflectivity of about 50% at 514nm and a stop band width of 33nm. Enhanced 526nm room temperature PL emission has been observed from a λ cavity with c-InGaN/GaN MQWs active layer grown on 12 stacks backside AlGaN/GaN DBR.

1. Introduction

Local area networks based on plastic optical fibres (POF) demand highly efficient light sources which emit at 510nm, the wavelength of minimum attenuation of a PMMA step-index POF. The most promising materials for this application are III-nitrides, where by varying the composition of InGaN, 510nm emission can be obtained. In 1992, Schubert et al proposed a new device structures, called resonant cavity light emitting diode (RCLED), in which the active region is put between two mirrors (one side or two distributed Bragg reflectors (DBR)[1]. This device has advantages compared to conventional LEDs, such as higher spontaneous emission efficiency, improved spectral purity and higher output efficiency due to the highly reflective back mirror, which make the RCLED well suitable for applications in POF networks. Naranjo et al demonstrated the feasibility of green RCLED based on hexagonal III-nitride[2].

Beside the hexagonal (wurtzite) configuration, III-nitrides can also crystallize in cubic (zincblende) configuration. Since the band gap of cubic III-nitrides is about 200meV lower than that of their hexagonal counterparts, 510nm light emission can be obtained in InGaN active layers with reasonably lower In content. This may be an advantage due to the well-known difficulties in the growth of InGaN with high In content.

In this paper, we report the growth and properties of InGaN/GaN MQWs and c-AlGaN/GaN DBRs for green light using plasma assisted molecular beam epitaxy (MBE).

2. Experiments

All structures were grown on 3C-SiC substrate by plasma assisted MBE. Prior to the growth, the 3C-SiC substrates were chemically etched and annealed for 10 hours at 500°C. Then, a GaN buffer layer was grown on the SiC substrate at 720°C[3]. The 6 folds InGaN/GaN MQWs were deposited on a 700nm thick c-GaN buffer layer. The barrier thickness was about 10nm and the well thickness was 4nm. InGaN layers were deposited under In-rich conditions

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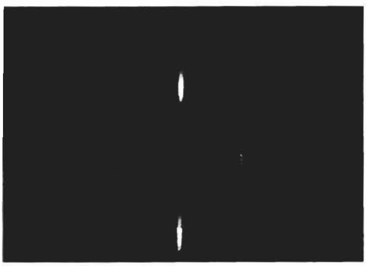
at a growth temperature of 610°C. We used two different types of procedures for the InGaN well growth. For type A samples, the InGaN layers were covered by a few nanometer thick GaN layer at 610°C, then the temperature was ramped up to the GaN growth temperature of 720°C to grow the rest of the barrier. For type B samples, growth was interrupted between the well and the low temperature GaN barrier growth. All other growth conditions were the same. The growing surface was *in-situ* monitored by reflection high energy electron diffraction (RHEED). DBR which is formed by 15.5 layer-stacks c-$Al_{0.3}Ga_{0.7}N$/GaN was grown at 750°C. A λ cavity with InGaN/GaN MQWs as active layer were grown on top of a 12 stacks DBR .

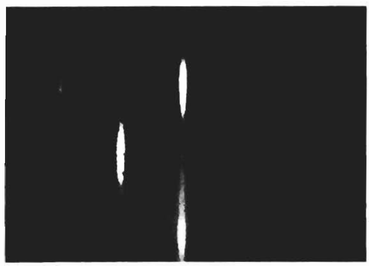
The structural properties of our samples were characterized by high resolution X-ray diffraction (HRXRD). Photoluminescence (PL) measurements were performed at room temperature using excitation with a 325nm He-Cd laser. The DBR surface was checked by scanning electron microscopy (SEM).

