Growth and Characterization of InGaN/GaN MQWs on Two Different Types of Substrate

Taek Sung Kim, Jae Young Park, Tran Viet Cuong, and Chang Hee Hong

Abstract—**We report on the growth and characterization of InGaN/GaN MQWs on two different types of sapphire substrates and GaN substrates. The InGaN/GaN MQWs are grown by using metalorganic chemical vapor deposition. Our analysis of the satellite peaks in the HRXRD patterns shows, GaN substrates InGaN/GaN MQW compared to sapphire substrates InGaN/GaN MQW, more compressive strain on GaN substrates than on sapphire substrates. However, results of optical investigation of InGaN/GaN MQWs grown on GaN substrates and on sapphire substrates, which have lower Stokes-like shift of PL to GaN substrates compared to sapphire substrates, are shown to the potential fluctuation and the quantum-confined Stark effect induced by the built-in internal field due to spontaneous and strain-induced piezoelectric polarizations. The InGaN/GaN MQWs are shown to quantify the Stokes-like shift as a function of *x*.**

Index Terms—**InGaN, MQWs, PL, photo- current, MOCVD**

I. INTRODUCTION

GaN substrates and related grown MQWs have attracted increasing attention because they are expected to have smaller strain and smaller Stokes shift compared to the sapphire substrates as well as to the improvement in internal quantum efficiency for light emitting diodes (LEDs). It has recently been recognized that the spontaneous emission efficiency, η, of sapphire substrates InGaN/GaN MQW LED is determined by a balance between the exciton localization and the wave function separation due to the quantum-confined Stark effect (QCSE), that is a result of an electric field, F, normal to the QW plane due to spontaneous and piezoelectric polarization. Since field effects degrade η with an increase in InN mole fraction x, it is difficult to obtain high η longer wavelength LEDs or LDs operating in pure green spectral range [1]. InGaN/GaN MQWs grown GaN substrates are preferable to obtain pure blue or green LEDs.

We have investigated the characterization in grown InGaN/GaN MQWs on sapphire substrates and GaN substrates using methods that were high-resolution x-ray diffraction (HRXRD), photoluminescence (PL), and photocurrent (PC) measurements.

II. EXPERIMENTS

InGaN/GaN MQW were grown by using MOCVD. The precursors of Ga, In, and N were trimethylgallium (TMGa), trimethylindium (TMIn), and ammonia (NH3), respectively. After having been loaded into the reactor, the substrates were thermally cleaned in hydrogen ambient for 10 min at 1100℃; then, a 25-nm-thick GaN nucleation layer was deposited at 560℃. The InGaN/GaN QW structures were grown on sapphire substrates and GaN substrates at 770℃ and at 1130℃, we varied the indium composition from x = 16% to 22%. The cap layer was deposited at a high temperature on top of the InGaN/GaN MQW. The well number and the thickness were kept constant at 7 and 25 Å, respectively,

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while the thickness of the barrier was kept constant at 100 Å. HRXRD was used to determine the layer thickness and the indium content by comparing measured and simulated rocking curves. The photocurrents and the photoluminescence were measured at room temperature. Photoluminescence spectra were taken with the 325-nm line of an 18-mW He-Cd laser. The luminescence was analyzed by using a 1-m double-grating monochromator and was detected by using a GaAs photomultiplier tube. For the photocurrent measurements, the sample was cut into 3×3 mm^2 pieces, and two coplanar electric contacts with a 1-mm spacing were formed with indium solder. A quartz-tungsten halogen lamp was used as the photo-excitation light source. The photocurrent spectrum was analyzed by using a 500-mm grating monochrometer. The photocurrent signal was picked up with a lock-in amplifier and recorded using a computer. A bias of 0.5 V was supplied by a current source using a Keithley 236 source measurement unit for the conductivity measurements.

