Characteristics of $In_xGa_{1-x}N$/GaN single quantum well grown by MBE

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ABSTRACT

Structural and optical properties of $In_xGa_{1-x}N$, as well as $In_{0.1}Ga_{0.9}N$/GaN single quantum well (SQW) grown on sapphire (0001) substrate with an based GaN using rf-plasma assisted MBE have been investigated. The quality of the $In_xGa_{1-x}N$ film was improved as the growth temperature increased. In PL measurements at low temperatures, the band edge emission peaks of $In_xGa_{1-x}N$ was shifted to red region as an indium cell and substrate temperature increased. For $In_{0.1}Ga_{0.9}N$/GaN SQW, the optical emission energy has blue shift about 15meV in PL peak, due to the confined energy level in the well region. And, the FWHM of the $In_{0.1}Ga_{0.9}N$/GaN SQW was larger than that of the bulk $In_{0.1}Ga_{0.9}N$ films. The broadening of FWHM can be explained either as non-uniformity of Indium composition or the potential fluctuation in the well region. Photoconductivity (PC) decay measurement reveals that the optical transition lifetimes of the SQW measured gradually increased with temperatures.

INTRODUCTION

Due to their superior physical properties, the group Ⅲ-nitride wide band gap semiconductors have been recognized recently as very important materials for fabricating optoelectronic devices operating in the blue/UV region and electronic devices capable of operating under high-power and high-temperature conditions [1],[2]. Also, $In_xGa_{1-x}N$ provide better radiative recombination efficiency and it is free from the defect-related luminescence than AlGaN [3]~[4]. However, $In_xGa_{1-x}N$ crystal was originally conducted at low temperatures during the growth and it is still insufficient to realize blue LD's[5].

Despite the remarkable progress in device development, a few studies have been investigated $In_xGa_{1-x}N$ QW structure by using RF-MBE [6]. In this study, we analyzed the properties of $In_xGa_{1-x}N$ depending on the growth temperature through XRD and observed its surface morphology by SEM. And we measured the band-edge transition in PL depending on the growth temperature and In flux in $In_xGa_{1-x}N$. Also, after we have grown the $In_xGa_{1-x}N$ SQW structure by using RF-MBE, we investigated the carrier life time in SQW by photoconductivity (PC) decay measurement and observed the energy shift bound to well region by carrying out the photoluminescence (PL).

EXPERIMENTS

Ⅲ- nitride films were grown on sapphire(0001) substrates by radio-frequency plasma assisted molecular beam epitaxy. Prior to the film growth, the substrate surfaces were exposed to an activated nitrogen beam for 5min to be completely covered with nitride layer when the RF power was 400W. A 70nm-thick GaN nucleation layer at 530℃ followed by an undoped GaN layer were grown as the base for each sample. The based GaN layer was grown about 1㎛ at 750℃. The growth temperature of $In_xGa_{1-x}N$ film was varied from 650℃ to 750℃, as well as Indium flux varied. The barrier GaN film was grown on the $In_xGa_{1-x}N$ at the same temperature. After the growth, each sample was characterized by PL, XRD, SEM and photoconductivity (PC) measurements. The excitation source of PL measurements was the 325nm line of He-Cd laser, and the power intensity of the laser was from 1mW to 10mW. For the PC measurement, the edge of the barrier layer of SQW was removed by KOH solution for 10second. Ohmic contact to the samples for the PC measurements was made by Indium. Then they were cooled or heated to their respective measurement temperature from 77K to 400K.

RESULTS AND DISSCUSION

We investigated the quality of based GaN films by DCRC measurements. The full width half maximum (FWHM) of the based wurzite GaN was about 700arcsec, and it has a good surface morphology.

Figure 1 shows that the XRD spectra measured the $In_xGa_{1-x}N$ films on based GaN with an input flux of [In]/([In]+[Ga])=0.28 as a growth temperature. The XRD spectrum sensitively shifted to low-angle side as a growth temperature decreased. We couldn't observe the InN(0002) peak reported any other group[7] at the low temperature growth. Also, the crystal quality of the $In_xGa_{1-x}N$ goes bad as a high indium mole fraction increased. Indium content of the $In_xGa_{1-x}N$ films was reduced as the growth temperature increased. It means that the indium dissociated from the surface at high temperature growth. The d_{hkl} value of lattice integer of the $In_xGa_{1-x}N$ films as the indium contents was fitted in the inset of Fig.1. The lattice integer d can be fitted by the function as d=2.59306+0.23067x, where x is the indium mole faction.

