Electrical and Structural Characterization of GaN for Optoelectronic Applications

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Abstract:

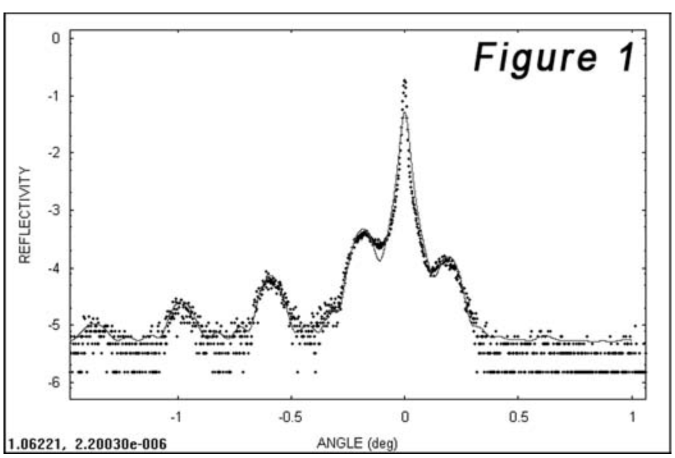
Many possible applications for Gallium Nitride (GaN) are currently being researched in the field of optoelectronics. GaN has a wide, direct band gap, which is useful for making LEDs that emit light in both the visible and ultraviolet spectrums.

This project focuses on the growth of N-face GaN films, specifically InGaN/GaN and p-type films. X-ray diffraction (XRD) is used to analyze the crystallographic structure and composition of GaN films. XRD analysis of InGaN/GaN multiple quantum well structures shows that at a given growth temperature, more Indium is incorporated into N-face films than into Ga-face films. Additionally, p-type GaN:Mg films were grown and analyzed using Hall effect measurements.

Practical uses of N-face GaN derive from the fact that it has the opposite polarization from Ga-face GaN with respect to the growth axis; it is thus useful for polarization engineering in optoelectronic devices.

Introduction:

There is enormous potential for the use of LEDs in the world today due in part to the inefficiency of conventional fluorescent and incandescent. On average, an incandescent bulb requires fifty times the power an LED needs to generate the same amount of light, and has less than 1% the lifetime. LEDs have the capability of achieving power efficiencies near 100%. GaN is an excellent material for the growth of LEDs because it has a wide, tunable direct band gap.



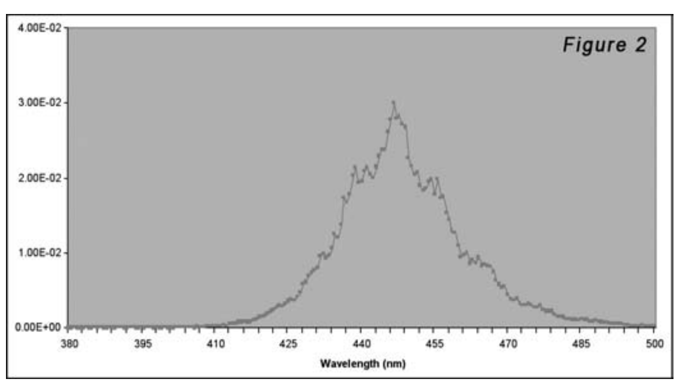
Procedure:

GaN films were grown via Molecular Beam Epitaxy, typically in the form of multiple quantum well structures containing alternating layers of GaN and InGaN. X-ray diffraction, atomic force microscopy, photoluminescence, Hall effect, capacitance-voltage measurements, and deep level transient spectroscopy were used to characterize the films.

Triple axis XRD was performed using a Sharp MRD Pro II diffractometer to determine the exact thickness and composition of GaN and InGaN films. Digital Instruments D3000 and D3100 Atomic Force Microscopes were used to confirm uniformity of film surfaces as well as to measure their rms roughness.

Photoluminescence is used to optically characterize films after growth. The PL system shines a helium-cadmium laser at the sample. The energy from the laser excites electrons into the conduction band of the GaN. These electrons then fall back into their normal states in the valence band, releasing light with energy equal to the band gap. The emission of light from the sample is measured by a spectrometer and plotted as a function of varying wavelength. This information can be used to determine the wavelength of light being emitted and to approximate its intensity.

