MORPHOLOGY AND PHOTOLUMINESCENCE STUDY OF InGaN/GaN(In) HETEROJUNCTIONS

G.K. GAHRAMANOVA, R.B. JABBAROV

Institute of Physics, Azerbaijan National Academy of Sciences, G. Javid av., 131, Baku 1143, Azerbaijan

Email: gulnaz qehremanova@hotmail.com,

The characterization of the MOVPE (Metal Organic Vapour Phase Epitaxy) grown semi-polar {11-22}InGaN multiple quantum wells have been demonstrated and the excitation source power-dependent photoluminescence properties of InGaN/(In)GaN multiple quantum wells heterojunctions were investigated.

Keywords: III-nitrides, heterostructures, multiple quantum wells, semipolar, photoluminescence, InGaN, Atomic Force Microscopy
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1. INTRODUCTION

Over the last three decades group III-nitrides semiconductors have been studied extensively for their optoelectronic and electronic applications such as Light Emitting Diodes (LEDs), high temperature/power devices and chemical, gas and biological sensors [1-5]. The pioneering research on nitride semiconductors by Pankove, Amano, Akasaki, Nakamura and many others established the potential applications of these semiconductors in optoelectronics. It was only in the 1990's that high quality defects free GaN was successfully grown using Metalorganic Vapour Phase Epitaxy (MOVPE) and Metal Organic Chemical Vapor Deposition (MOCVD) [6-8]. With the recent developments in crystal growth technology and the ability to control the doping there has been an increased interest in GaN based heterostructures. Due to the combined effect of spontaneous and piezoelectric effects these heterostructures can form a high density and a high mobility electron gas channel. This high density electron gas makes these hetero structures ideal to be used as sensors. [9]

Most importantly, semipolar InGaN/GaN multiple quantum wells (MQWs) interesting compromise for achieving emission in the green–yellow region. Semipolar crystal directions are those, where the above mentioned internal fields are strongly reduced as a consequence of the crystalline symmetry, but not totally avoided. The semipolar {11-22} plane, being inclined by about 60° with respect to the polar c-plane. Thus, semipolar {11-22} plane has substantially reduced piezoelectric polarization compared to the c-plane [10]. Ultimately, nonpolar and semipolar nitrides may play a role in enabling both LEDs and laser diodes in the green–yellow region. Continued improvements in longer wavelength device efficiencies as well as sustained development of larger-area, high-quality, nonpolar substrates, will be critical for their commercial success. Unfortunately, the optical performance of these devices typically degrades with increasing In content in these layers, leading to the so-called "green gap" [1]. In addition, the quantum efficiency (EQE) in InGaN QWs LEDs decreases significantly in green oblast due to high dislocation density results from the lattice mismatch between the sapphire substrate and GaN leading to large non-radiative recombination rate, and charge separation from the polarization fields in the QW leading to reduction of the electron-hole wave function overlap and radiative recombination rate in particular for green-emitting QWs. We have proposed InGaN/InGaN MQW that focused mainly to improve the optical output power, and improved QE.

2. EXPERIMENT

2.1 Substrate preparation

In the prepare process of the semi-polar {11-22} structures, r-plane {10-12} sapphire substrate is used. The semi-polar {11-22} QWs orientation and related r-plane {10-12} (sapphire substrate have a tilting angle with respect to the c-plane {0001}, respectively $58,4^0$ and $57,6^0$.

In the photolithography process, a photoresist has been used and the substrate is rotated. By choosing a high speed of the rotation the thin photoresist was spread on the substrate and the substrate was covered by photoresist. In the next step the photoresist was exposed by UV light using pattered mask. After exposing, the unexposed parts of the photoresist are removed by chemical developer. The photoresist itself is patterned by optical lithography with a stripe shadow mask with an opening of 3 µm and a period of 6µm. In the next step the desired angle of trench side –wall was achieved via Reactive Ion Etching (RIE). After RIE, in order to remove the photoresist mask stripes on the substrate first oxygen plasma cleaning was done. Then in the chemical solutions of KOH and H_2SO_4 the sample was cleaned completely from residuals. Then the silicon dioxide (SiO_2) was sputtered on top of the sample (or c-plane facet) a mask to get covered with SiO_2 to avoid parasitic growth (Fig. 1). All non c-plane facets are covered with SiO_2. The GaN nucleates on the c-plane sidewall, forms triangular-shaped stripes and coalesces after a suitable growth time to a closed semipolar surface (Fig. 1).