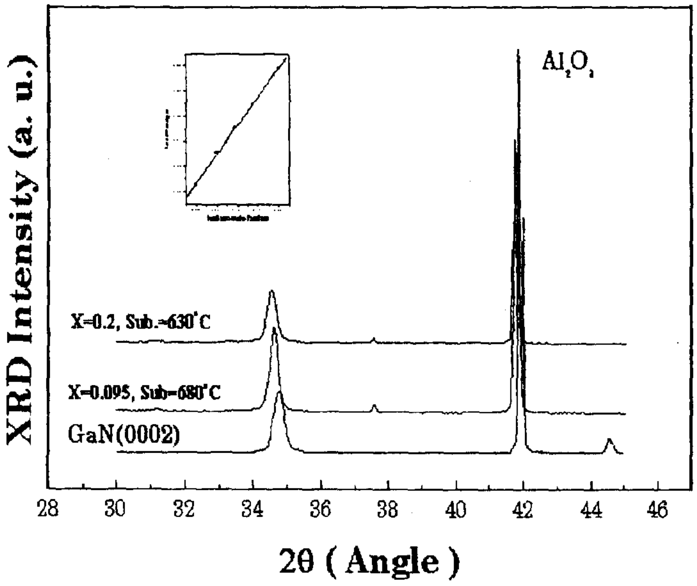
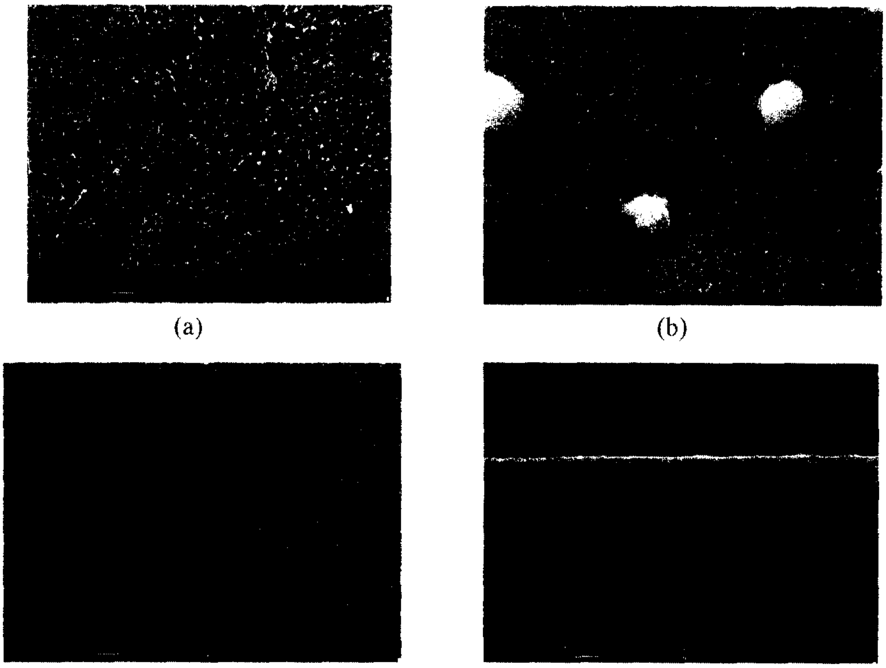


Fig.1. XRD spectra at various indium contents $In_xGa_{1-x}N$ film grown on the based grown GaN. The d value of lattice integer is shown in the inset.

Fig.2 (a), (b) and (c) show that the surface morphology of the $In_xGa_{1-x}N$ film depends on the growth temperature. We can observe a droplet in the surface of the $In_xGa_{1-x}N$ films grown at low temperature, and the surface morphology of the $In_xGa_{1-x}N$ films is not good, because Indium has a segregation property at low temperature. Thus, it shows that the crystal quality of the $In_xGa_{1-x}N$ films goes bad as the indium mole fraction increased at the low temperature growth. This result is accord with the XRD result. The Fig.2 (d) shows the cross-sectional SEM image of the $In_xGa_{1-x}N$ films. The growth rate of 0.44 μm/hour was measured for the $In_xGa_{1-x}N$ films.

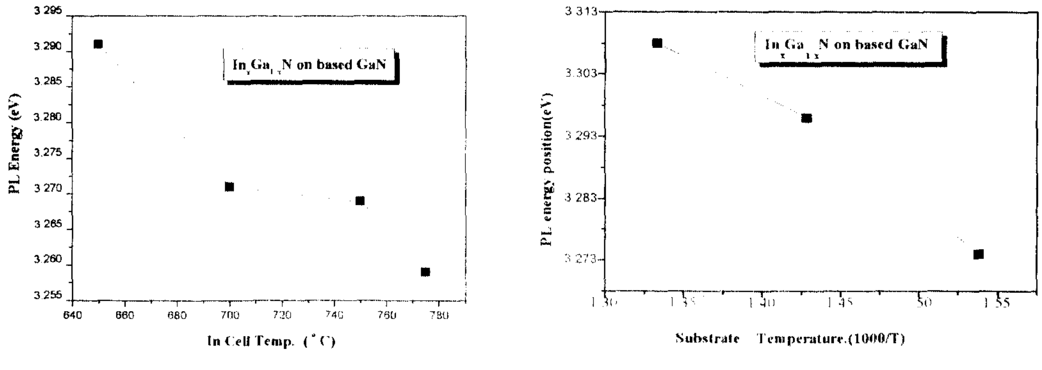


(a) (b)

(c) (d)

Fig.2. SEM images of $In_xGa_{1-x}N$ surfaces and cross-section ;
Growth temp.(a) 650℃ (b) 700℃ (c) 750℃(d) cross-section

We can observe the strong band edge emission of the $In_xGa_{1-x}N$ without yellow luminescence. Fig.3 (a) shows that the PL peak position shifted from 3.291eV to 3.259eV at 10K as the indium flux increased with fixed growth temperature. The PL peak position shifted to high-energy region as the growth temperature increased in Fig.3 (b), because the indium dissociated from the substrate at high growth temperature. These results suggest that the growth temperature of the $In_xGa_{1-x}N$ film sensitively affect Indium mole fraction of the $In_xGa_{1-x}N$ films. We determined the indium mole fraction of the $In_xGa_{1-x}N$ films with this formula ($Eg=3.503-2.68X+1.02X^2$)[8]. We obtained that the highest indium mole fraction of 0.1 by PL.



