Optical properties of GaN grown over SiO_2 on SiC substrates by molecular beam epitaxy

John T. Torvik[a] and Jacques I. Pankove
Astralux Inc., Boulder, Colorado 80301

Eleftherios Iliopoulos, Hock M. Ng, and Theodore D. Moustakas
Boston University, Department of Electrical and Computer Engineering and Center for Photonics Research, Boston, Massachusetts 02215

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We investigate the optical properties of GaN grown over SiO_2 on SiC substrates by electron cyclotron resonance assisted molecular beam epitaxy. The photoluminescence spectra and refractive index of GaN were compared for GaN/SiO_2/SiC and GaN/SiC. Strong band-edge luminescence was observed at 3.40 eV from the GaN on both SiO_2/SiC and on SiC. No defect-related yellow luminescence was observed. The refractive index of GaN at 1.96 eV (632.8 nm) was measured at 2.22 and 2.24 for GaN/SiO_2/SiC and GaN/SiC, respectively. © *1998 American Institute of Physics.* [S0003-6951(98)03302-6]

III–V nitrides are the materials of choice for short-wavelength emitters such as green, blue, and ultraviolet light-emitting diodes and lasers.[1] A major challenge in the growth of III–V nitrides is the lack of a lattice-matched substrate with compatible thermal properties.[2] Sapphire is a commonly used substrate for epitaxial III–V-nitride growth, and the *c*-plane (0001) has a lattice mismatch of 16% with GaN.[3] Epitaxial III–V-nitride layers are also often grown on SiC substrates, where the GaN and 6H–SiC lattice mismatch is 3.3%.[2] The large lattice mismatch between the most common substrates and GaN results in a high defect density in epitaxial GaN layers. This is true even with the use of low-temperature AlN (Ref. 4) and GaN (Ref. 5) nucleation (buffer) layers. These defects probably contribute to low mobilities, high background electron concentration, and nonradiative recombination. Recently, GaN grown over SiO_2 on GaN/AlN (buffer layer)/SiC substrates by metalorganic chemical vapor deposition (MOCVD) was shown to contain significantly fewer threading dislocations as measured by transmission electron microscopy (TEM).[6] Epitaxial lateral overgrowth of III–V nitrides by MOCVD has also been reported using various buffer layers on sapphire substrates.[7–9] It was found that a lateral-to-vertical growth rate ratio up to 4:1 can be achieved over SiO_2 on GaN/sapphire by MOCVD.[9] We compare the optical properties of GaN grown without buffer layers over thermally grown SiO_2 on SiC to GaN grown directly on SiC by electron cyclotron resonance assisted molecular beam epitaxy (ECR-MBE).

In this letter, we report on the optical properties of GaN grown over patterned SiO_2 on SiC by ECR-MBE. We achieved uniform coverage of a 1-μm-thick epitaxial GaN film over a lateral distance of up to 300 μm over SiO_2 between exposed SiC areas. Photoluminescence (PL) and ellipsometry measurements revealed that the optical properties are comparable for GaN/SiO_2/SiC and GaN/SiC.

The GaN epitaxial layers for this study were grown by ECR-MBE on commercial SiC substrates. A detailed description of the growth system is given elsewhere.[10] The sample structures consists of a 1-μm-thick *n*-type ($\sim 10^{18}$ cm^{-3}) GaN epilayer grown directly on oxidized and patterned bulk *p*-type (5×10^{17} cm^{-3}) Si-face 6H–SiC. The GaN was Si doped. A schematic of the sample cross section is shown in Fig. 1. The arrows labeled measurements 1 and 2 indicate where the PL and ellipsometry were performed to separately probe the GaN/SiO_2/SiC and GaN/SiC. Note that low-temperature GaN or AlN nucleation (buffer) layers were not used. The SiC films were cleaned with organic solvents and an RCA treatment[11] immediately prior to the thermal wet oxidation. A 0.1-μm-thick SiO_2 layer was grown in a quartz furnace at 1175 °C. Rectangular holes, ranging from 80×80 μm^2 to 250×250 μm^2, were defined in the SiO_2 using photolithography and a buffered oxide etch (H_2O:HF, 6:1). The holes were separated by up to 300 μm. Uniform GaN grew in the holes and on the surrounding SiO_2. PL measurements were performed using a focused He–Cd laser at 3.82 eV (325 nm). The signal was dispersed in a 0.5 m grating monochrometer (blazed at 250 nm), detected by a photomultiplier tube, and recorded using a computer. Ellipsometry was performed with a He/Ne laser at 1.96 eV (632.8 nm). All measurements were made at room temperature.

The GaN surface morphology was inspected using optical and scanning electron microscopy and found to be featureless. The mirrorlike surface was free of cracks, pits or

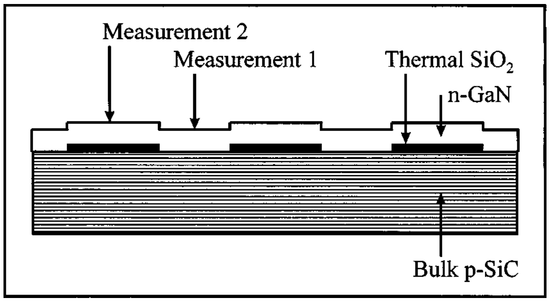

FIG. 1. Cross-sectional schematic of GaN/SiO_2/SiC sample structure. The GaN thickness is 1 μm, and the SiO_2 thickness is 0.1 μm. The openings in the SiO_2 range from 80×80 μm^2 to 250×250 μm^2, and are spaced up to 300 μm apart.