131 H.Javid ave, AZ-1143, Baku
ANAS, G.M.Abdullayev Institute of Physics
E-mail: jophphysics@gmail.com

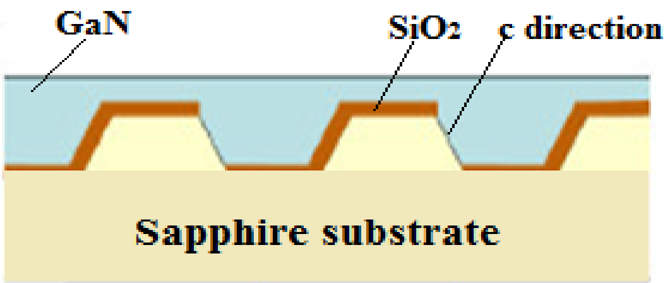

Fig.1. Demonstration of patterned sapphire substrate with 6 µm periodicity of trenches (3 µm opening and 3 µm grooves) and GaN template on it.

2.2 Structuring process and growth of {11-22}GaN and InGaN/GaN(In) quantum wells

The MOVPE growth was done in a commercial Aixtron-200/4 RF-S HT reactor using the standard precursors ammonia (NH3), trimethylgallium (TMGa), trimethylaluminum (TMAl), trimethylindium (TMIn) and triethylgallium (TEGa). The growth starts with about 20nm thick standard AlN nucleation layer at relatively low temperature of about 950˚C. For the subsequent GaN growth, a reactor temperature of about 1020˚C is chosen. The GaN gets pushed in c-direction and builds triangularly formed stripes, which coalesce after a suitable growth time to a semipolar {11-22}-oriented surface. An in-situ deposited SiN interlayer helps to improve the crystal quality by stopping defects penetrating to the sample surface. By decreasing the growth temperature of the topmost GaN layer to 970˚C, the growth gets pushed further in c-direction and the coalescence of the stripes gets improved (Fig. 1).

After growing GaN template the two main MQWs samples have been grown and demonstrated in this paper. One of them InGaN/GaN (barrier layer without indium contents) MQWs heterojunctions second one is InGaN/InGaN (barrier layer with indium contents) MQWs heterojunctions.

On top of the {11-22} oriented GaN template, the growth conditions were same for these two samples, so that the 5 pair InGaN quantum wells with a thickness of 2.3 nm and the GaN or InGaN barriers with a thickness of about 8 nm were grown periodicity at a temperature of about 720˚C and 755˚C respectively.

3. RESULTS AND DISCUSSIONS

This study investigates the morphology of semipolar InGaN MQWs using Optical microscope and Atomic Force Microscopy (AFM). Figure 2a shows a typical optical microscope image of 5 pairs semipolar InGaN/GaN MQW heterostructures which modified by 100x, respectively figure 2b illustrates the surface of 5 pairs semipolar InGaN/GaNIn MQW heterostructures surface. From the images the morphology 3 µm opening and 3 µm grooves stripe on the surface easily visible on the two samples. AFM was performed to assess the morphology of the 50x50 μm^2 surface. The 2D AFM amplitude forward images have been demonstrated in Figure 3a and 3b for the InGaN/GaN and InGaN/GaNIn samples respectively. AFM measurements show a surface roughness of 22 nm, Root mean square (RMS) 26 nm for QWs with GaN barrier and the surface roughness of 24 nm, RMS 28 nm with GaInN barrier in an area of 50µm × 50μm^2 (Fig 3c and 3d respectively). From the figure 3e and 3f the differences of AFM dimensions between the samples is clearly compared.

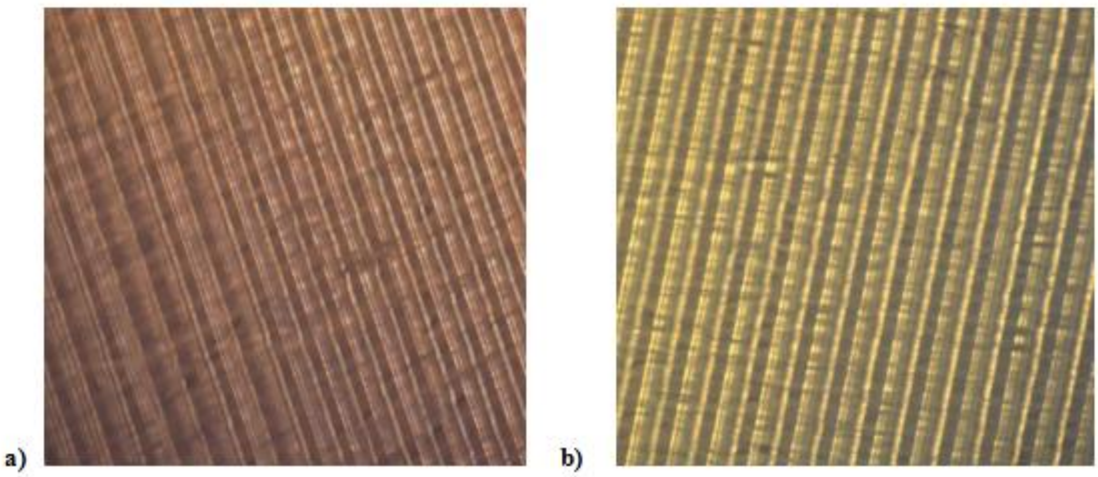

Fig. 2. Optical microscope images of {11-22} InGaN/GaN (a) and InGaN/GaNIn (b) MQW heterostructures .

