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MBE Growth and Properties of GaN, $Al_xGa_{1-x}N$ and AlN on GaN/SiC Substrates

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Growth of GaN, AlGaN, and AlN by molecular beam epitaxy (MBE) is being studied at NCSU using GaN/SiC substrates. The GaN/SiC substrates consist of ~3 μm thick GaN buffer layers grown on 6H-SiC wafers by MOVPE at Cree Research, Inc. These GaN/SiC substrates exhibit double-crystal x-ray diffraction rocking curves as narrow as 85 arc sec FWHM(0002). Both an electron cyclotron resonance (ECR) plasma source and a radio frequency (rf) plasma source were investigated for the growth of III-V nitrides by MBE. Film quality was correlated with the optical emission characteristics of each type of nitrogen plasma source employed. The best films were those grown using the rf nitrogen plasma source. This source was found to emit a much larger fraction of atomic nitrogen and 1st-positive series excited molecular nitrogen in contrast to the ECR plasma source which mainly produced 2nd-positive series excited molecular nitrogen and nitrogen molecular ions when operated under the same conditions.

The benefit of homoepitaxial growth of GaN using GaN/SiC substrates was seen by the observation of surface reconstructions before, during, and after GaN, AlGaN and AlN film growth by MBE. MBE film growth rates were 1000 to 4000 Å/hr. The MBE-grown GaN films exhibit remarkably intense photoluminescence (PL) dominated by a sharp band-edge peak at 3.409 eV having a FWHM of 29.7 meV at room temperature. When cooled to 4.2 K, the GaN PL band edge feature, due presumably to excitonic emission, splits into two sharp peaks having FWHMs of only 4-5 meV. Double-crystal x-ray rocking curve measurements of selected MBE-grown GaN films yielded (0002) diffraction peaks having FWHMs as narrow as 156 arc sec.

Vertical-cross-section TEM studies clearly show that the MBE-grown GaN layers replicate the quality of the underlying MOVPE-grown GaN buffer layer on SiC. The TEM studies revealed dislocation densities as low as 10^8 per cm^2 in both the MBE-grown GaN layers and the underlying MOVPE-grown GaN buffer layers. The best MBE-grown GaN layers synthesized to date show dislocation densities of less than 10^7 per cm^2. Thus we conclude that, under proper growth conditions, MBE can produce GaN films having properties which are as good as the best GaN layers grown by MOVPE.

N-type GaN has been grown by MBE using Si as the dopant. P-type GaN has been obtained using Mg as the dopant. PL spectra from these layers reflect the presence of the respective dopants. The room temperature PL spectrum of a 1 μm thick MBE-grown heavily doped n-type GaN:Si film is dominated by a very intense peak at 3.39 eV due, we believe, to a donor-hole (D,h) optical transition associated with the Si donor. If this is the case, this would correspond to a donor activation energy E_d of about 19 meV for the Si donor in GaN.. Hall effect measurements on this sample yielded a room temperature carrier concentration $n = 1.2 \times 10^{20}$ cm^{-3} and an electron mobility $\mu_n = 65$ cm^2/V-s. A representative room temperature PL spectrum for a 0.7 μm thick MBE-grown p-type Mg-doped GaN film was also obtained. The p-type character of this GaN:Mg sample was confirmed by thermal probe techniques. The PL emission peak at 3.25 eV is believed to be due to an electron-to-acceptor (e,A) optical transition associated with the Mg doping. If this is the case, this would correspond to an acceptor ionization energy E_a for the Mg acceptor of about 160 meV in GaN.

$Al_xGa_{1-x}N$ films (x ~0.06-0.08), grown by MBE on GaN/SiC substrates, exhibited 2D nucleation as seen by RHEED and showed strong PL edge emission at 3.62-3.69 eV at 295 K. $Al_xGa_{1-x}N$/GaN (x ~0.06-0.08) MQW structures were also grown by MBE. PL emission was observed from both the $Al_xGa_{1-x}N$ cladding layer and the GaN QWs with the relative PL peak intensities dependent on cladding layer thickness. 2D growth of AlN, with an accompanying surface reconstruction, has also been achieved by MBE. Structural properties of the AlN layers are presently under investigation and will be reported at the conference.

$Al_xGa_{1-x}N$/GaN double heterostructures have also been prepared by MBE. These p-on-n structures were processed into 250 μm x 250 μm mesa diodes using standard processing techniques. The LEDs emit bright violet light at temperatures ranging between 77 - 220 K. At room temperature, however, the emission is quite broad and is includes emission from deep states.

