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GaN Layers Grown by HVPE on P-type 6H-SiC Substrates

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Abstract

Gallium nitride films were successfully grown by HVPE technique on p-type 6H-SiC substrate. The layers exhibit high crystal quality as was determined by X-ray diffraction. Photoluminescence (PL) of these films was measured. The PL spectra were dominated by band edge emission. Concentration N_d-N_a in undoped epitaxial layers ranged from $2x10^{17}$ to $1x10^{19}$ cm^{-3}. Mesa-structures formed by reactive ion etching showed good rectifying current-voltage characteristics for GaN/SiC pn heterojunctions.

1. Introduction

1.1. HVPE Advantages

The HVPE method is a promising technique for deposition of thick GaN single crystal layers. The main advantages of this method are high growth rate and low cost. Recent progress in HVPE growth shows that high quality GaN layers can be obtained [1] [2] [3]. The crystalline, electrical and optical properties of these films are comparable with the best characteristics reported in the literature for GaN produced by MOCVD [4] [5] and MBE [6] [7].

Besides, HVPE allows one to grow high quality GaN layers on SiC substrates without any buffer layer [1]. This feature is important for producing electronic devices with vertical geometry.

1.2. GaN/SiC Heterodevices

The direct deposition of GaN on SiC also provides one the opportunity to create devices based on GaN/SiC heterojunctions (e.g. heterojunction bipolar transistor) [8] [9]. Recently p-GaN on n-SiC has been successful grown by MBE and junction characteristics have been achieved. [10].

1.3. Alternative to Ohmic Contact to p-GaN?

One of the obstacles in GaN device fabrication is the absence of a suitable ohmic contact to p-GaN. To overcome this problem, the inverse GaN device structure i.e. pSiC (substrate)/pGaN/.../nGaN may be used. The best ohmic contact to p-GaN [11] has a resistivity about 3 orders of magnitude higher than that for n-GaN [11] [12] and about 2 orders of magnitude higher than that for p-SiC [13]. A large area p-contact to SiC will contribute negligibly to the overall device series resistance. However to the best of our knowledge there are no reports on growth GaN on p-type SiC substrates.

In this paper we report on properties of n-GaN layers grown by HVPE directly on p-type SiC substrates. Preliminary result on n-GaN/p-SiC heterojunction are presented**.**

2. Experiments

2.1. GaN Epitaxial Growth

GaN n-type layers were grown by HVPE on p-type 6H-SiC manufactured by Cree Research, Inc. The N_d-N_a concentration in the wafers was about $1x10^{18}$ cm^{-3}. The layers were deposited on the on-axis (0001)Si face of the substrates. A hot-wall open flow reactor was employed. HCl was reacted with liquid Ga to form GaCl gas which was transported to the growth zone where it was reacted with NH_3 resulting in GaN deposition on the SiC substrate. The thickness of the GaN layers ranged from 0.5 to 2 µm. The GaN growth rate was controlled from 0.02 to 0.4 µm/min

2.2. Mesa-structure and Contacts

Mesa-structures (150 µm diameter) were formed by reactive ion etching [14] using dichlor-difluoromethane (CCl_2F_2). Two kind of metal compositions were used as ohmic contacts to n-GaN. They were Ti/Ni contacts annealed at 1000°C [11] and as deposited Al contacts (for GaN films with N_d-N_a>10^{18} cm^{-3}). Both of them were used as a mask for GaN plasma etching. Al or In were used as a backside contact to SiC substrate.

2.3. Investigation

The layers were characterized using x-ray diffraction. Capacitance- voltage measurements were performed employing a Hg-probe. Luminescent properties of the GaN layers were also examined. Current-voltage and capacitance-voltage characteristics of mesa-structures were investigated. Electron beam induced current (EBIC) and back scattered electron (BSE) techniques were used to study GaN/SiC heterojunction.

3. Results

3.1. Crystal quality

The GaN layers was a smooth over the entire wafer. The full width at half maximum (FWHM) of double crystal x-ray ω-scan rocking curves (RC) for (0002) GaN reflection ranged from 120 to 700 arcsec (Figure 1). It was found that the FWHM of RC's for ω-scan are much larger than FWHM for $\omega,2\Theta$-scan. This feature of the x-ray RC is similar to RC characteristic obtained for GaN grown on n-6H-SiC substrates [l]. It may be proposed that in both cases the dislocation distribution in the epitaxial layers is between an uniform distribution and a block-mosaic structure where blocks of the material having low dislocation density are separated from one another by dislocation boundaries. It was found that there are rather large residual thermal strains in GaN layers. If the thickness of the layer exceeds ~ 1.5 µm cracks formation is observed.

