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$Al_xGa_{1-x}N$ and GaN/$Al_xGa_{1-x}N$ Quantum Wells Grown by Gas Source Molecular Beam Epitaxy

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Abstract $Al_xGa_{1-x}N$ and GaN/$Al_xGa_{1-x}N$ quantum wells were successfully grown on basal plane sapphire substrates by gas source molecular beam epitaxy using ammonia as nitrogen source. Photoluminescence measurements were carried out for the samples grown. The results show that the blue shifts in optical transition energy due to quantum size effect are 57meV at room temperature and 49meV at 80K for the GaN/$Al_{0.12}Ga_{0.88}N$ quantum well sample having 6 GaN wells each with width of 7nm.

PACC: 8115G, 7280E, 7855, 6865; **EEACC**: 0510D, 2520D, 2530B

1 Introduction

GaN and $Al_xGa_{1-x}N$ are potential materials for use in ultraviolet light-emitting diodes and detectors, short wavelength lasers and high temperature and high power electronics[1]. The commercial availability of superbright blue light-emitting diodes[2] and the realization of the room temperature continuous wave operation of blue lasers based on the GaN system with lifetime more than 1000h[3,4] are clearly indicative of the great potential of this material system. It is expected that all GaN based devices will take advantages of quantum well (QW) structures of GaN/$Al_xGa_{1-x}N$ and InGaN/GaN, thus the growth and study of III-V nitride QWs are very important. Recently, several authors have reported the successful growth and optical properties of these quantum well structures[5,6]. Using ammonia as nitrogen source we have grown high quality GaN films on (0001) sapphire substrates by gas source molecular beam epitaxy (GSMBE)[7~9]. In this paper we report the successful

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growth of $Al_xGa_{1-x}N$ and GaN/$Al_xGa_{1-x}N$ quantum wells and the results of photoluminescence of the samples grown.

2 Experimental Procedure

A home-made GSMBE system was employed to grow the $Al_xGa_{1-x}N$ and GaN/$Al_xGa_{1-x}N$ quantum well samples. All samples were grown on C-plane sapphire substrates. High pure elemental gallium and aluminum were evaporated from Knudsen effusion cells, and high pure ammonia was employed as nitrogen source. After solvent degreasing and thermal out-gassing, the substrates were introduced into the growth chamber where they were heated to about 800℃ and exposed to a flux of ammonia for surface nitridation. The substrate temperature was then lowered to about 500℃ for the deposition of a thin GaN buffer layer. Finally the temperature was raised to about 800℃ for the growth of about 0.4~1μm thick GaN film. The $Al_xGa_{1-x}N$ films and GaN/$Al_xGa_{1-x}N$ quantum wells were grown on top of the grown thick GaN films at a substrate temperature of about 800℃. All of the layers grown were unintentionally doped. The GaN/$Al_xGa_{1-x}N$ quantum well sample consists of 6 periods of 7nm-thick GaN quantum wells clad by 8nm-thick $Al_xGa_{1-x}N$ barrier layers. Its structure is schematically illustrated in Fig. 1.

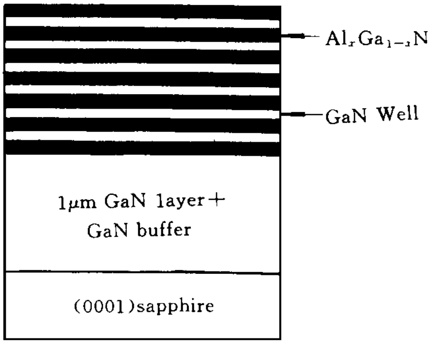

Fig. 1 Schematic structure of the GaN/$Al_xGa_{1-x}N$ quantum well sample

Photoluminescence (PL) measurements were performed using the 325nm line of a He-Cd laser as the excitation source and the emitted PL signals were collected from the epilayer front surface and were directed to a monochromator. The signal was detected using a GaAs photomultiplier tube.