3. Results and Discussion

Fig.1 shows the RHEED patterns of the InGaN surface obtained before and after growth interruption. The RHEED patterns of A and B samples were spotty during the InGaN growth.



a)



b)

Fig.1 RHEED pattern of the InGaN growth,
a) before growth interruption, b) after growth interruption

After the growth interruption in type B samples, we observed a (1×4) reconstruction and a streaky pattern, indicating a smooth surface. The intensity of the RHEED pattern also increased after interruption. We think that this is due to the evaporation of In atoms from the surface during the growth interruption. HRXRD (-1-13) reciprocal space maps revealed that the InGaN wells are pseudomorphically grown on the GaN barrier layers. HRXRD (002) ω-2θ line scans of type A and B samples are shown in Fig.2. The superlattice peaks are clearly resolved, indicating a good interface quality for both type of samples. The measured data have been fitted by a full-dynamical simulation shown as full curves in Fig.2. The effective well thickness and the average In molar fraction were obtained from the simulation. Type A samples had a well thickness of about 4.4nm and an average In molar fraction of 13.7%. Type B samples had a lower In molar fraction of 12.1%, and a well thickness of 3.7nm. We suggest that the observed differences are due to In segregation. After the InGaN well growth, an In metal layer remains on the InGaN surface. Without growth interruption (type A samples) the In atoms stay on the surface. During the low temperature GaN layer growth, the In atoms will be absorbed into the GaN barriers yielding a larger InGaN well thickness and a higher In molar fraction. In contrast, during the growth interruption of type B samples, the In metal layer can evaporate from the surface.

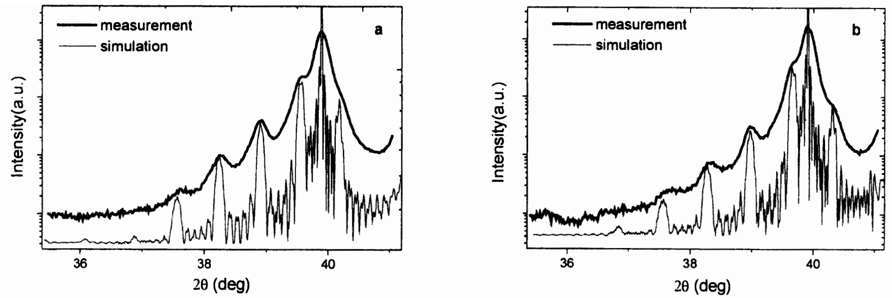


Fig.2 HRXRD (002) ω-2θ scans of a) type A sample, b) type B sample.

Fig.3 shows the room temperature PL spectra from type A and type B samples (dot line), respectively. The InGaN emission is dominant in all spectra. No emission from the GaN barriers is observed demonstrating the high recombination efficiency of our c-InGaN MQWs. We use Gaussian functions to fit the PL spectra. The emission of the type A sample is asymmetric and can be fitted by two Gaussian peaks and a weak peak for the band tail-like contribution. The PL emission peak from type B samples has a reduced line width (FWHM) and can be fitted with only one dominant Gaussian peak and also a weak additional peak. We believe that the second dominant emission of type A samples is due to recombination of e-h pairs in a region of high In content formed by segregated In at the InGaN/GaN interface.

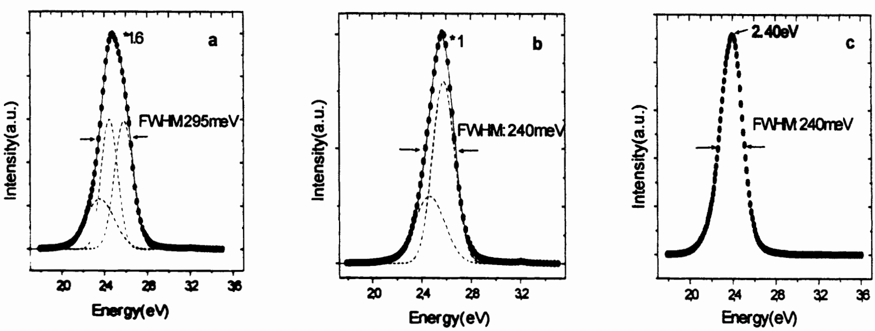


Fig.3 Room temperature PL result from the two different type of samples.
a) type A, b) type B, c) another type B sample with 16% In molar content.