(a) (b)

Fig. 3. Photoluminescence peak position of the $In_xGa_{1-x}N$ films grown on based GaN
(a) at various indium cell temperatures and (b) vs. inverse substrate temperature.

One of the interesting features in Fig.4 is that the blue shift observed at 10K. It is about 15meV when the well thickness is about 100 Å. As reported by Keller *et.al.*[9]., the quantum size effects in $In_xGa_{1-x}N$ based QWs are observed only for thickness less than 30 Å ,but are not same case in our structures. We could not observe the yellow band and phonon relation peak of the $In_xGa_{1-x}N$ film that reported the other group [10]. The emission origin of the SQW at 10K is the transition among the confined energy levels in the well. The FWHM of this transition increased more than that of the $In_xGa_{1-x}N$ is caused by the interface fluctuation [11]~[12].

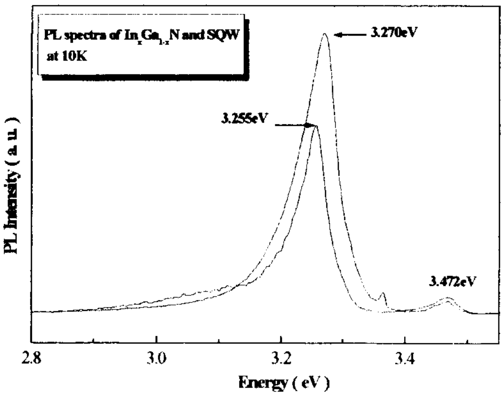


Fig.4. PL spectra of the $In_xGa_{1-x}N$ (dotted line) and single quantum well (solid line) measured at 10K, showing D^oX of the GaN at 3.472eV.

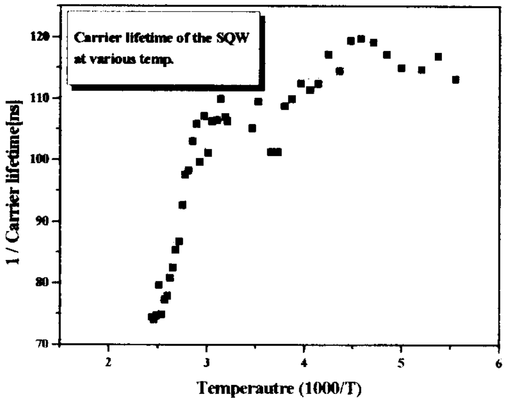


Fig.5. Carrier lifetime of the SQW(x=0.09,Well=200 Å) measured by photoconductivity at various temperatures.

The decay of the transition was well fitted by the single exponential characteristics as $I(t)=A_1exp(-(t/\tau))$. But the other group was reported that they could be fitted to a hyperbolic decay that is the characteristic of a bimolecular recombination [13]. Therefore, our results show that the origin of the decay behavior is not the bimolecular recombination. We have measured the recombination dynamics of the optical transitions in the SQW as shown in Fig.5. It shows that τ slightly increases with temperature up to 300K. However, the lifetime gradually increases above 300K. To our knowledge, this linear increasing of the recombination lifetime with temperature has not been reported for the nitride material yet. Since the recombination lifetime reported, a linear behavior of τ vs T by the PL at low temperatures has been observed previously in GaAs/AlGaAs MQW and is now regarded as a unique property of radiative recombination in MQW [14]. Thus, our photoconductivity data show that the radiative recombination is the dominant process, which demonstrates the high quality of the SQW sample used here, because the recombination lifetime was not reported the above R.T. Thus, a better approach would be needed for more detail experiments.

SUMMARY

In PL measurements at low temperatures, the band edge emission peaks of $In_xGa_{1-x}N$ was shifted to red region as the indium cell and substrate temperature increased. It means that the indium atom was dissociated from the surface at high temperature. For $In_{0.1}Ga_{0.9}N$/GaN SQW, the optical emission energy have blue shift about 15meV in PL peak, due to the confined energy level in the well region. And, the FWHM of the $In_{0.1}Ga_{0.9}N$/GaN SQW was larger than that of the bulk $In_{0.1}Ga_{0.9}N$ films. The broadening of FWHM can be explained either as non-uniformity of Indium composition or the energy fluctuation in the well region. The transition lifetime in the SQW was increased at high temperature region. This result is unusual case comparing other works. To our knowledge, the increasing of carrier life time is due to the dominant radiative recombination in the well region.

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