Spinning; Dazed and Confused: GaN-based Spin Polarized Emitters

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BIOGRAPHY

Ian T. Ferguson: Is currently a Professor and the Chair of Electrical and Computer Engineering at the University of North Carolina at Charlotte. His current research currently focuses on the area of wide bandgap materials and devices using GaN and ZnO, and developing these materials for energy and nanotechnology applications in the area of illumination, solar, spintronic and nuclear detection applications. He has have authored over 380 refereed publications, seven book chapters, ten conference proceedings, one book and multiple patents. He founded the International Conference on Solid State Lighting which is now in its 12th year. He has also been actively involved in the entrepreneurial process of establishing new companies, receiving a National Small Business Association Tibbets Award for contributions to the SBIR program.

TECHNICAL ABSTRACT

Wide bandgap dilute magnetic semiconductors (DMS) have recently been of interest due to theoretical predictions of room temperature ferromagnetism in these materials [1]. Tremendous progress has been made in doping the III-Nitrides with transition metals or rare earth elements with the aim of obtaining room temperature ferromagnetism. However, the mechanism for the observed ferromagnetism in this system is still not clear.

The interest in wide bandgap diluted magnetic materials for spintronic applications was originally derived from a theoretical model by Dietl *et. al.* [2]. This model predicted room temperature ferromagnetism for $Ga_{1-x}Mn_xN$ and $Zn_{1-x}Mn_xO$ with 5% Mn incorporation and $3.5x10^{20}$ holes/cm^3. Two primary explanations for this result were given: 1) The smaller lattice constant leads to stronger spin-dependent interaction between localized spins and holes in the valence band, which in turn leads to larger ferromagnetic coupling; 2) The ferromagnetism in compounds with small anions, such as nitrides, is not detrimentally affected by spin-orbit interactions, which scale as Z^4 (where Z is the atomic number). GaN based materials are attractive as they already have a well-established technological base for optoelectronic devices (UV/Blue LEDs and lasers) and electronic devices (high power FETs), into which the DMS can be incorporated to develop spintronic devices.

To this end, several growth techniques have been applied to dope GaN with transition metals (TM; e.g. Mn, Fe and Cr). Though tremendous progress has been made in obtaining ferromagnetic GaTMN, it is often unclear whether the observed ferromagnetism is due to substitutional TM ions in the semiconductor lattice, unwanted precipitates, or a combination of both. In addition, TM-doping of GaN in general results in highly resistive material since TMs form deep acceptors and this means that they are unlikely to be useful as a DMS.

An alternative approach to TM doping is to use rare earth (RE) elements as dopants. REs have unpaired electrons in both the d and f orbitals and thus have a higher net magnetic moment as compared to TM ions. The recent observation of a giant magnetic moment of ~4000 μ_B/Gd atom and RT ferromagnetism in $Ga_{1-x}Gd_xN$ films grown by molecular beam epitaxy (MBE) has created extensive interest in this material [3]. The vast majority of these attempts to grow $Ga_{1-x}Gd_xN$ were completed by MBE. Despite many reports of RT ferromagnetism in $Ga_{1-x}Gd_xN$ there is still no agreement on the mechanism for the ferromagnetism. Interstitial oxygen (O_i) has been predicted to have a negative formation energy in $Ga_{1-x}Gd_xN$ and to add to the net magnetic moment of the film.

The authors of this work have produced the only reports of $Ga_{1-x}Gd_xN$ thin films grown by metalorganic checmical vapor deposition (MOCVD). These films were found to be ferromagnetic at room temperature and electrically conducting, However, it was only materials produced using $TMHD_3Gd$, which contains oxygen, that showed strong ferromagnetism; material grown using Cp_3Gd, which does not contain oxygen, did not show ferromagnetic behavior. In this paper, $Ga_{1-x}Gd_xN$ films grown with these two different metalorganic precursors are summarized and the first successful demonstration of $Ga_{1-x}Gd_xN$-based spin-polarized LED is detailed.

