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# Study of defects in GaN/sapphire using Rutherford backscattering spectroscopy and channeling

S K Sinha* and P K Barhai

Department of Applied Physics, Birla Institute of Technology, Mesra-835 215, Jharkhand, India

E-mail : sksinha@bitmesra.ac.in

**Abstract** : III-V nitrides like GaN, AlN, InN have opened up new opportunities in low-wavelength optical light emitters and in high frequency and high power electronic devices working at high temperature. But it is difficult to grow these materials due to lattice-mismatched substrate. GaN on sapphire were grown by MOCVD technique. Rutherford backscattering spectra together with channeling along [0001] axis were recorded to study the defects at the interface. Detail calculation shows that defects are distributed into the whole thickness of the film and are dislocations mainly aligned along the growth direction.

**Keywords** : GaN, interface defects, RBS/C.

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## 1. Introduction

III-V nitrides are recent development in the field of semiconductors. These semiconductor devices can work even at higher temperature in comparison to other semiconductor devices. GaN is the newly developed III-V semiconductors having applications in the field of optical light emitters and detectors from 1.9 to 6.2 eV. However there is problem in their growth due to the lattice mismatch from the substrates. The nearest lattice-matched substrate is sapphire (~13%). For the successful development of the devices a better understanding of defect formation at the interface is required. We have studied the defects at the interface using Rutherford backscattering spectroscopy and channeling techniques (RBS/C). The description of RBS/C can be found in the following references [1–3]. Because of the limitations of Auger/X-ray photoelectron spectro-scopy (AES/XPS) and secondary ion mass spectrometry (SIMS), analysis of the sample at different intervals in the sputtering process; RBS/C technique becomes preferable for the study of interface as low Z, high energy ions have a very much lower sputtering coefficient and knock on probability and can be used for analysis without the smearing effect.

## 2. Experimental

In the wurtzite structure, the lattice can be thought of two interpenetrating hexagonal lattices. The wurtzite GaN structure is described elsewhere [4,5]. The samples were grown at Lecce (Italy) on (0001) *c*-plane $Al_2O_3$ substrates in a horizontal LP-MOCVD system (AIXTRON 200 AIX RF), equipped with a rotating substrate holder, with TMGa, TMAl and pure $NH_3$ as source materials. Seven samples of varying thickness from 0.33 μm to 2.18 μm were grown on (0001) oriented $Al_2O_3$ substrate. RBS/C analyses were performed at the Laboratori Nazionali di Legnaro, Padova, Italy by using $^4He^+$ delivered by the beams 2-MV AN 2000 and 7-MV CN Van de Graaff accelerators. The beam energy was varied from 0.8 to 4 MeV. Channeling spectra were obtained by using a high precision, three-axis goniometer. The scattering chamber is evacuated by a turbomolecular pump in the $10^{-7}$ mbar range. At the chamber entrance, different diaphragms can be selected so that the beam spot on the sample can be changed both in shape and

*Corresponding Author

size. Two solid state Si detectors can be independently and remotely moved by stepping motors to any angle in the range 0°–180°. The differential precision in the angle setting is better than 0.01°, while the absolute value of the angle can be calibrated within each run with respect to the actual beam direction with a precision better than 0.05°. This fact is very important in the case of grazing angle incidence and/or emergence experiments. Sample holder is remotely operated by stepping motors that are fully computer controlled.

Both IBM and Comell scattering geometries [6] can be used. However, all the experiments described in this paper were performed with the IBM geometry and 170° scattering angle. Rectangular diaphragms of different widths at the chamber entrance and in front of the detectors allow high depth resolution grazing incidence and/or emergence experiments.

The active surface area of the detectors was either 25 or 50 mm$^2$, but the detector diaphragms defined smaller area to achieve optimum energy resolution and detection efficiency. The pulses from the detector were amplified by commercial electronics and fed to the multichannel analyser. Energy spectrum distortion was minimized by pulse pile-up inspection and rejection with a time resolution better than 500 ns and by using count rates of not more than a few thousands of counts per second. Overall dead time correction was performed by counting, with fast electronics, all the pulses used to drive a Gated Biased Amplifier and the integral of the counts in the recorded spectrum.