It must be pointed out that the crystal quality of the epitaxial layer strongly depends on the substrate quality (Figure 1). It was found that the crystal quality of GaN films grown on n-type SiC at the same growth conditions is better than those grown on p-type SiC. This fact may be associated with difference in crystal quality of used SiC wafers. The FWHM of RC's of n-type SiC wafers is less than that of p-type SiC wafers. Detailed study of substrate crystal quality effect on GaN structural perfection will be published elsewhere. [15]

3.2. Luminescence

The GaN layers were characterized by photoluminescence (PL) at 80 and 300 K. The PL experiments were performed using a pulsed nitrogen laser with a peak power of 2 kW. The PL spectra (Figure 2,3) showed a sharp ultraviolet peak centered at ~361 nm (80 K), with the FWHM of ~4 nm (37 meV). At 300K the FWHM was ~8 nm (72 meV). Some samples exhibited a strong blue luminescence band at 430-450 nm which may be attributed to structural defects or autodoped impurities.

3.3. Electrical properties

N_d-N_a concentration in the n-GaN layers was measured to be the range from $2x10^{17}$ to $1x10^{19}$ cm^{-3}. It was found that the background concentration depends on crystal quality of the GaN layer. We may assume that high donor concentration is caused by some kind of structural defects in GaN layer.

3.4. Electrical properties of mesa-structures

The capacitance-voltage (C-V) characteristics of the GaN/SiC pn heterojunctions measured at frequencies of 10 kHz and 1 MHz were linear when plotted in $C^{-2.5}$-V coordinates (Figure 4), which is typical for an anisotype heterojunctions with high densities of interface states. The cut-off voltage was about 2.02 V at 1 MHz and about 2.08 V at 10 kHz. This value is close to the built-in potential for n-GaN/p-6H-SiC heterojunction estimated using Anderson's model to be 2.17 V [16].

The structures showed good rectifying characteristics for GaN/SiC pn heterojunctions. (Figure 5) Breakdown voltages is ranged from 15 to 100 V. The turn-on voltage for forward I-V characteristic was ~2V which corresponds to build-in potential of the heterojunction. (Figure 5a) It should be note that the value of cut-off voltage determined from C-V measurements is closed to the turn on voltage for forward I-V characteristics. Detail study of electrical characteristics of the GaN/SiC heterojunction, influence of interface on electrical properties and the theoretical calculation for the bandgap diagram will be published [16].

A weak electroluminesence (EL) was detected in some samples at room temperature. The EL was dark red when a forward voltage was applied and white-blue under reverse bias.

3.5. EBIC

The location of heterojunction inside the structures was determined by simultaneous detection of EBIC and BSE signals by scanning electron probe on the cleaved structure. Figure 6 shows BSE and EBIC signal profiles across an GaN/SiC heterostructure. As known, EBIC curve maximum corresponds to the middle of the space charge region. In the investigated structures a shift of EBIC signal maximum from the GaN/SiC interface to SiC was observed. The shift value was about 0.03 µm. This value is close to half of the space charge region width at zero bias of 0.06 µm determined by C-V measurements.

4. Summary

Gallium nitride films have been successfully grown on SiC by HVPE technique. For the first time, p-type 6H-SiC wafers were used as substrates for GaN deposition. The layers exhibit high crystal quality as was determined by X-ray diffraction. The FWHM for the ω-scan rocking curve for (0002) GaN reflection was ~120 arcsec. The photoluminescence spectra for these films were dominated by band edge emission. The FWHM of the edge PL peak was about 37 meV at 80 K. The minimum N_d-N_a concentration in undoped layers was 2×10^{17} cm^{-3}.

Mesa-structures were formed by reactive ion etching. GaN/SiC pn heterojunctions showed good rectifying characteristics. The value of cut-off voltage determined from C-V and I-V measurements was about 2 V. This value is close to the built-in potential estimated by Anderson's model for 6H-SiC/GaN heterojunctions. EBIC study showed that the space charge region of the heterojunction is shifted towards the SiC substrate.

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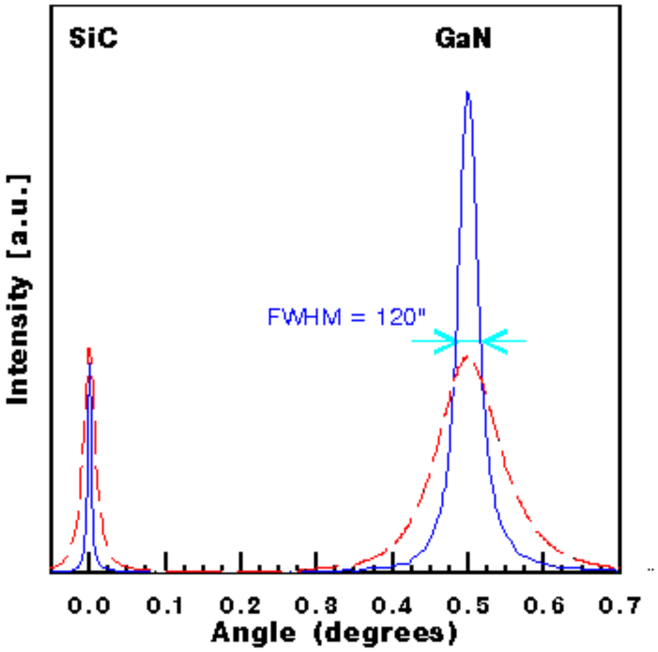