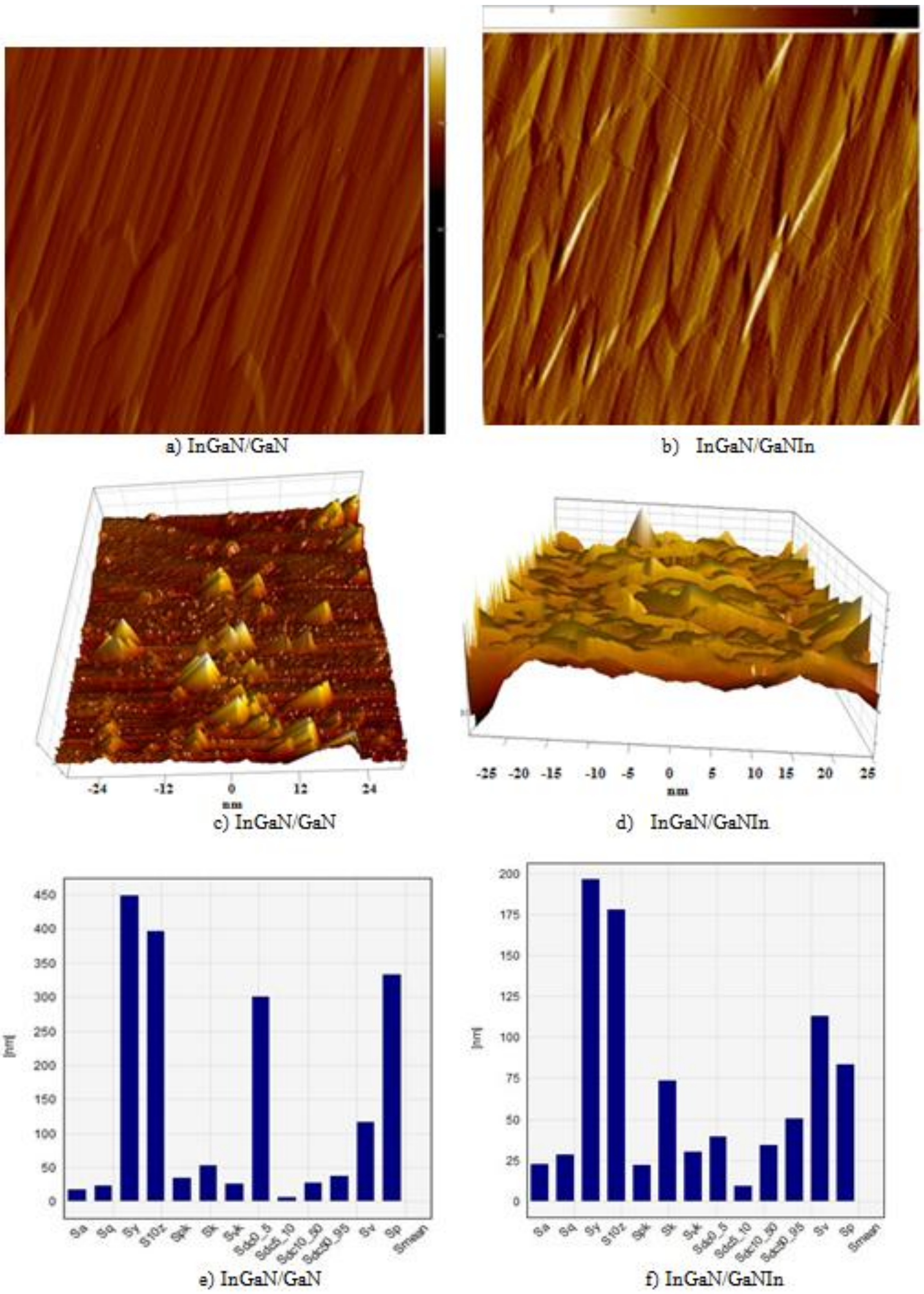

Fig.3. Morphology and roughness of semipolar InGaN/GaN(In) MQW heterostructures on 50 x50μm^2 surface area. a), b) AFM 2D amplitude forward , c), d) AFM 3D images, e), f) AFM characterizations parameters (Sa- Roughness Average, Sq- Root mean square, Sy-peak-peak, S10z-ten point height, Spk-reduced peak high, Sk-core roughness depth, Svk-reduce valley depth, Sdc0_5, Sdc5_10, Sdc10_50, Sdc50_95-5%, 5-10%, 10-50%, 50-95% height, Sv- max valley depth, Sp-max peak height, Smean-mean height).

