Optical Properties of AlGaN Quantum Well Structures

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ABSTRACT

We demonstrate 230-250 nm efficient ultraviolet (UV) photoluminescence (PL) from AlN(AlGaN)/AlGaN multi-quantum-wells (MQWs) fabricated by metal-organic vapor-phase-epitaxy (MOVPE). Firstly, we show the PL properties of high Al content AlGaN bulk (Al content: 85-95%) emitting from near band-edge. We systematically investigated the PL properties of AlGaN-MQWs consisting of wide bandgap AlGaN (Al content: 53-100%) barrier. We obtained efficient PL emission of 234 and 245 nm from $AlN/Al_{0.18}Ga_{0.82}N$ and $Al_{0.8}Ga_{0.2}N/Al_{0.18}Ga_{0.82}N$ MQWs, respectively, at 77 K. The optimum value of well thickness was approximately 1.5 nm. The emission from the AlGaN MQWs were several tens of times stronger than that of bulk AlGaN. We found that the most efficient PL is obtained at around 240 nm from AlGaN MQWs with $Al_{0.8}Ga_{0.2}N$ barriers. Also, we found that the PL from AlGaN MQW is as efficient as that of InGaN QWs at 77 K.

INTRODUCTION

AlN or AlGaN is very attractive material for the application to ultraviolet (UV) laser diodes (LDs), light-emitting diodes (LEDs) or photo detectors, because the direct transition energy can be adjusted between 6.2 eV (AlN) and 3.4 eV (GaN). UV LDs or LED are expected to realize the large capacity optical memories or compact UV measurement systems. Recently, the efficient UV light sources are expected in the field of chemical industry or medical applications.

However, there are some large problems preventing us from achieving UV optical devices. The most serious problems are difficulty to obtain efficient UV emission from AlGaN quantum wells (QWs), in contrast to InGaN QWs, and hole injection through high Al content (more than 30%) AlGaN alloy. Recently some research groups reported on the approaches to realize UV optical devices using GaN or AlGaN materials [1,2]. We have already achieved 333 nm current injection emission from $Al_{0.03}Ga_{0.97}N/Al_{0.25}Ga_{0.75}N$ QWs using Mg-doped AlGaN/GaN super-lattice hole conducting region [3].

The purpose of this work is to obtain efficient UV emission as well as blue emission already obtained from InGaN QWs. Last year, we have obtained 280 nm intense photoluminescence (PL) emission from AlGaN QWs at 77 K [4]. Also, we reported on the PL enhancement in GaN/AlGaN QWs induced by Si-doping due to the compensation of large piezoelectric field in the well [5].

In this work, we demonstrate the first intense UV PL around 230 nm from AlGaN multi-quantum-wells (MQWs) consisting of high Al content AlGaN or AlN barriers. We obtained the growth condition of high Al content AlGaN. We obtained a single peak spectrum from high Al content AlGaN bulk (Al content up to 80%) emitting from the near band-edge. Then we fabricated AlGaN-MQWs consisting of wide bandgap AlGaN (Al content: 53-100%) barriers. The well thickness dependence of PL properties is systematically investigated. We show efficient emission around 230 nm obtained from the AlN/AlGaN MQWs. Finally, the PL intensities are compared between AlGaN MQWs with various Al content of AlGaN barriers, and InGaN and GaN QWs.

EXPERIMENTS AND DISCUSSIONS

The samples were grown at 76 Torr on the Si-face of an on-axis 6H-SiC(0001) substrate, by a conventional horizontal-type MOVPE system. As precursors ammonia (NH_3), trimethylaluminum (TMAl), and trimethylgallium (TMGa) were used with H_2 as carrier gas. N_2 gas was independently supplied by a separate line in order to control the gas flow. Typical gas flows were 2 standard liters per minute (SLM), 2 SLM, and 0.5 SLM for NH_3, H_2, and N_2, respectively. The molar fluxes of TMGa and TMAl for the growth of $Al_xGa_{1-x}N$ (x=0.11-1) were 38 and 2.6-45 µmol/min, respectively. At this condition, the growth rate of $Al_{0.11}Ga_{0.89}N$, $Al_{0.40}Ga_{0.60}N$ and AlN were approximately 2.4, 1.0 and 0.4 µm/h, respectively. The substrate temperature measured with a thermocouple located at the substrate susceptor during the growth was 1140 °C for all layer. All samples were undoped.

