Room Temperature Magneto-optical Properties and Atomic Layer Epitaxy of III-Nitrides

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1. Introduction

Ferromagnetic (FM) semiconductor devices utilizing both the charge and spin of electrons can be used to process and store information. III-nitride semiconductors, InN, GaN, AlN, and their alloys doped with transition metals (TM) and rare earth (RE) elements have been recognized as important semiconductors for electronics, optoelectronics and room temperature (RT) spin electronics device applications [1]. There has been successful demonstration on growth of TM and RE-doped FM III-nitrides by different methods for example metalorganic chemical deposition (MOCVD), molecular beam epitaxy, and pulsed laser deposition [2-9].

In this talk we present results on the enhancement of magnetic properties of Er-doped GaN epilayer structures grown by MOCVD, with illumination from a light emitting diode (LED). Although, 10-20% enhancement was measured, the growth is challenged by solubility of RE elements in III-nitrides. Also at high temperatures the RE ions diffuse across the interface there by degrading interfaces in complex device structures. So we propose plasma-assisted atomic layer epitaxy (ALE) as an alternative growth technique. ALE is a low temperature, conformal, layer by layer growth process where each precursor is pulsed and the growth chamber is purged after each pulse [10-13]. It would be a new direction for the growth of complex FM device structures with sharp interfaces.

2. Experiment

The GaN:Er samples examined in this study were grown by MOCVD on (0001) c-plane sapphire substrates. The growth of these samples began with a thin GaN buffer layer, followed by a GaN epilayer template [14]. Following MOCVD growth the samples were characterized by x-ray diffraction (XRD) and photoluminescence (PL) measurements. The powder XRD spectra indicated high crystallinity and no second phase formation. Subsequently, magneto-optical properties were characterization using an alternating gradient magnetometer (AGM) and 371 nm commercial light emitting diode.

To explore an alternative growth method, undoped AlN layers were grown at ≤500 °C on MOCVD GaN/a-plane sapphire templates, using a Cambridge Nano Tech (CNT) Fiji 200 ALE system. These ALE layers were characterized by variable angle spectroscopic ellipsometery, atomic force microscopy, X-ray photoelectron spectroscopy, and x-ray diffraction (XRD).

3. Results and discussions

MOCVD grown Er-doped GaN epilayers exhibited hysteresis behavior at RT as measured by an AGM. As shown in Fig.1(a), when the samples were illuminated at a wavelength of 371 nm, an increase in saturation magnetization was observed for the sample. The percentage increase ranged from 10 -25% as shown in Fig 1(b). The data indicate that electron hole pairs created by incident photons from the LED source facilitate ferromagnetic ordering in GaN:Er layers.

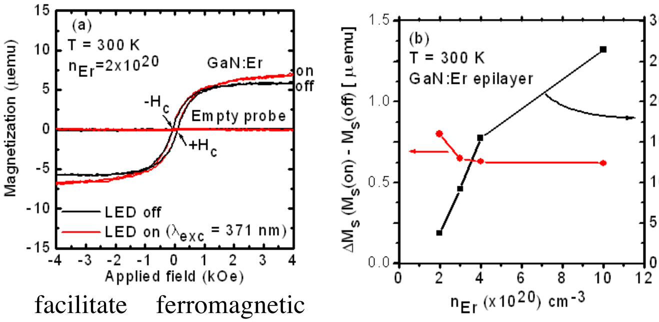

Fig. 1 Hysteretic data taken at RT for a GaN:Er single layer sample with n_{Er}~2x10^{20} cm^{-3} under LED-off and LED-on conditions. (b) The measured ΔM$_S$ and M$_S$(off) values for the single layer samples plotted as a function of Er concentration. [3]

MOCVD growths are carried out at about 1000 °C. At these temperatures, RE ions can diffuse across the interface. Also FM can be destroyed. Thus an alternative low temperature growth method (for example ALE) is important to explore. ALE is an excellent potential method for low temperature growth of RE doped III-nitrides. In ALE growth low vapor pressure of RE MO source can be handled by sending high pressure push gas into the source. Since its low temperature process, RE element diffusion would be small and heterostructures could have sharp interfaces. Also, ALE provides an atomic scale thickness control.

Recently, crystalline quality AlN films were grown by plasma-assisted ALE [12]. Figure 2 shows the θ/2θ XRD peaks from ALE AlN on GaN/a-Al_2O_3 templates. Clearly, (0002) peaks of AlN and GaN are observed. The GaN peak is dominant and has rocking curve FWHM of ~435 arc-sec which is typical for MOCVD GaN on sapphire. As shown in inset of Fig. 2(a), the FWHM value of the (0002) AlN peak of 37 nm thick film is about 670 arc-sec, which is close to typical value for much thicker AlN grown on GaN templates by MOCVD (2 μm, 400 arc-sec [15]) and MBE (1.58 μm, 420 arc-sec [16]).

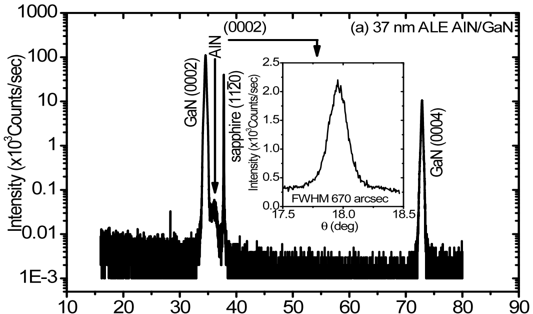

Figure 2. XRD peaks from the AlN/GaN/a-sapphire stack. Insets show the rocking curve of ALE grown AlN (0002) reflection. The rocking curve FHWM is 630 arc-sec for growth conditions: T_g = 500 °C, 10 sec purge, TMA pulse length =0.06 sec, and 300 W N_2 plasma =20sec. [12]

4. Summary

We have shown that illumination of Er-doped GaN epilayer structures at a wavelength of 371 nm from a LED leads to an enhancement of magnetic properties. Electron hole pairs created by incident photons from the LED facilitate RT ferromagnetic ordering in the GaN:Er layers, suggesting a carrier-mediated mechanism. To enhance carrier mediated FM, device integration and reduce interface degradation at high temperature, III-nitrides growth at low temperatures is preferred. We have grown device quality AlN by ALE at 500 °C as a demonstration. Thus, ALE would be a new technique to grow RE-doped III-nitrides for RT FM.

5. Open Questions

- Can ALE compete with MOCVD and MBE?
- What is a mechanism of FM in III-N DMS?
- What are the advantage and disadvantages of ALE?

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