Electrical measurements performed include Hall effect, CV measurements, and DLTS. Micro-Hall effect samples were processed in a clean room using



GaN films grown in the MBE system. These samples had square contacts 50 μm to a side. The Hall Effect measures the change in resistance through the material when a magnetic field is applied. From this change in resistance, the concentration and mobility of charge carriers can be calculated.

CV measurements were used to develop profiles of the concentration of donors or acceptors with respect to depth in the sample. Preliminary work was done to correct errors associated with the measurement of CV data. The impedance analyzer assumes a diode to be a resistor in parallel with a capacitor; however, this model does not account for the Schottky resistance of the metal contacts on the LED. By taking capacitance measurements at various frequencies, this Schottky resistance can be approximated, allowing for accurate CV data.

Often times in a material, impurities are present which create what are called trap levels. These levels are located in the band gap and momentarily "trap" carriers which could be in the conduction or valence bands. Even if the carriers are only held at the trap level for a small fraction of a second, performance can be degraded. High frequency devices, operating in the megahertz regime, will lose a significant amount of power just from momentary trapping of electrons.

Results and Conclusions:

Physical characterization of films grown yielded positive results. When films were analyzed using XRD, they were typically found to be of the thickness and composition desired. Typical GaN/InGaN MQW structures had alternating layers of about 10 nm of GaN and 4 nm of InGaN. Additionally, rms roughness values obtained from AFM scans were on the order of one to two nanometers. Photoluminescence spectra for these structures yielded wavelengths of 445 nm, in the blue light regime.

Another research aspect for this project was the attempt to grow a p-type N-face GaN film. An Mg-doped GaN film was grown in an attempt to achieve p-type doping and was characterized via the Hall effect. Hall effect measurements showed a hole concentration of 1×10^{17} holes/cm^3 and a hole mobility of 9.6 cm^2/V·s, the first recorded p-type N-face GaN film.

Preliminary results were obtained from performing DLTS on a film with a series of diodes processed onto it. This film was an N-type GaN film with a SiN cap to reduce leakage currents in the film. An electron trap was found in the material with an activation energy of approximately 75 to 90 meV, thereby indicating that the impurity present creates a trap level 75 meV below the conduction band.

Future Work:

Continued research must be conducted in order to more completely understand the trap levels present in our films. The concentration, carrier type, and activation energy of these traps can be characterized in a variety of our MBE-grown films in order to try to determine their source and perhaps eventually determine how to eliminate them. Furthermore, the study of the growth of N-face GaN films is still in its infancy. N-face growth of GaN/InGaN will be optimized until luminescence is achieved, and then LEDs will be fabricated from these films. Finally, GaN LEDs need to be optimized for output and power efficiency in order to make it useful to the industrial community and to society as a whole.

Acknowledgements:

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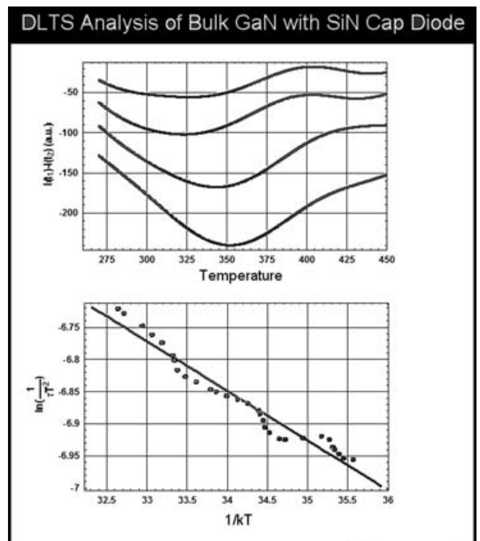

Figure 3

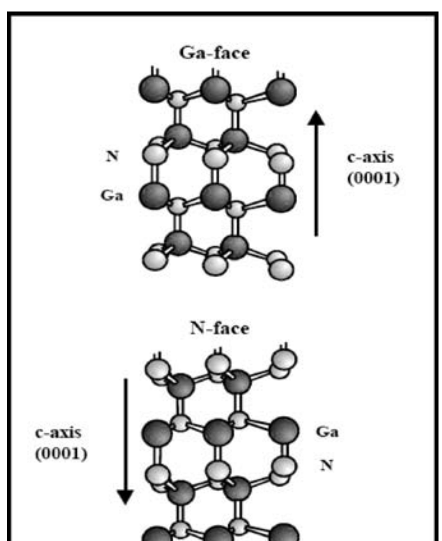

Figure 4