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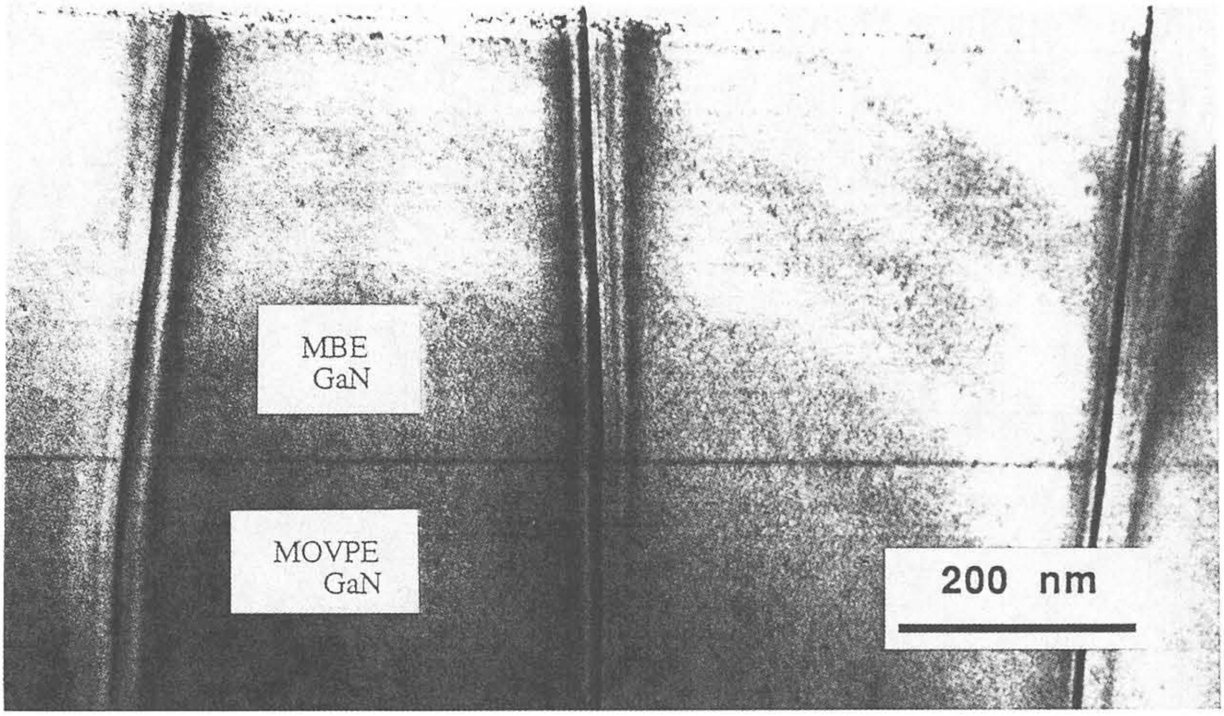

Figure 1. Vertical cross-section TEM of MBE-grown GaN on GaN/SiC substrate.

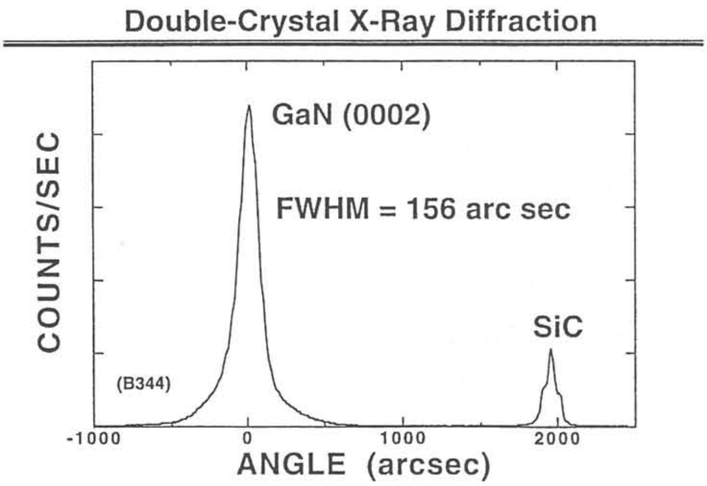

Figure 2. X-ray diffraction from MBE-grown GaN.

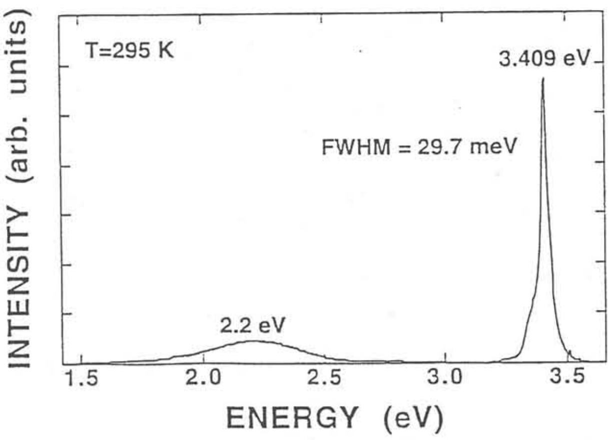

Figure 3. Photoluminescence from undoped GaN.