3 Results and Discussion

Four samples have been grown and will be discussed in the following. The first samplef (sample A) is a GaN film which has a thickness of about 1.0μm. The second and third samples (sample B and C) consist of, from the bottom of the wafer up, a thin GaN buffer layer, a GaN layer and a $Al_xGa_{1-x}N$ layer. Although these two samples have the same thickness of the $Al_xGa_{1-x}N$ layers (about 0.6μm), the thickness of the GaN layers of them is different, being 0.4μm for sample B and 1.0μm for sample C, The fourth (sample D) is a GaN/$Al_xGa_{1-x}N$ quantum well sample with structure shown in Fig. 1. All these samples were grown under identical growth conditions except the aluminum effusion cell temperatures. The structures of these samples are summarized in Table 1. The layer thicknesses are estimated from the growth rates.

Table 1 The structures of the discussed samples

Sample	Thickness of the GaN buffer layer/nm	Thickness of the GaN layer/μm	Thickness of the AlGaN film/μm	Thickness of the GaN quantum well/nm	Thickness of the AlGaN barrier layer/nm
Sample A	30	1.0	0	0	0
Sample B	30	0.4	0.6	0	0
Sample C	30	1.0	0.6	0	0
Sample D	30	1.0	0	7	8

Fig. 2 presents the room temperature PL spectra of samples A, B, and C. The emission lines peaked at 325nm and 651nm come from the excitation source of the He-Cd laser. From the spectra of sample A, only one peak centered at about 365nm with a full width at half maximum (FWHM) of about 8nm (75meV) can be clearly observed. This peak originates from the near-band-edge emission of the GaN film. The other weak broad band peaked at about 550nm is the so-called yellow photoluminescence (YL) band which has usually been observed in undoped and silicon-doped GaN films grown by metal-organic chemical vapor deposition and by MBE. Although intensive work has been done to clarify its origin, the origin of the YL band is still unknown. The YL band may be attributed to the native defects[10, 11] which are produced during the growth of GaN films. On the spectra of sample A, the narrow near-band-edge emission line with a FWHM of about 8nm (75meV) is much stronger than the broad YL band, indicating that the GaN film is of high quality. However, on the PL spectra of sample B, two peaks are clearly observed. One is the near-band-edge emission line peaked at about 343nm with a FWHM of about 17 nm (179meV). This peak originates from the $Al_xGa_{1-x}N$ film. The other broad band centered at about 523nm is attributed to the transitions related to deep level defects. The YL band dominates for this sample, indicating that it has a poor optical quality.

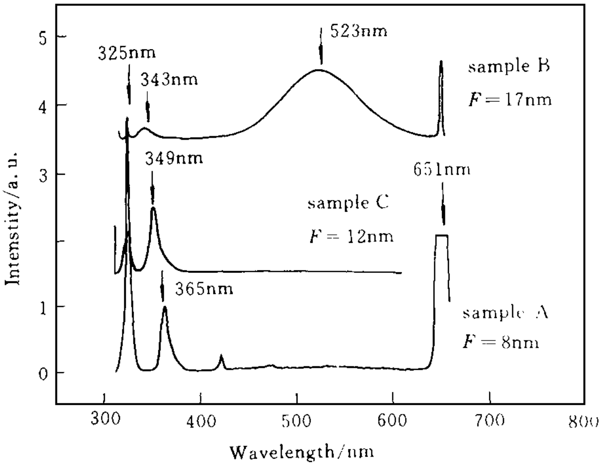

Fig. 2 The room temperature PL spectra of one GaN sample and two $Al_xGa_{1-x}N$ samples with $x=0.12$ and 0.09

The PL spectra of sample C are also shown in Fig. 2. From the spectra of this sample, we can see that the near-band-edge emission line peaked at about 349nm with a FWHM of about 12nm (122meV) dominates, indicating that sample C is of high quality. In contrast to sample B, the peak intensity of the near-band-edge emission line of sample C is much stronger than that of its YL band. Since the GaN layer of sample B is about 0.4μm thick and the GaN layer of sample C is about 1μm thick, the difference in AlGaN quality between these two samples may be due to the difference in GaN layer thickness. Due to the large lattice mismatch (about 13.8%) between GaN film and sapphire substrate, usually the thicker the GaN film grown, the higher the quality of it. Therefore the 1μm-thick GaN layer is of higher quality, which leads to the improvement in the optical quality of the AlGaN film grown on the GaN film.