Figure 1. X-ray ω-scan rocking curves for GaN layers grown on different substrate. The blue line represents RC for best GaN layer grown on p-6H-SiC substrate. The FWHM of peak from substrate is 24 arcsec. This value is significantly less than 65 typical for used substrates. The RC for GaN layer on convinient substrate is presented by red line.

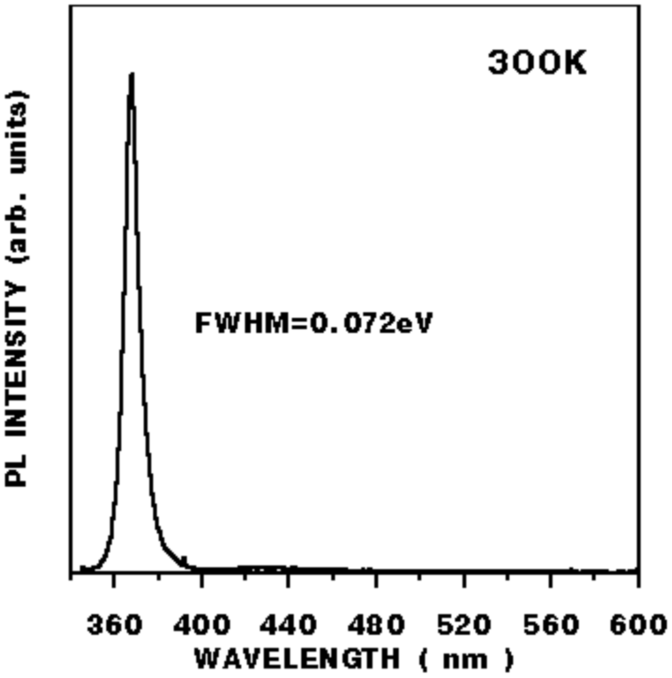

Figure 2. Room temperature PL spectrum for GaN layer.

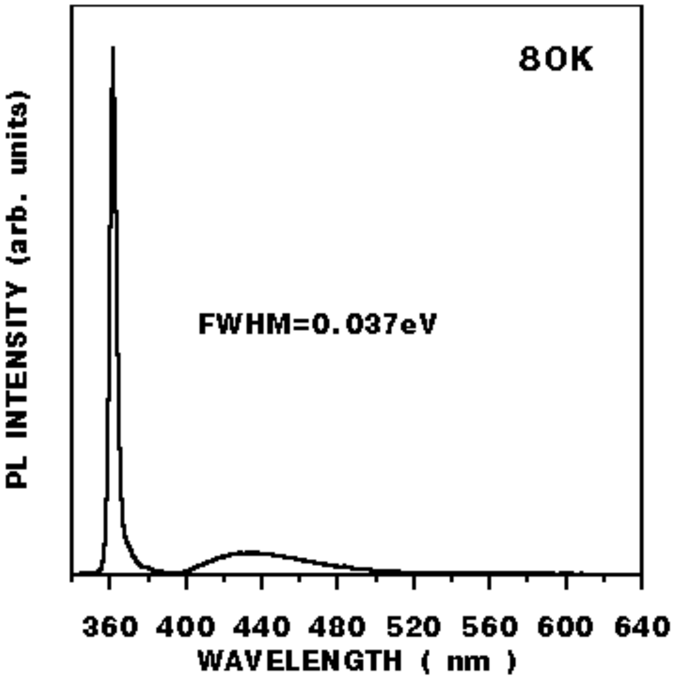

Figure 3. PL spectrum for GaN layer at T=80 K .