Using the optimal type B growth procedure and increasing the In molar content to 16% we obtain structures with a room temperature PL emission at 2.4eV with FWHM of 240meV (Fig3.c), which may form the active region of green RCLEDs. The PL peak energies of all our samples are about 300meV below the InGaN band-gap energy which has been obtained by ellipsometry of thick c-InGaN layers with identical composition, revealing that the PL emission is due to localized In-rich recombination centres.

DBR consisting of 15.5 stacks c-AlGaN/GaN has been directly grown on 3C-SiC. We found no cracks under SEM. Reciprocal space maps of the (-1-13) reflection revealed that the AlGaN layers were fully strained on GaN, the Al molar ratio is 0.31. The maximum reflectivity of the DBR was 0.48 at the center of the stop band at 2.41eV. The transfer matrix model was used to calculate the reflectivity of our DBRs. Including interface roughness scattering, the simulated curve showed a good agreement with the measured data yielding the thickness of the AlGaN and GaN layers (55nm and the 52.7nm).

PL spectra on the structure in which one λ cavity with the central InGaN/GaN MQWs active layer combine a 12 stacks backside DBR mirror show a blue shift in the emission peak from 526nm to 512nm with the detection angle changing from 0° to 35° (Fig.5). The PL intensity is enhanced by the backside mirror in both spectra. All these results reveal the cavity effect and the strong reflection from the backside c-AlGaN/GaN DBR.

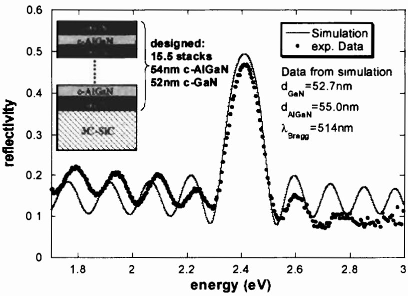


Fig.4 Measured and simulated reflectivity combining of a c-AlGaN/GaN DBR (15.5 stacks).

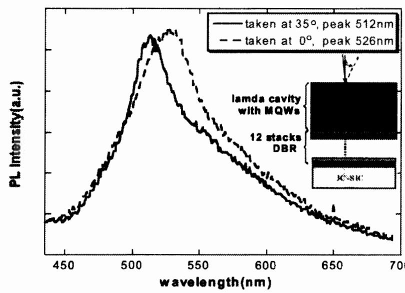


Fig.5 room temperature PL from a structure with a backside DBR taken at different directions.

4. Conclusions

We have shown that the photoluminescence of c-InGaN/GaN MQWs can be improved by growth interruption allowing segregated In atoms to evaporate from the surface. Using this procedure we obtained structures with a room temperature PL at about 510nm and a FWHM of 240meV, respectively. The 15 stacks c-AlGaN/GaN DBR has maximal reflectivity of 48% at 2.41eV. Enhanced light emission at 526nm from a structure combining a λ cavity with a central c-InGaN/GaN MQWs active layer and 12 stacks backside DBR has been shown and may be considered as a first building block of a green RCLED based on cubic III-nitrides.

Acknowledgement

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References

[1] E.F.Schubert,Y.H.Wang,A.Y.Cho,L.W.Tu and G.J.Zydzik, *Appl. Phys. Lett.* **60**, 921, 1992.

[2] F.B. Naranjo, S. Fernándenz, M.A. Sánchez-García, F.Calle and E. Calleja, *Appl. Phys. Lett* **80**, 2198, 2002.

[3] D.Schikora,M.Hankeln,D.J.As,K.Lischka,T.Litz,A.Waag et al, *Phys .Rev. B* **54**, R8381, 1996