The Al concentration x in the $Al_xGa_{1-x}N$ films can be determined approximately from the near band edge PL peak positions of the $Al_xGa_{1-x}N$ films. With increasing x, the direct energy band gap of the $Al_xGa_{1-x}N$ increases. At room temperature, the variation of the energy band gap $E_g(x)$ of $Al_xGa_{1-x}N$ with x can be expressed as[12]

$$E_g(x) = 6.2x + 3.39(1-x) - x(1-x) \qquad (1)$$

From this formula and Fig. 2 we can easily know that the Al concentration of sample B is $x \approx 0.12$ and that of sample C is $x \approx 0.09$.

Figure 3 shows the PL spectra of sample D which is of a GaN/$Al_xGa_{1-x}N$ quantum well. The peak positioned at 325 nm comes from the He-Cd laser. Other peaks originate from the sample: the emission lines peaked at 344nm (on 300K spectra) and 339nm (on 80K spectra) correspond to the near-band-edge emission due to recombination in the AlGaN barrier layers; the peaks at 365nm (on 300K spectra) and 359.6nm (on 80K spectra) are the near-band-edge emission lines of the 1.0μm-thick GaN layer (see Fig. 1), and those at 359nm (on 300K spectra) and 354.6nm (on 80K spectra), appearing between the barrier layer luminescence and the bulk GaN emission, are attributed to the confined particle transitions in the quantum well. The blue shifts in energy due to the quantum size effect are about 57meV at room temperature and about 49meV at 80K temperature. The estimated GaN quantum well thickness and the $Al_xGa_{1-x}N$ barrier layer thickness according to growth rates are about 7nm and 8nm, respectively. Since the growth conditions (including Al and Ga effusion cell temperatures) of the $Al_xGa_{1-x}N$ barrier layer on sample D are identical with those of the $Al_xGa_{1-x}N$ layer on sample B, the Al concentration of the AlGaN barrier layer is also 0.12, being the same as that of sample B. The accurate calculation of the confined particle transition energies in GaN/$Al_xGa_{1-x}N$ quantum well is difficult and will not

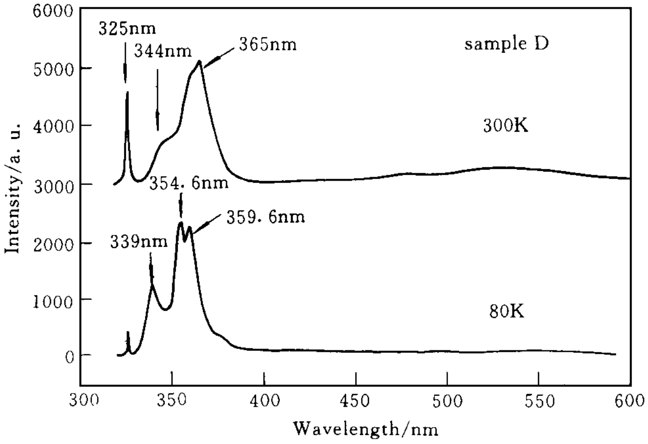

Fig. 3 The room temperature and 80K PL spectra for the GaN/$Al_xGa_{1-x}N$ quantum well sample with $x = 0.12$

be discussed in this paper.

4 Conclusion

$Al_xGa_{1-x}N$ and GaN/$Al_xGa_{1-x}N$ quantum wells have been successfully grown on basal plane sapphire substrates by GSMBE using ammonia as nitrogen source. The photoluminescence measurements were performed for the samples grown to study their optical properties. For the GaN/$Al_{0.12}Ga_{0.88}N$ quantum well sample with well thickness of about 7nm and barrier thickness of about 8nm, the blue shifts in energy due to the quantum size effect are about 57meV at room temperature and about 49meV at 80K.

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