Characterization of Semipolar, and N-Face Group III Nitrides

Jason Winders, Electrical Engineering, Penn State University
NNIN REU Site: Nanotech, University of California at Santa Barbara

NNIN REU Principal Investigator: Umesh K. Mishra, Electrical & Computer Engineering, UC Santa Barbara
NNIN REU Mentor: Arpan Chakraborty, Electrical & Computer Engineering, UC Santa Barbara
Contact: jcw215@psu.edu, mishra@ece.ucsb.edu

Abstract:

Gallium nitride (GaN) is a wide, direct band gap material used for optoelectronic and electronic devices. Conventional GaN-based structures used in these devices are grown along the Ga-face or polar c-axis. This results in the presence of piezoelectric and spontaneous polarization in the quantum wells. This polarization and subsequent separation of electron and hole wave-functions in the quantum wells reduces the overall performance of conventional optoelectronic devices such as light emitting diodes (LEDs) and lasers. Performance can potentially be improved by growing GaN-based quantum wells along the semi-polar direction. These quantum wells are almost free from the polarization effects, and thereby promise increased efficiency and performance of these devices. In addition to growing along the semipolar direction, devices are also grown with a nitrogen-face or N-face GaN. These devices still are polarized, but the polarization is the opposite that of c-plane GaN. When fabricating these devices, it is extremely important to have high quality films. Defects in the crystalline structure limit device performance.

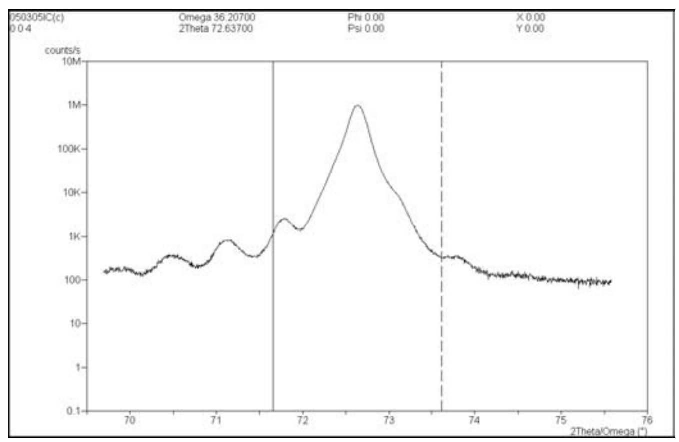
There are two main methods used for characterizing these films; x-ray diffraction and atomic force microscopy (AFM). X-ray diffraction is used to analyze the crystallographic structure and the composition of the films. AFM takes nanoscale topographical images of the films. This can be used to find sub-micron defects and surface roughness in the film. Once the film quality and composition are characterized, devices are fabricated, and electrically and optically characterized. These characterizations help optimize the properties of the semipolar and N-face GaN-based films, which provides better fabrication of devices. Currently the film quality has a large amount of defects. There is a high surface roughness, which inhibits device fabrication.

Introduction:

There is a growing demand for higher power LEDs. When compared to conventional lights, LEDs use less power, are compact, generate less heat, and have long lifetimes. LEDs in the blue to deep UV range have many applications. These have a potential to increase the storage density of optical storage devices, aid in water purification, detect and decontaminate biological agents, and provide efficient sources of light. Semipolar devices show great promise to fill the demand for devices for these applications. In order to fabricate devices, the growth of the film must be optimized to achieve a quality comparable to c-plane GaN based films.

Procedure:

The nitride films in this work are grown by metal-organic chemical vapor deposition (MOCVD). Multiple quantum well structures are formed by growing alternating layers of indium gallium nitride (InGaN) and GaN to form the active region of the LEDs. After