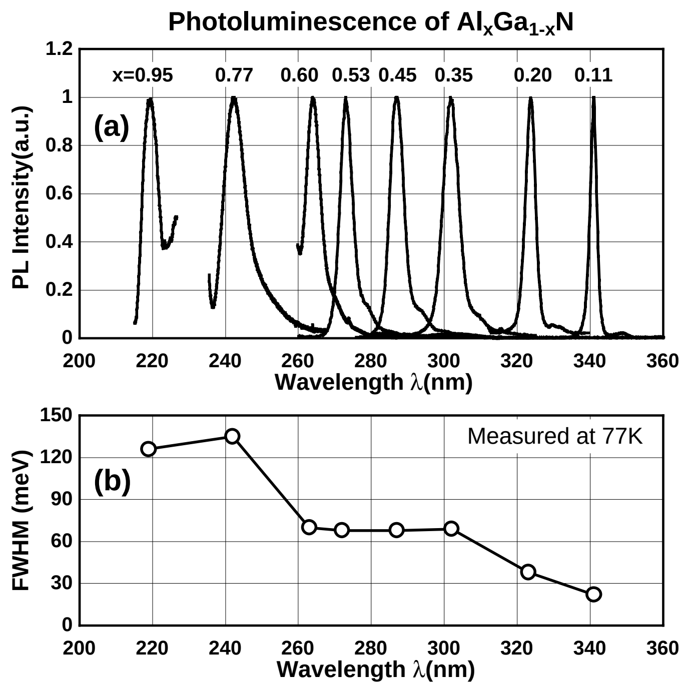

Figure 1. *PL spectra of $Al_xGa_{1-x}N$ (x=0.11-0.95) films grown on 6H-SiC measured at 77 K.*

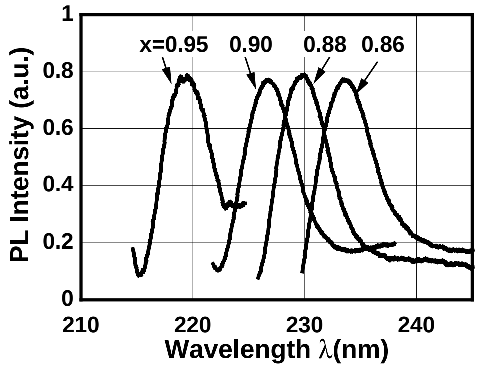

Figure 2. *PL spectra of high Al content $Al_xGa_{1-x}N$ (x=0.86-0.95) films measured at 77 K.*

At first, we show the optical properties of high Al content AlGaN alloy. Figure 1 shows (a) the PL spectra and (b) full width at half maximum (FWHM) of the PL peak of AlGaN films measured at 77 K. The AlGaN alloy was grown directly on a very thin (~5 nm) AlN layer deposited on SiC. Figure 2 also shows the PL spectra of high Al content AlGaN (Al content is 85-95%). The thickness of AlGaN film was approximately 250 and 400 nm for AlN and $Al_{0.11}Ga_{0.89}N$, respectively. As seen in Fig. 1 and 2, single peak spectra were obtained for Al contents of 0.11-0.95 emitting from near band edge. The yellow emission around 500-550 nm was negligible even for high Al content AlGaN. The phonon-replica peaks are seen at the low energy side of each spectra for Al content of 0.11-0.53, confirms the good crystal quality of the AlGaN. The typical value of FWHM of the spectrum was approximately 20, 65 and 120 meV for the Al content of 10-12%, 35-60% and 70-95%, respectively. The increased FWHM observed for the Al content of 35-60% may be due to the layer composition fluctuation during the growth. The large FWHM (120 meV) observed for high Al content AlGaN indicates that at this moment the crystal quality of AlN is not so good compared with that of GaN.

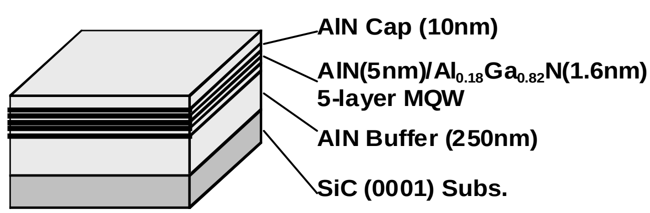

Figure 3. *Schematic layer structure of fabricated $AlN/Al_{0.18}Ga_{0.82}N$ MQW sample.*

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Table I. Material and the thickness of buffer, barrier, well layers, and PL peak wavelength range of each series of AlGaN MQWs.