The whole scattering chamber is fully isolated and acts as a Faraday cup. The overall precision in the beam current integration (by means of a commercial current integrator) is better than 0.5%. The RBS/C experiments are calibrated by using Ta/Si standard samples having accuracy better than 2% [7].

In order to avoid channeling effects in single crystals, the sample is rotated, while random spectra (RR) are recorded, in this way the beam describes a cone around a given axial direction, so that planar channeling effects are averaged. Random spectra are analysed by a computer simulation program [8], where trial concentration profiles for the different elements are optimised until good agreement between the simulated and experimental spectra is found within the statistics.

## 3. Results and discussion

The RR RBS of the GaN4 on sapphire is shown in the Figure 1. Simulation of this RR spectrum is shown by the solid line while the aligned spectra by dotted lines.

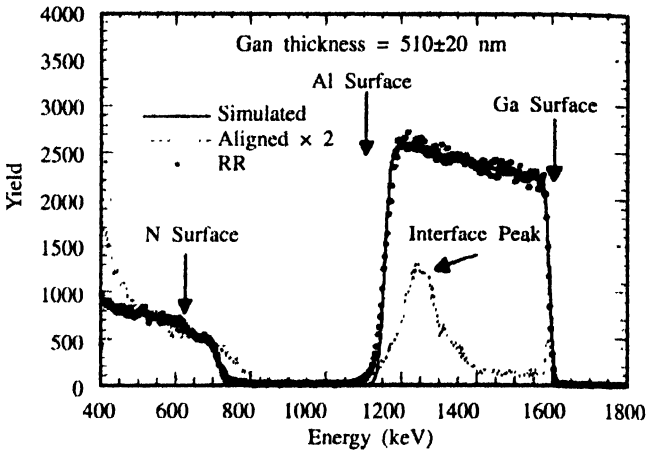


**Figure 1.** Random rotaed RBS (?), its simulation (—) and aligned × 2 (---) spectra along [0001] axis of GaN4 recorded using 2 MeV He$^+$ beam.

Surfaces of Ga and N are also shown in the figure. Al surface is shifted inward as it is not at the surface. From the RBS/C spectra, the calculation of chi minima ($\chi_m$) determines the crystalline quality. $\chi_m$ measures the crystalline quality at the surface of the sample.

As seen in Table 1, crystalline quality is bad for the thinnest sample no. GaN6. In the case of the thinnest sample GaN6, the analyzed region reaches the interface so this sample seems to have a worst crystalline quality than the others. For the thickness from 0.51 μm and above, the crystalline quality remains same. The measured surface peak corresponds to ~1.8 monolayer (ML) which is a good.

**Table 1.** RBS/channeling of GaN on sapphire.

| Sample # | GaN thickness (μm) | ($\chi_m$) (%) | Surface peak ($10^{15}$ Ga atoms/cm$^2$) |
|---|---|---|---|
| GaN1 | 2.00 ± 0.02 | Contaminated | Contaminated |
| GaN2 | 2.18 ± 0.02 | | |
| 2.1* | | 1.2 ± 0.2 | 4.4 ± 0.02 |
| 2.2 | | 1.3 ± 0.2 | 4.4 ± 0.02 |
| GaN3 | 0.99 ± 0.02 | 1.1 ± 0.2 | 4.3 ± 0.02 |
| GaN4 | 0.51 ± 0.02 | 1.2 ± 0.2 | 4.2 ± 0.02 |
| GaN5 | 1.43 ± 0.02 | 1.3 ± 0.2 | 4.6 ± 0.02 |
| GaN6 | 0.33 ± 0.02 | 1.7 ± 0.2 | 4.7 ± 0.02 |
| GaN | 0.94 to | 1.2 ± 0.2 | 4.4 ± 0.02 |
| 7** | 1.06 ± 0.02 | | |

* 2.1 means spot no 1 on sample 2; ** Non-uniform.