III. RESULTS AND DICUSSION

The structural properties of InGaN/GaAs MQWs for two different types of substrates were investigated by using HRXRD [2]. Fig. 1 shows that the HRXRD pattern for the (0002) reflection from InGaN/GaN MQWs structures with the different substrates and indium composition. The strongest peak in each HRXRD pattern is due to the GaN. In the HRXRD pattern, InGaN satellite diffraction peaks are observed. The satellite peaks arise from the periodicity of the QWs. The well-defined satellite peaks observed implies a coherent periodicity of the InGaN/GaN heterostructure and suggest the presence of abrupt interfaces. For instance, the separation between the main peak (GaN) and the first-order satellite peak characterizes the average MQW mismatch caused by tetragonal compressive deformation and leads to a determination of the indium molar fractions in the wells. As Fig. 1 shows, GaN substrates InGaN/GaN MQW compared to sapphire substrates InGaN/GaN MQW, more compressive strain on GaN substrates than on sapphire substrates. From the position of the HRXRD peaks, we can estimate the thickness of one period (barrier and well). In principle, the average indium composition of the QW and the period can be determined from the relative positions of the 0th and higher order peaks in the HRXRD patterns. The period (P) is given by

$$P = \frac{n\lambda}{2(\sin\theta_n - \sin\theta_{0th})} \tag{2}$$

where n is the order of the nth satellite peak, θ_n is its diffraction angle, and θ_{0th} is the angle of the 0th-order peak. From the results of the HRXRD analysis for the as-grown InGaN/GaN MQWs, P is calculated as about 125 Å. The indium compositions in well layers were about 16% and 22%, and the well and the barrier widths were 25 and 100 Å, respectively.

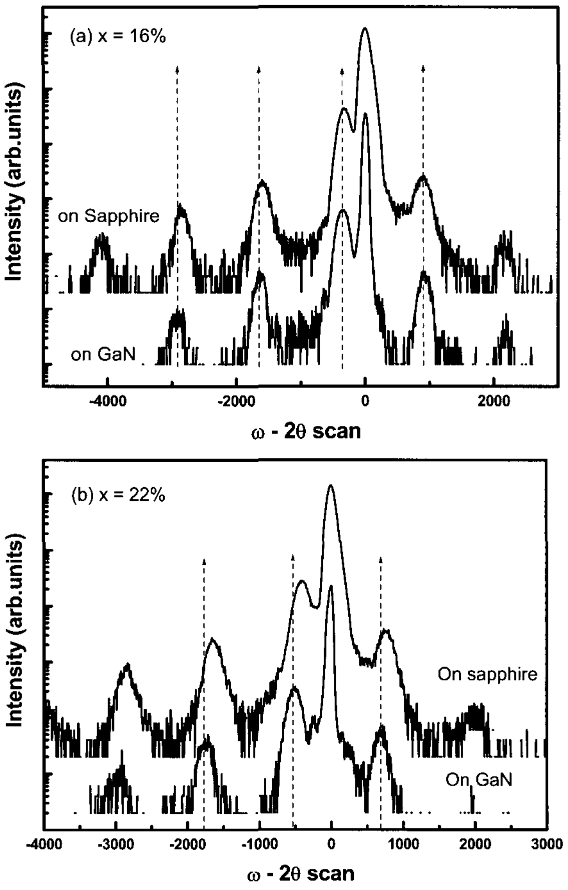


Fig. 1. The HRXRD pattern for the (0002) reflection from InGaN/GaN MQWs structures with the different substrates and indium composition.