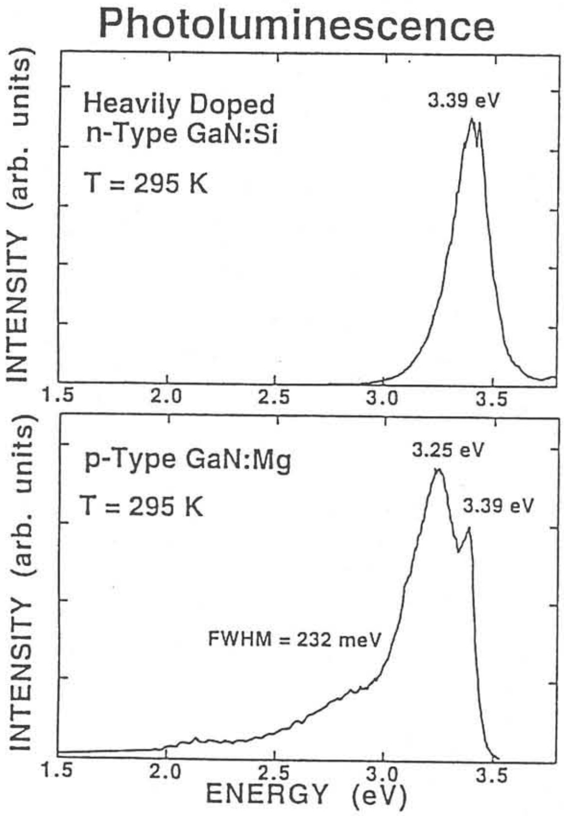

Figure 4. Photoluminescence from doped GaN.

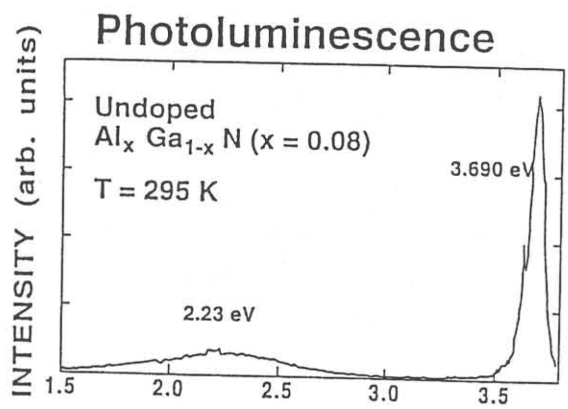

Figure 5. Photoluminescence from $Al_xGa_{1-x}N$.

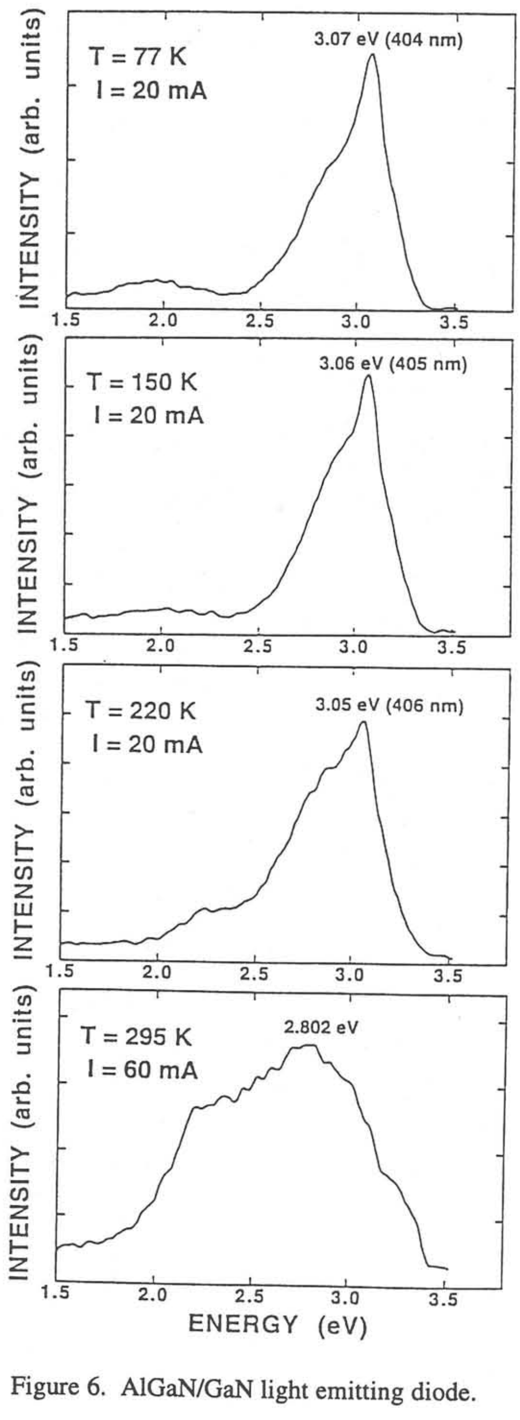

Figure 6. AlGaN/GaN light emitting diode.