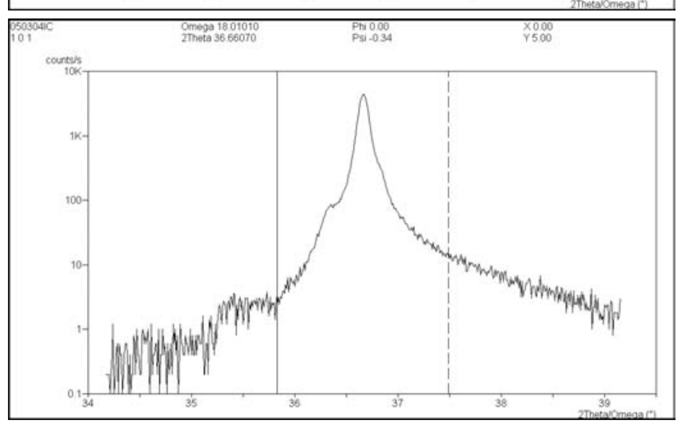


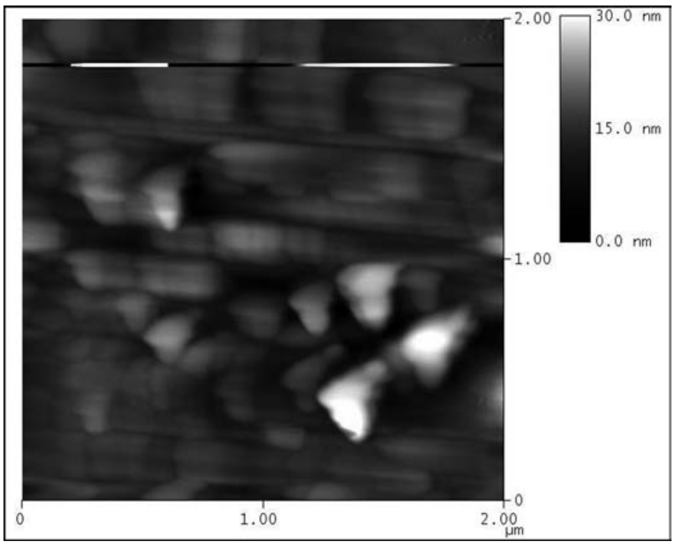
Figure 1, above: XRD of polar c-plane InGaN.

Figure 2, below: XRD of semipolar InGaN.

the growth of these films, they are characterized using x-ray diffraction (XRD) and atomic force microscopy (AFM). XRD is used to analyze the crystallographic structure of the film including composition, and stress. AFM takes a topographical image of the surface that can be used to find surface roughness and defects such as pits. If a surface is rougher than the thickness of the quantum structures that are grown, it is a good sign that the structures are not formed into coalescent layers.

Results And Conclusion:

The XRD data (Figure 1, 2) shows differences between polar c-plane InGaN-based quantum structures and semipolar InGaN-based quantum structures respectively. In the polar c-plane sample, the central peak is the GaN peak. The additional peaks located to the left of this GaN peak are the superlattice peaks due to the interference between the GaN and InGaN layers.



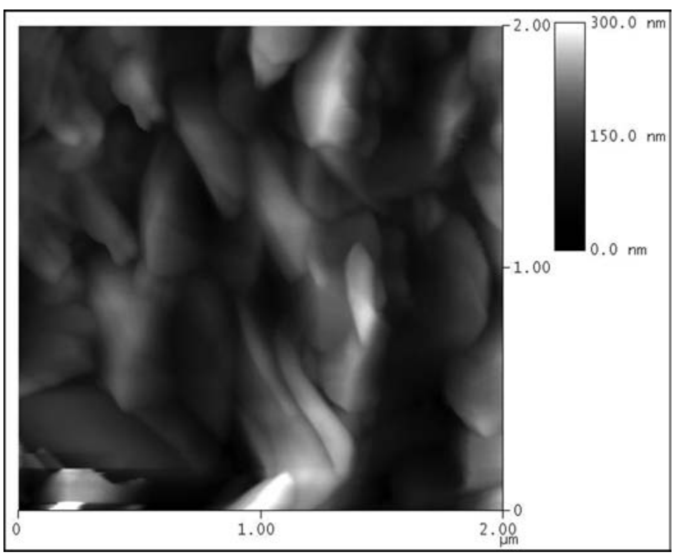


Figure 3, above: 2 µm AFM image of semipolar GaN.

Figure 4, below: 2 µm AFM image of n-face GaN.

These represent the presence of multiple coherent InGaN layers in the film. Taking the peak locations on the 2θ axis, with the growth time for the barrier and well, the indium concentration and barrier and well thicknesses can be computed. The semipolar sample has the main GaN peak, but it is lacking the InGaN superlattice peaks. The only sign of the indium in the film is the small shoulder on the left side of the GaN peak. This shows that there is indium in the film, but due to defects in the film, such as disorder, the quantum structures are not coherently formed. They should be in quantum layers.

The AFM images (Figures 3, 4) show the surface morphology of semipolar GaN and N-face GaN respectively. The semipolar GaN has a rough surface with a RMS roughness of about 10 nm. The N-face GaN has a surface roughness of about 45 nm. Also when larger scans were completed of the surface, large hexagonal features were found. These were compared to conventional c-plane GaN which have an RMS roughness of less than 0.2 nm. This level of roughness was unacceptable. The quantum wells, which were the foundation of the operation of these devices, were in the range of 2 nm thick.

When comparing these films, it is apparent that MOCVD growth of semipolar and N-face GaN-based films is still in its infancy. The semipolar XRD shows a lack of superlattice peaks. The AFM data shows a rough surface, which proves that the film is not growing uniformly. This agrees with the XRD data, which shows the lack of quantum structures. There is some disorder that is affecting the quantum wells. They are not completely forming, and only forming in places. These defects in the film need to be resolved. The growth of GaN based films needs to be optimized before functional devices can be fabricated.

Future Work:

Future work includes the optimization and characterization of the MOCVD growth of semipolar and N-face GaN basd films. The film quality needs to be improved to achieve a comparable quality to polar c-plane GaN. Once the film quality is optimized, Hall effect devices and LEDs will be fabricated and characterized. This research is continuing to develop quality films.

Acknowledgements:

The author wishes to thank Prof. Umesh K. Mishra, Arpan Chakraborty, SSLDC, UCSB, NNIN and NSF.