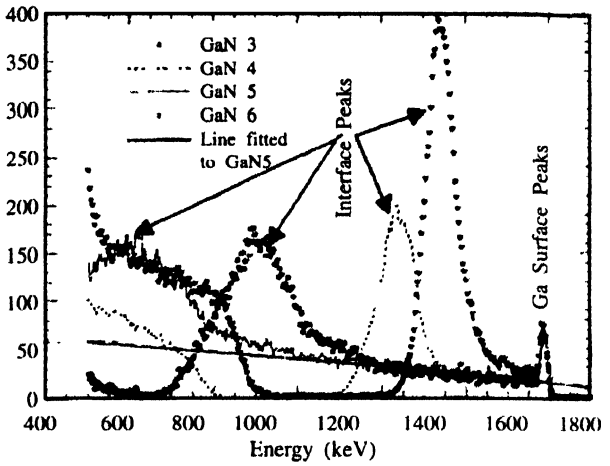


**Figure 2.** Aligned spectra of the different thickness GaN along [0001] axis recorded using 2 MeV $He^+$ beam.

The aligned spectra along the crystallographic axis [0001] of all the GaN samples are shown in the Figure 2. In the case of aligned spectra, there is a dramatic reduction of the backscattering yield of Ga from the near surface region of the sample and thereafter the yield increases as the helium is backscattered from deeper into the GaN layer. As GaN5 is the thickest sample, for clarity, a line fitted to it using 2 MeV $He^+$ beam, which is used to find the interface peak is also shown in the figure. However GaN2 is the thickest sample recorded, its interface analysis has been performed using 4 MeV helium beam. Analyses on planes inclined with respect to the normal showed that there are a lot of defects (dislocations) into the layer but estimate to the theoretical value (<1.7 ML). They are mainly parallel to the growth direction so they are not seen by channeling along [0001].

Table 2 shows the calculation of the interface defects. Proper care has been taken while calculating the interface peaks by considering decrease in energy as the ion beam penetrate inside. As the incident ion beam energy decreases, the collision cross sectional area increases and therefore correction factor corresponding to the energy has been used as listed in the Table 2. Figure 3 shows the plot of interface peak *verses* the square root

**Table 2.** Peak dose at the GaN/sapphire interface.

| GaN # | Tail integral | Interface peak integral | Correction factor | Interface peak($10^{16}$ Ga atoms /cm$^2$) |
|---|---|---|---|---|
| | RBS/C using 800 KeV $He^+$ ion beam energy | | | |
| 2248 | | 29371 | 0.51 | 3.09 |
| | RBS/C using 1400 KeV $He^+$ ion beam energy | | | |
| 755 | | 9308 | 0.73 | 4.28 |
| | RBS/C using 2000 KeV $He^+$ ion beam energy | | | |
| 191 | | 4801 | 0.82 | 5.08 |
| | RBS/C 4000 KeV using $He^+$ ion beam energy | | | |
| 73 | | 1544 | 0.93 | 7.34 |

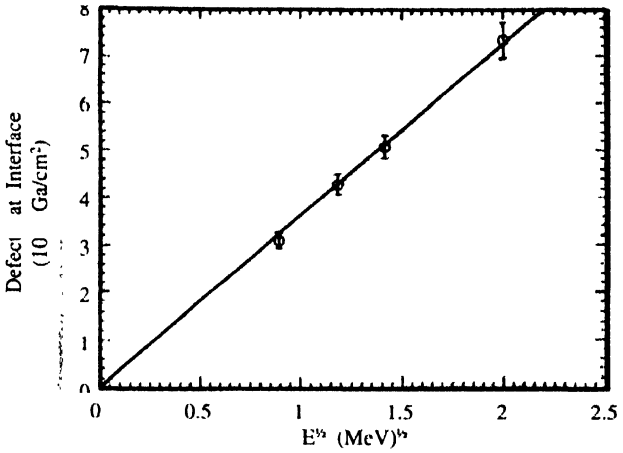


**Figure 3.** Defects at the interface with the fitted straight line *versus* the square root of the incident ion beam energy confirming that the defects are due to edge dislocation.

of the incident beam energy. The straight-line plot implies that the defects at the interface are due to the network of edge dislocations [3].

## 4. Conclusions

GaN were grown on sapphire by MOCVD technique. The thickness of GaN was varied from 0.33 m to 2.18 μm. Spectra of RBS and channeling in [0001] direction were recorded. Energy of the helium ion beam was varied from 0.8 MeV to 4 MeV. From the detailed analysis of RBS/C spectra, we conclude that defects at the GaN/sapphire interface is due to dislocations and is distributed along the growth direction.

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