Sample Series	Structure	Buffer (Thickness)	Barrier (Thickness)	Well (Thickness)	Peak Wavelength
(a)	5-layer MQW	AlN (250 nm)	AlN (5 nm)	$Al_{0.18}Ga_{0.82}N$ (1.2-3.3 nm)	229-285 nm
(b)	5-layer MQW	$Al_{0.8}Ga_{0.2}N$ (250 nm)	$Al_{0.8}Ga_{0.2}N$ (5 nm)	$Al_{0.18}Ga_{0.82}N$ (0-3.3 nm)	238-288 nm
(c)	5-layer MQW	$Al_{0.7}Ga_{0.3}N$ (300 nm)	$Al_{0.7}Ga_{0.3}N$ (5 nm)	$Al_{0.12}Ga_{0.88}N$ (1.4-2.7 nm)	255-303 nm
(d)	5-layer MQW	$Al_{0.53}Ga_{0.47}N$ (400 nm)	$Al_{0.53}Ga_{0.47}N$ (5 nm)	$Al_{0.11}Ga_{0.89}N$ (0-6.7 nm)	272-343 nm

Then, we fabricated four series of AlGaN MQW samples, consisting of different Al content AlGaN barriers. Figure 3 shows an example of schematic layer structure. Table I summarizes the material and the thickness of buffer, barrier, well layers, and PL peak wavelength range of each series of AlGaN MQWs. In order to achieve a flat surface suitable for the growth of AlGaN quantum wells, an approximately 250-400 nm thick AlN(AlGaN) buffer layer followed by a very thin AlN layer was deposited. We confirmed a step-flow grown surface by atomic force microscopy (AFM) for the sample series (a), (b), and (c). After that, a five-layer MQW structure consisting of several-nm thick $Al_xGa_{1-x}N$ wells (x=0.11-0.18) and 5 nm-thick $Al_yGa_{1-y}N$ barriers (y=0.53-1), and 10nm-thick $Al_yGa_{1-y}N$ cap (y=0.53-1) were grown. The well or barrier thickness is estimated simply from the growth rate of bulk material.

Figure 4 shows PL spectra of (a) $AlN/Al_{0.18}Ga_{0.82}N$ and (b) $Al_{0.80}Ga_{0.20}N/Al_{0.18}Ga_{0.82}N$ five-layer MQWs for various well thickness, excited with Xe-lamp light source (215 nm) measured at 77 K. The well thickness was varied ranging 1.2-3.3 nm and 0-3.3 nm for sample series (a) and (b), respectively. We obtained single-peak intense PL emission from each MQWs. The most efficient emission was obtained at the wavelength of 234 and 245 nm from $AlN/Al_{0.18}Ga_{0.82}N$ and $Al_{0.8}Ga_{0.2}N/Al_{0.18}Ga_{0.82}N$ MQWs, respectively. The optimum value of well thickness was approximately 1.5 nm. The PL intensity of the MQWs were several tens of times larger than that of AlGaN bulk.

The quantized level shift is obviously observed. The PL intensity heavily depends on the well thickness. The rapid reduction of the PL intensity with the increase of the well thickness may be caused by a reduction of the radiative recombination probability due to the large piezoelectric field in the well [6]. The reduction of the emission intensity for thin well may be mainly due to the increase of nonradiative recombination on the hetero-interfaces. For the sample series (c) and (d), we observed the similar tendency obtained for (a) and (b).

Finally, the PL intensities are compared between AlGaN MQWs with various Al content of AlGaN barriers. Figure 5 shows the PL spectra of the samples (a)-(d) shown in Table I for optimized QW thickness measured at 77 K. All samples were excited with Xe-lamp light source (215 nm) with the same excitation condition. From Fig. 5, we found that the most efficient emission is obtained around 245 nm for AlGaN MQW systems and that the optimum Al content for AlGaN barrier is 80%. The PL intensity of QW is strongly depending on the buffer conditions. More efficient emission is expected from AlN/AlGaN QWs by improving the crystal quality of AlN buffer and barriers. We have also found that the PL intensity of AlGaN QWs is as strong as that of the $In_{0.02}Ga_{0.98}N/In_{0.20}Ga_{0.80}N$ QW and much stronger than that of $Al_{0.12}Ga_{0.88}N/GaN$ MQWs at 77 K [4]. However, at room temperature, the emission from AlGaN and GaN QWs are much weaker in comparison with InGaN QWs. The next subject is to obtain efficient UV emission at room temperature.

