Near ultraviolet emission from nonpolar cubic $Al_xGa_{1-x}N/GaN$ quantum wells

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(Received 21 June 2006; accepted 7 August 2006; published online 26 September 2006)

In this contribution the authors studied the optical properties of cubic $Al_xGa_{1-x}N/GaN$ single and multiple quantum wells. The well widths ranged from 2.5 to 7.5 nm. Samples were grown by rf-plasma assisted molecular beam epitaxy on free standing 3*C*-SiC (001) substrates. During growth of $Al_{0.15}Ga_{0.85}N/GaN$ quantum wells clear reflection high energy electron diffraction oscillations were observed indicating a two dimensional growth mode. They observe strong room temperature, ultraviolet photoluminescence at about 3.3 eV with a minimum linewidth of 90 meV. The peak energy of the emission versus well width is reproduced by a square-well Poisson-Schrödinger model calculation. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2357587]

Group III-nitrides crystallize in the stable wurtzite structure or in the metastable zinc blende structure. State-of-the-art hexagonal group III-nitrides are grown along the polar *c* axis, which produce strong internal electric fields. These "build-in" polarization-induced electric fields limit the performance of optoelectronic devices which employ quantum well active regions. Especially the spatial separation of the electron and hole wave functions caused by the internal fields reduces the oscillator strength of transitions and limits the recombination efficiency of the quantum wells.[1] To get around this problem, much attention has been focused on growth of wurzite structures with nonpolar orientations, e.g., growth along the *a*, *m*, or *R* directions.[2–4] Because of their higher crystallographic symmetry cubic nitrides grown in (001) direction offer an alternative way of producing nitride-based quantum structures that are unaffected by internal polarization fields. Unfortunately, the zinc blende GaN polytype is metastable and can only be grown in a very narrow window of process conditions.[5] However, the use of nearly lattice matched, freestanding high quality 3*C*-SiC substrates led to substantial improvements of the crystal quality of *c*-III nitrides.[6]

In this letter we report on the optical properties of nonpolar cubic AlGaN/GaN quantum wells (QWs) grown on 3*C*-SiC substrates by molecular beam epitaxy. We observe near-UV photoluminescence (PL) emission at room temperature. The linewidth of the PL from our QWs is comparable to that from nonpolar *h*-AlGaN/GaN quantum wells.[4,7]

All cubic $Al_xGa_{1-x}N/GaN$ quantum wells used for this investigation were grown on freestanding 3*C*-SiC (001) substrates by rf-plasma assisted molecular beam epitaxy. Before growth of the quantum structures an 800 nm thick GaN buffer layer was deposited on the 3*C*-SiC substrate. The buffer and the *c*-AlGaN/GaN quantum wells were grown at a substrate temperature of 720 °C. The layers were deposited using a well defined metal coverage of 1 ML of the growing surface.[8] The quantum structures consist of 6 nm thick $Al_xGa_{1-x}N$ barriers and GaN wells with a width of 2.5 −7.5 nm and were sandwiched between 50 nm AlGaN cladding layers. During growth the surface reconstruction was monitored *in situ* by refection high energy electron diffraction (RHEED). Room temperature and low temperature (2 K) photoluminescence spectroscopy using the 325 nm line of a HeCd laser was applied to characterize the QW emission properties. High resolution x-ray diffraction (XRD) measurements made with a Philips MRD X'Pert diffractometer using the Cu $K\alpha$ radiation revealed the quantum well dimensions and the composition of the barriers.

The full widths at half maximum (FWHMs) of XRD rocking curves of the *c*-GaN buffer and the $Al_{0.15}Ga_{0.85}N$ cladding layers were almost identical (26 arc min for the *c*-GaN buffer and 29 arc min for the AlGaN), revealing that the density of defects does not increase at the AlGaN/GaN interface. Reciprocal space maps of the asymmetric GaN (-1-13) reflex show that the $Al_{0.15}Ga_{0.85}N$ barriers are pseudomorph to the *c*-GaN buffer.