Fig. 2 shows PL and PC spectra taken at room temperature for the grown InGaN/GaN MQWs on sapphire substrate with different indium composition. A Stokes-like shift of the main InGaN PL with respect to the band edge measured by PC spectroscopy is clearly observed for all the samples, and the degree of the Stokes-like PL shift increases with indium composition of the InGaN/GaN MQWs. A Stokes-like shift of the InGaN/GaN MQWs are ~38 meV and ~52 meV for the indium compositions in well layers were about 16% and 22%, respectively. The InGaN/GaN MQW on sapphire substrates are shown to quantify the Stokes-like shift as a function of x [3, 4]. Fig. 3 shows measured the Stokes-like shift and calculation of InGaN/GaN MQW on sapphire substrates versus indium composition. The large Stokes-like shift of PL with respect to the PC band edge can be attributed to the potential fluctuation and the quantum-confined Stark effect induced by the built-in internal field due to spontaneous and strain-induced piezoelectric polarizations [5].

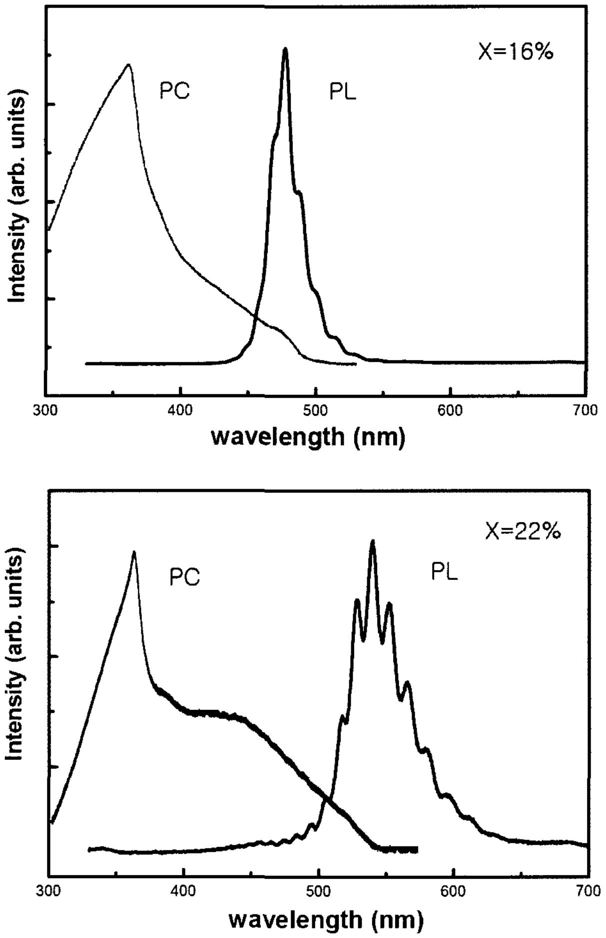


Fig. 2. PL and PC spectra taken at room temperature for the grown InGaN/GaN MQWs on sapphire substrate with different indium composition.

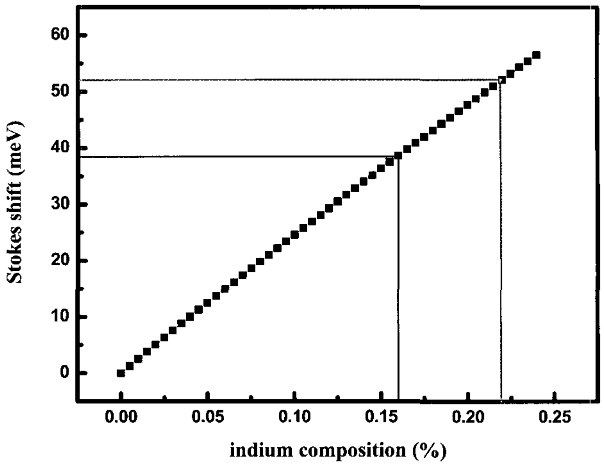
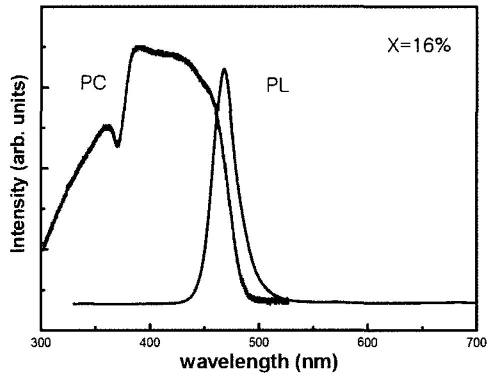


Fig. 3. Measured Stokes-like shift and calculation of InGaN/GaN MQW on sapphire substrates versus indium composition.

