Is GaN:Gd a Viable rRoute for Spin Polarized Emitters?

A. G. Melton[1], B. Kucukgok[1], Z. Liu[1,2], N. Dietz[3], N. Lu[1,4] and I. T. Ferguson[1,3]

[1]Department of Electrical and Computer Engineering, UNC Charlotte, Charlotte, NC, US
[2] R&D Center for Semiconductor Lighting, Chinese Academy of Sciences, Beijing, P. R. China
[3]Department of Physics and Astronomy, Georgia State University, Atlanta, GA, US
[4]Department of Engineering Technology, UNC Charlotte, Charlotte, NC, US

1. Introduction

GaN:Gd thin films have been grown by Metalorganic Chemical Vapor Deposition (MOCVD) [1] and these films were found to be ferromagnetic at RT and electrically conducting although the mechanism for the ferromagnetism was not well understood [2]. In this work, we have completed a systematic investigation of interrelationship of chemical, magnetic, and electrical properties of GaN:Gd. First-principle calculations based on density functional theory have shown that the ferromagnetism was likely mediated by interstitial oxygen. This was confirmed, in part, because ferromagnetism was only observed in GaN:Gd thin films grown using $TMHD_3Gd$, an oxygen containing metalorganic Gd precursor. It was found that the GaN:Gd was residually n-type (mid $10^{17}cm^3$) rather than the highly resistive material grown using TMs and could be effectively n-type (Si) or p-type (Mg) doped without losing their ferromagnetic properties. These Si and Mg Co-doped GaN:Gd films could then be used for spin-injection into spin light emitting diodes (LEDs) and other spintronic devices [3]. Preliminary spin-polarized GaN:Gd-based LEDs where produced which had a maximum spin polarization of 14.6% at 5000 Gauss and exhibited magnetic hysteresis at room temperature (Fig. 1).

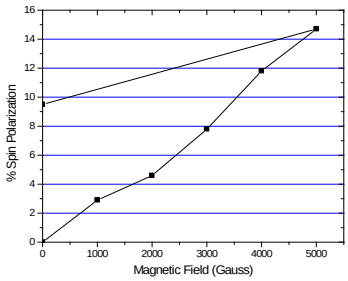

Fig 1: *Degree of polarization of EL from $Ga_{1-x}Gd_xN$-based LED at sequentially applied magnetic fields at RT.*

2. Experimental Approach and Results

GaN:Gd and the reference GaN LEDs were both mounted on a non-magnetic DIP package for functional testing under magnetic field. This testing was performed in a Faraday configuration, in which the LED is placed inside the poles of an electromagnet capable of generating up to 5000 Gauss magnetic field. Current is passed through the devices, and the resulting electroluminescence (EL) is collected and focused through a quarter wave (QW) plate. As expected, no response for was seen for the reference GaN LED with magnetic field for either Right Circularly Polarized (RCP) or Left Circularly Polarized (LCP) EL from these devices. This was not the case for the GaN:Gd LED which showed a systematic variation of the RCP and LCP emission in with magnetic 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. A maximum EL polarization of 14.6% was observed at an applied field of 5000 Gauss at room temperature showing evidence for spin injection at room temperature. The final measurement shows a persistent EL polarization of 9.3% after removal of the applied magnetic field (Fig 1).

3. Conclusions

The microscopic mechanisms for the incorporation of Gd in GaN and its electrical, optical and magnetic properties are still subject to extensive scientific research and debate. Many first-principles calculations based on density functional theory (including this group) predict that crystal defects are important contributors to the observed magnetic moments. The interplay of the electrical, optical and magnetic properties of GaN:Gd as spin-injection layers is not well understood and require further investigation.

4. Open Questions

- What is the origin of the colossal magnetic moment observed by some researchers in GaN:Gd?
- What is the site of the Gd incorporation in the lattice and does clustering occur?
- What is the role of oxygen for the stabilization of the ferromagnetism?
- Do these devices exhibit spin injection or is some other mechanism responsible?

References

[1] Z. Liu, X. Yi, J. Wang, J. Kang, A. G. Melton, Y. Shi, N. Lu, J. Wang, J. Li, and I. Ferguson; Applied Physics Letters, vol. 100, pg. 232408, 2012.

[2] S. Gupta, T. Zaidi, A. Melton, E. Malguth, H. Yu, Z. Liu, X. Liu, J. Schwartz, and I. T. Ferguson; Journal of Applied Physics, vol. 110, pg. 083920, 2011.

[3] M. Jamil, T. Zaidi, A. Melton, T. Xu, and I. T. Ferguson; "$Ga_{1-x}Gd_xN$-Based Spin Polarized Light Emitting Diode" 2010 MRS Fall Meeting, MRS Proceedings, vol. 1290, 2011.