During the initial growth of the AlGaN and GaN layers weakly damped oscillations of the intensity of the RHEED specular spot were observed. AlGaN related RHEED oscillations are depicted in Fig. 1. They indicate a two dimensional growth mode even at substrate temperatures of 720 °C which is a relatively low temperature for *c*-AlGaN growth. The period of the RHEED oscillations allowed measuring the growth rate with an accuracy of 0.01 ml/s.

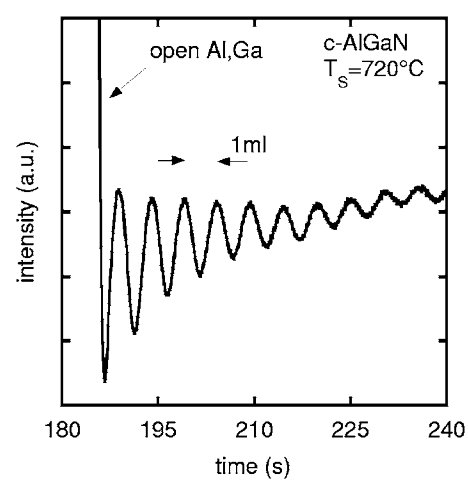

FIG. 1. Weakly damped RHEED oscillations measured during c-$Al_{0.15}Ga_{0.85}N$ growth. The growth rate is of 0.19±0.01 ml/s.

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0003-6951/2006/89(13)/131910/3/$23.00

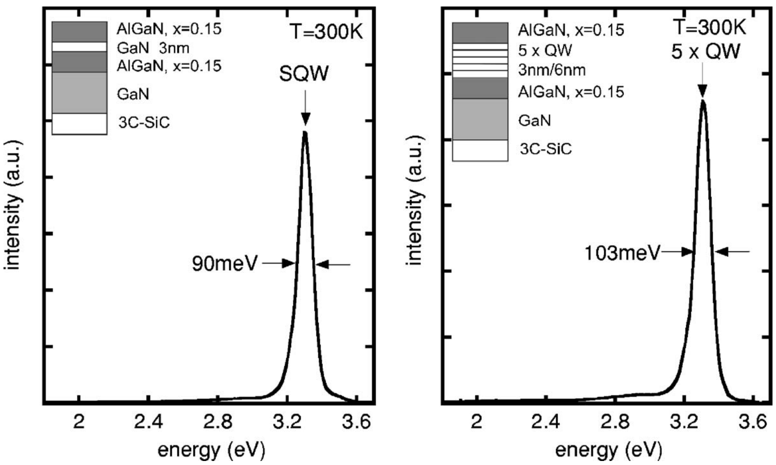

FIG. 2. Room temperature photoluminescence of cubic $Al_{0.15}Ga_{0.85}N/GaN$ single and multiple quantum well structures. The QW transition energy is $E=3.30$ eV and the linewidths are 90 meV for the SQW and 103 meV for the MQW.

Figure 2 shows the room temperature photoluminescence spectra of a single quantum well (SQW) structure (left side) and a multiple quantum well (MQW) structure (right side) excited with a HeCd-UV laser. The dimensions of the quantum structures are 3 nm thick wells and 6 nm barriers. We observe a strong emission at 3.30 eV. The emission lies between the *c*-GaN emission at 3.2 eV and the emission of the $Al_{0.15}Ga_{0.85}N$ cladding layer at about 3.48 eV.[9] Therefore we assign the observed strong UV emission to radiative recombination of electron-hole pairs in the QWs. The emission of the AlGaN barriers is suppressed due to an efficient collection of excess carriers from the barriers in the well region indicating a diffusion length of about 50 nm in the AlGaN barriers, in good agreement with earlier results of cathodoluminescence investigations.[10] No additional yellow luminescence at about 2.25 eV which is related to defects in nonpolar or polar hexagonal nitrides[2] was observed.