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A simplified schematic of $Ga_{1-x}Gd_xN$-based spin-polarized LED is shown in Figure 1. The n- and p- type regions in the spin LED were the Ga1-xGdxN layers based on the films dis-cussed in Section V. The device structure consisted of a 500 nm n-type layer, followed by GaN/InGaN multiple quantum well (MQW) active region, and finally a p-type region. A GaN-based reference LED structure was also produced without the Gd. I-V curves for the two LEDs are shown in Figure 1. It can be seen that the $Ga_{1-x}Gd_xN$ LED has a larger series resistance and a slightly higher turn on voltage. This would be expected due to the higher resistance of the p-type $Ga_{1-x}Gd_xN$.

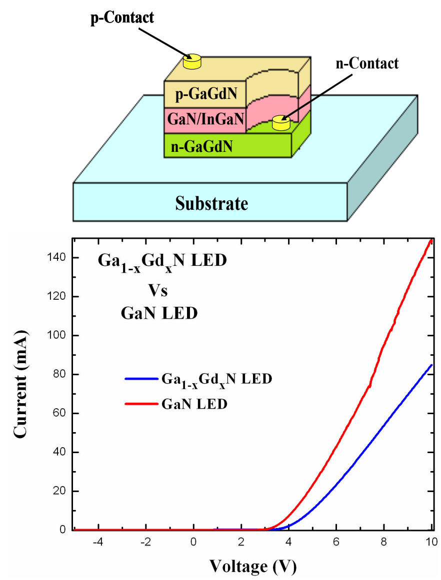

Figure 1: Schematic of LED device structures of $Ga_{1-x}Gd_xN$ LED and I-V curves for the $Ga_{1-x}Gd_xN$ LED and the reference device.

The $Ga_{1-x}Gd_xN$ LED and the reference GaN LED were both mounted on a non-magnetic DIP package for testing under magnetic field. This was performed in a Faraday configuration at magnetic fields up to 5000 Gauss magnetic. The resulting electroluminescence (EL) is collected and focused through a quarter wave (QW) plate and a linear polarizer combination that is set to ensure that only the desired left or right circularly polarized light is seen by the spectrometer. The $Ga_{1-x}Gd_xN$ LED shows a clear difference in the intensities of left and right circularly polarized light depending the magnitude and polarity of the magnetic field (Figure 2). Only a slight variation in left or right circularly polarized light is observed with the application of external magnetic field to the reference GaN LED.

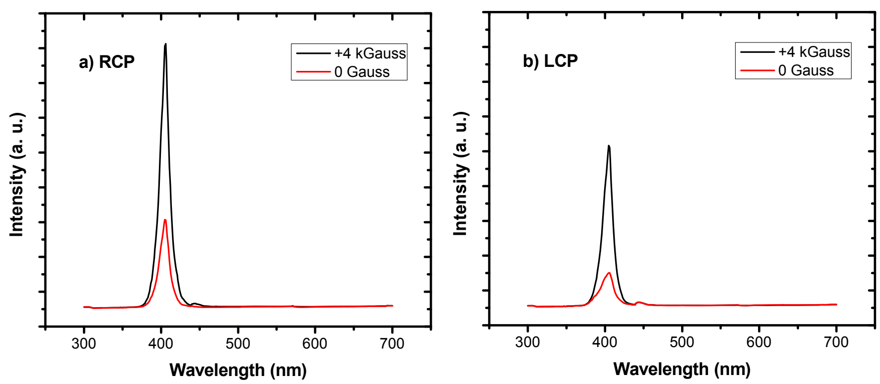

Figure 2: Right (RCP) and left (LCP) circularly polarized EL from Ga1-xGdxN-based spin LED (plotted on same scale). Both right and left circularly polarized light are significantly in-creased by a 4 kGauss applied field.

The primary figure of merit for a spin LED is the degree of polarization, P_{spin}, which is defined as the difference between the left and the right circularly polarized light intensities divided by their sum. EL polarization of 14.6% was observed at an applied field of 5000 Gauss at room temperature. This is comparable to the 22.1% polarization at 10,000 Gauss and 10 Kelvin reported for a $Ga_{1-x}Mn_xAs$ LED. The final measurement at 0 Gauss shows a persistent EL polarization of 9.3% after removal of the applied magnetic field. It was found that the sign of the applied magnetic field did not change the sign of the EL spin polarization for this device. Additional studies are needed to fully understand this behavior and to investigate the performance of alternate $Ga_{1-x}Gd_xN$-based device structures.

Keywords: Spin Polarized LED, MOCVD, Nitride DMS

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