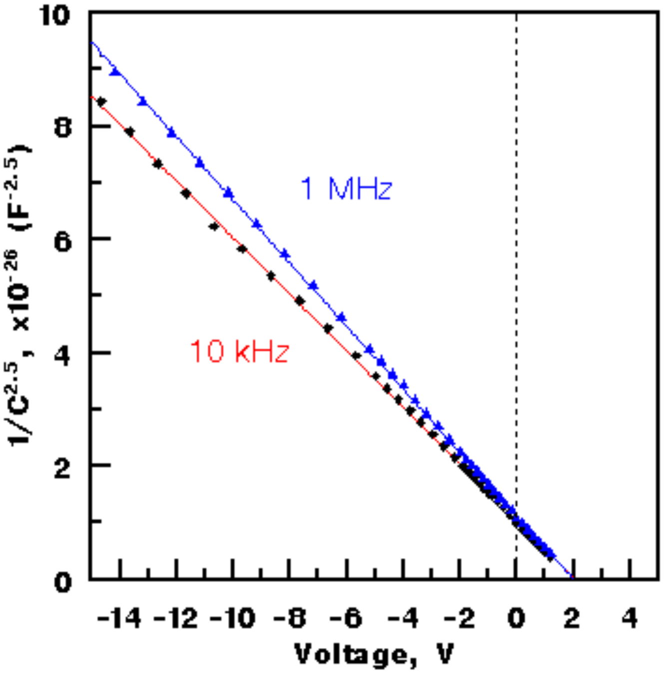

Figure 4. The capacitance-voltage characteristics of the GaN/SiC pn heterojunctions measured at frequencies of 10 kHz (red-solid line) and 1 MHz (blue-dashed line).

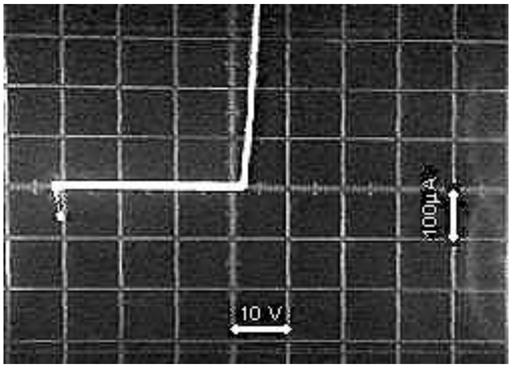

Figure 5. Current-voltage characteristic of n-GaN/p-SiC heterojunction diode (vertical scale - 100 µA/div, horizontal scale- 10 V/div).

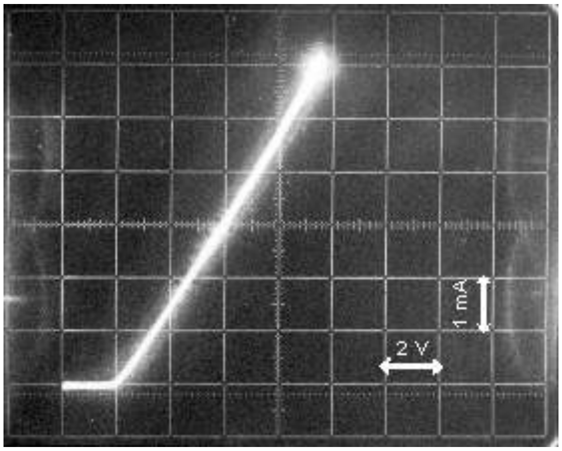

Figure 5a. Forward current-voltage characteristic of n-GaN/p-SiC heterojunction diode (vertical scale - 1 mA/div, horizontal scale- 2 V/div).

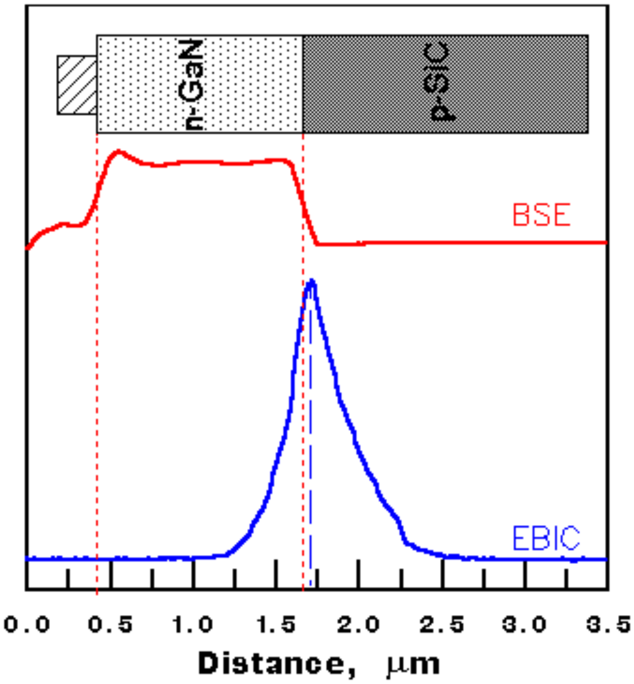

Figure 6. Schematic cross-section drawing for n-GaN/p-SiC heterojunction diode and EBIC/BSE signal profiles across the stucture.