The linewidths of the room temperature QW emission are 90 meV for the SQW and 103 meV for the MQW, respectively. The low temperature (2 K) linewidths are 64 meV for the SQW and 80 meV for the MQW, respectively. We suppose that the difference of the SQW and the MQW linewidth is due to weak fluctuations of the width of individual quantum wells in the MQW structure. Notably, the linewidth of the *c*-$Al_{0.15}Ga_{0.85}N/GaN$ QW emission is close to values recently reported for nonpolar *a*-plane hexagonal AlGaN/GaN quantum wells.[2,7] This may indicate the potential of cubic quantum structures for application in nonpolar devices. However, the PL linewidth of our QWs exceeds that of the emission from polar (*c* plane) hexagonal AlGaN/GaN QWs which is most likely due to the higher density of dislocations in metastable cubic structures.

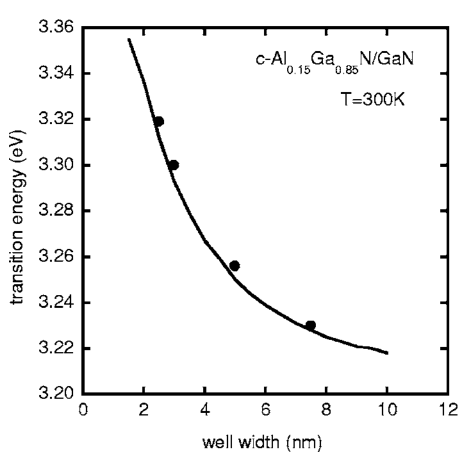

FIG. 3. Transition energies of cubic $Al_{0.15}Ga_{0.85}N/GaN$ MQWs as a function of the well width. The dots are experimental data; the curve is calculated using a self-consistent Poisson-Schrödinger model.

The room temperature PL peak energies of our cubic $Al_{0.15}Ga_{0.85}N/GaN$ quantum wells are plotted versus well width in Fig. 3. We find a decrease of the emission energy with increasing well width. The full curve in Fig. 3 is calculated using a square well self-consistent Poisson-Schrödinger calculation.[11] We assume a 70:30 ratio of the conduction and valence band discontinuities.[12] The effective masses of electrons and holes in *c*-GaN and *c*-$Al_{0.15}Ga_{0.85}N$ are $m_e=0.15m_0$,[13] $m_h=0.8m_0$ and $m_e=0.156$, and $m_h=0.86$,[14] respectively. We find excellent agreement between experimental and calculated data indicating that, unlike in polar *h*-group III nitride based quantum structures, polarization and piezoelectrical effects are absent in *c*-III nitrides with a (001) growth direction. The shift of the emission energy versus width of cubic QWs is almost identical to that of nonpolar *a*-plane hexagonal AlGaN/GaN QWs with a similar composition.[7]

In summary cubic $Al_{0.15}Ga_{0.85}N/GaN$ single and multiple quantum wells were grown on 3*C*-SiC/GaN substrates. During growth of $Al_{0.15}Ga_{0.85}N/GaN$ QWs clear RHEED oscillations were observed allowing a stringent control of the growth rate and indicating two dimensional growths of the respective layers. The peak energy of the emission from our cubic $Al_{0.15}Ga_{0.85}N/GaN$ QWs follows the square-well Poisson-Schrödinger model and demonstrates the absence of polarization induced electrical fields. The FWHM of *c*-QW luminescence is almost identical to values reported for nonpolar hexagonal AlGaN/GaN quantum wells. Our results obtained with quantum wells grown on 3*C*-SiC substrates indicate that the well known thermodynamic metastability of the cubic nitrides does not necessarily limit their application for polarization free structures.

The authors would like to thank H. Nagasawa and M. Abe from SiC Development Center, HOYA Corporation, for supplying the 3*C*-SiC substrates.

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