Fig. 4 shows PL and PC spectra taken at room temperature for the InGaN/GaN MQWs grown on GaN substrate with different indium composition. A Stokes-like shift of the main InGaN PL with respect to the band edge measured by PC spectroscopy is clearly observed for all the samples, and the degree of the Stokes-like PL shift increases with indium composition of the InGaN/GaN MQWs. A Stokes-like shift of the InGaN/GaN MQWs is ~17 meV and ~21 meV for the indium compositions in well layers were about 16% and 22%, respectively. Fig. 5 shows measured the Stokes-like shift and compared Fig. 3 of InGaN/GaN MQW on GaN substrates versus indium composition. The InGaN/GaN MQW on GaN substrates are shown to quantify the Stokes-like shift as a function of x [3, 4]. The large Stokes-like shift of PL with respect to the PC band edge can be attributed to the potential fluctuation and the quantum-confined Stark effect induced by the built-in internal field due to spontaneous and strain-induced piezoelectric polarizations [5].



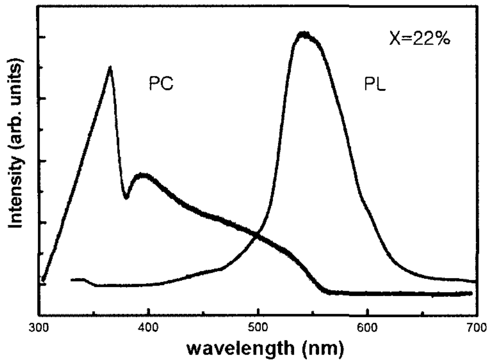


Fig. 4. PL and PC spectra taken at room temperature for the grown InGaN/GaN MQWs on GaN substrate with different indium composition.

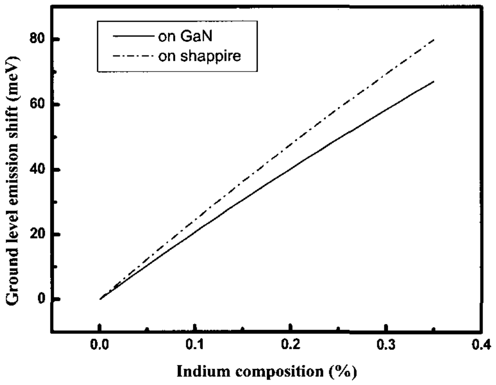


Fig. 5. Measured the Stokes-like shift and compared Fig. 3 of InGaN/GaN MQW on GaN substrates versus indium composition.

IV. CONCLUSIONS

We have investigated the characterization in grown InGaN/GaN MQWs on sapphire substrates and GaN substrates using methods that were high-resolution x-ray diffraction (HRXRD), photoluminescence (PL), and photocurrent (PC) measurements. Our analysis of the satellite peaks in the HRXRD patterns shows, GaN substrates InGaN/GaN MQW compared to sapphire substrates InGaN/GaN MQW, more compressive strain on GaN substrates than on sapphire substrates. However, results of optical investigation of InGaN/GaN MQWs grown on GaN substrates and on sapphire substrates, which have lower Stokes-like shift of PL to GaN substrates compared to sapphire substrates, are shown to the potential fluctuation and the quantum-confined Stark effect induced by the built-in internal field due to spontaneous and strain-induced piezoelectric polarizations. The InGaN/GaN MQWs are shown to quantify the Stokes-like shift as a function of x.

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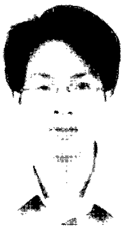

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