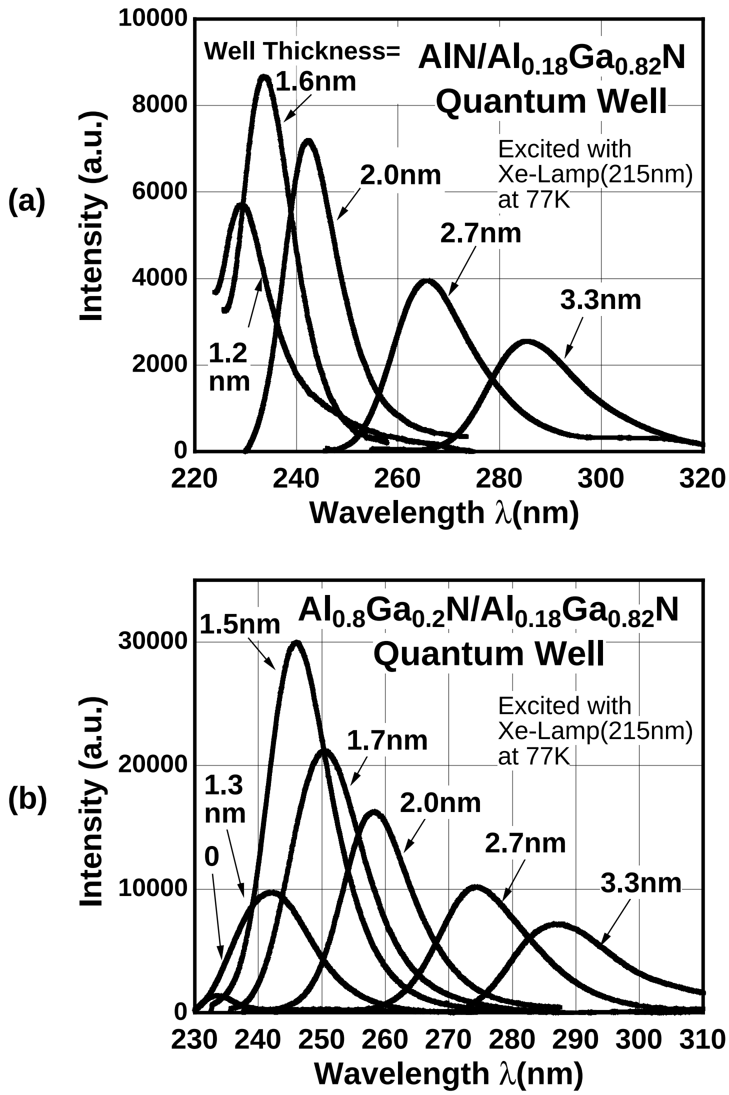

Figure 4. *PL spectra of (a) AlN/$Al_{0.18}Ga_{0.82}N$ and (b) $Al_{0.80}Ga_{0.20}N/Al_{0.18}Ga_{0.82}N$ 5-layer MQWs for various well thickness.*

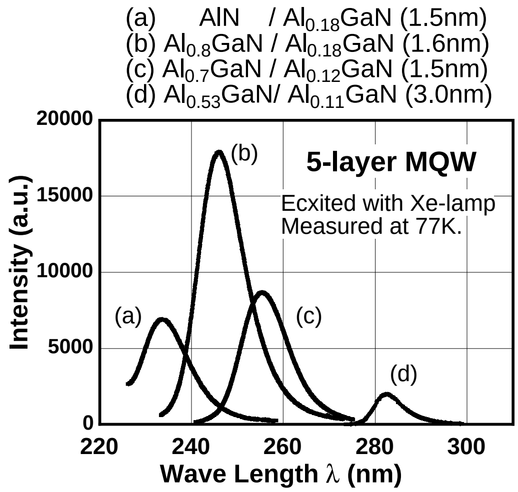

Figure 5. *Comparison of PL intensity at 77 K between AlGaN 5-layer MQWs with different Al content AlGaN barriers.*

CONCLUSION

We demonstrated 230-250 nm efficient UV PL from AlN(AlGaN)/AlGaN MQWs fabricated by MOVPE. We showed PL spectra of high Al content AlGaN bulk (Al content: 85-95%) emitting from near band-edge. We systematically investigated the PL properties of AlGaN-MQWs consisting of wide bandgap AlGaN (Al content: 53-100%) barrier. We obtained efficient PL emission of 234 and 245 nm from $AlN/Al_{0.18}Ga_{0.82}N$ and $Al_{0.8}Ga_{0.2}N/Al_{0.18}Ga_{0.82}N$ MQWs, respectively, at 77 K. The optimum value of well thickness was approximately 1.5 nm. The emission from the AlGaN MQWs were several tens of times larger than that of bulk AlGaN. We found that the most efficient PL is obtained at around 240 nm from AlGaN MQWs with $Al_{0.8}Ga_{0.2}N$ barrier. Also, we found that the PL from AlGaN MQW is as efficient as that of InGaN QWs at 77 K.

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