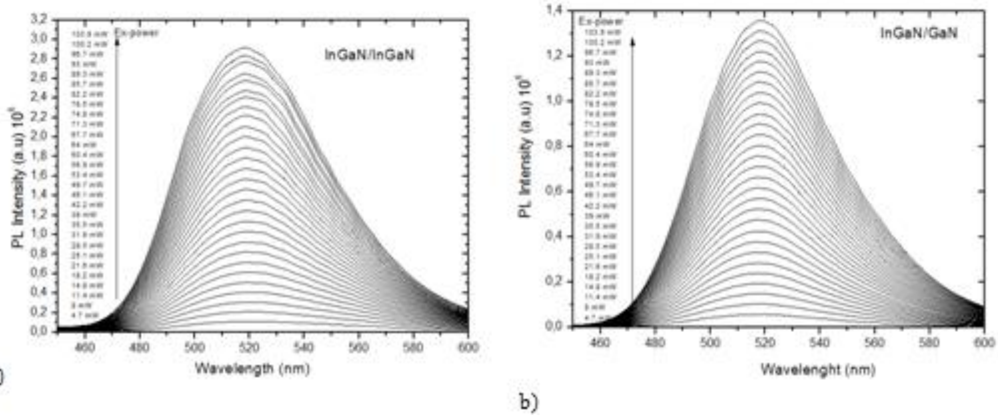

Fig. 4. At room temperature excitation power dependence photoluminescence. a) InGaN/GaN and b) InGaN/InGaN QWs heterostructures.

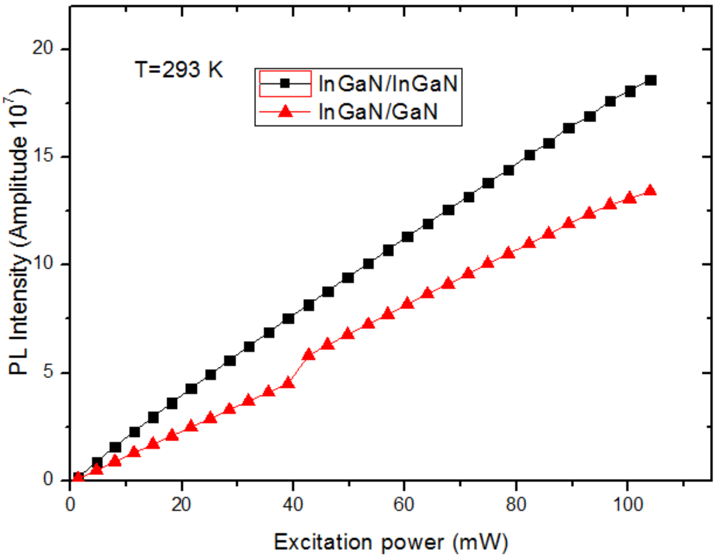

Fig. 5. The excitation source power dependence of integrated PL intensity at room temperature of (11-22) InGaN/GaN (red) and InGaN/InGaN (black) QWs heterostructures.

At room temperature excitation source power dependence photoluminescence (PL) properties of InGaN/GaN and InGaN/GaNIn MQW heterojunctions show peak position is not shifted with increasing excitation source power (Fig. 4 a,b), but PL intensity increased linearly with increasing excitation source power (Fig.5), indicating that "Quantum-confined Stark effect" (QCSE) in MQWs grown on semipolar direction is significantly reduced. The origin of the intense emission should be due to the strong confinement of the electron-hole pairs into the MQW structure. The strong confinement should increase e-h wave function overlap and radiative recombination rates. This InGaN barrier-related improvement in QE and efficiency droop could be useful for the realization of longer wavelength "green-gap" range LEDs where poor QE and efficiency droop are more prominent due to high indium (In) in the active region. Results shows that, the emission intensity of MQW structure is increased due to effect of InGaN barrier layer and it could be useful to realize LEDs with the "green-gap" regime wavelength emission with high QE and low droop.

4. CONCLUSION

We have demonstrated improvement of surface morphology in semipolar InGaN/(In)GaN MQWs heterostructures which grown by MOVPE. The roughness of the QWs where was 22 and 24 nm with GaN and InGaN barriers respectively. At room temperature PL intensity increased linearly with increasing excitation source power for two samples. We obtained improvement PL intensity of InGaN/InGaN MQWs compare to InGaN/GaN and this indicating that QCSE in MQWs growth on semipolar direction is significantly reduced and the results is useful to realize LEDs with the "green-gap" regime wavelength emission with high QE and low droop.

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