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[a] Electronic mail: jtt@indra.com

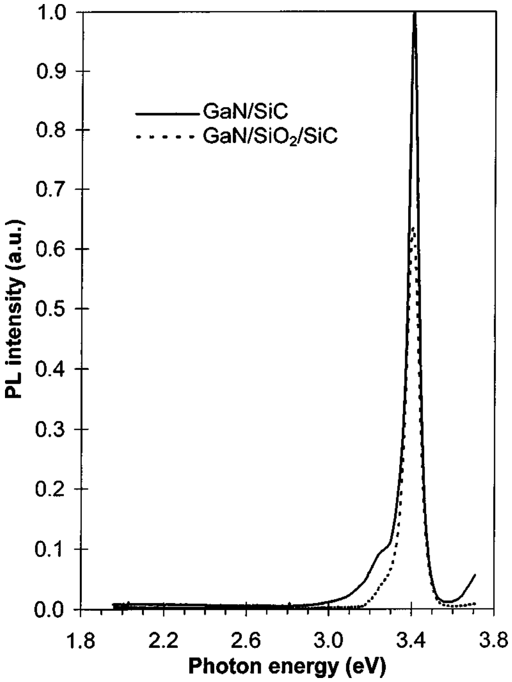

FIG. 2. Photoluminescence spectra of GaN/SiO_2/SiC and GaN/SiC. The excitation source was a focused He–Cd laser operating at 325 nm and 10 mW.

voids, and the film exhibited smooth transitions from GaN/SiC to GaN/SiO_2/SiC.

Two typical PL spectra from GaN/SiO_2/SiC and GaN/SiC are shown in Fig. 2. Strong band-edge luminescence was observed in both cases centered at 3.40 eV. The full width at half maximum (FWHM) was 56 and 76 meV for the GaN/SiC and GaN/SiO_2/SiC, respectively. The extracted values are summarized in Table I. Note that neither PL trace exhibits the characteristic yellow defect-related luminescence often observed in GaN.[12] The PL efficiency of GaN/SiO_2/SiC was 78% compared to that of GaN/SiC. This was measured from the ratio of the integrated PL intensities ($I_{\mathrm{GaN/SiO_2/SiC}}/I_{\mathrm{GaN/SiC}}$) taken from 3.0 to 3.5 eV. The reason why the efficiency is smaller for GaN/SiO_2/SiC is unclear, and further investigations are needed to answer this question. On the other hand, there is almost no peak/shoulder on the low-energy side of the band-edge peak at ~3.25 eV in the GaN/SiO_2/SiC spectrum compared to in the GaN/SiC spectrum. This peak/shoulder has been attributed to defects (stacking faults), which are nucleation sites for zinc-blende–GaN domains.[10] One can, therefore, speculate that there are less stacking faults in the GaN grown over SiO_2/SiC. TEM studies will be performed to investigate the GaN grown over SiO_2/SiC.

Ellipsometry was performed to measure the refractive index of GaN at 1.96 eV (632.8 nm). If the GaN grown over the SiO_2 were amorphous or porous, the index of refraction would be expected to change drastically from the value measured in GaN/SiC. The index of refraction of GaN was measured at 2.24 on SiC, which is in agreement with a previously published value.[13] This also corresponds to the value of 2.22 measured in GaN/SiO_2/SiC. The uncertainty in the refractive index is ±0.02. These values are consistent over a $1\times 1\ \mathrm{cm}^2$ area. It is also worth mentioning that the samples had to be very clean to make a good measurement. An RCA clean was needed in our case.

TABLE I. Photoluminescence peaks (E_{peak}), full width at half maximum (E_{FWHM}), and refractive index (n) for GaN/SiO_2/SiC and GaN/SiC.

	E_{peak} (eV)	E_{FWHM} (meV)	Refractive index (n)
GaN/SiO_2/SiC	3.40	76	2.22
GaN/SiC	3.40	56	2.24

The growth mechanism of the GaN on the SiO_2/SiC areas is presently unclear, and will require further work to unravel. Using MOCVD for epitaxial lateral overgrowth, the lateral-to-vertical growth rate is ~4:1.[9] Using MBE we found that a 1-μm-thick GaN film covered up to 300 μm of SiO_2. Since selective growth using a dielectric mask has proved difficult using MBE with elemental sources,[14] the growth might involve nucleation on the SiO_2.

In conclusion, we have compared the PL spectra and the refractive index of GaN grown over SiO_2 on SiC using ECR-MBE. Strong band-edge photoluminescence at 3.40 eV was observed from both the GaN/SiO_2/SiC and the GaN/SiC, without the presence of defect-related yellow luminescence. The luminescence efficiency of GaN on SiO_2/SiC was 78% compared to that of GaN on SiC. The GaN/SiO_2/SiC PL spectrum was slightly broadened, with a greatly attenuated defect-related PL at ~3.25 eV. The indices of refraction were close for GaN on SiO_2/SiC and SiC at 2.22 and 2.24, respectively. Overall, the optical properties of GaN/SiO_2/SiC were quite similar to those of GaN/SiC, which indicates that high-quality GaN was grown over SiO_2 on SiC.

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