The Influence of Strain Induced Electric Fields on Magnetization in Erbium doped GaN thin films

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Introduction:

In order for spintronics to become a practical technology, dilute magnetic semiconductors (DMS) with room temperature (RT) ferromagnetic (FM) behavior must be developed. Recent research has also focused on III-nitride semiconductors doped with rare earth (RE) elements. In particular, GaN thin films doped with Gd have been reported to exhibit FM behavior at RT with colossal Ms values [1] but erbium doping has also led to FM behavior but with much smaller MS values [2]. The origin of these magnetic properties is not well understood and many inconsistencies exists making it worthwhile to study the magnetic-optical properties of the very ions that induce the FM which should hence by influenced by the magnetic ordering. Optical spectroscopy should offer insights into the nature of the magnetic coupling among the ions.

Results and Discussion:

The magneto-optical properties of erbium-doped GaN (GaN:Er) epilayers grown by metal-organic chemical vapor deposition were studied. In these samples, the different tensile strains produced by the respective lattice mismatch for different substrates used (GaN/Al_2O_3, AlN/Al_2O_3, GaN/Si(111), and c-GaN bulk) for saturation magnetization have been observed that correlate with the expected tensile strain. These different strain environments of the ions can clearly be distinguished by the spectral response in combined excitation emission spectroscopy (Fig. 1). Under application of a magnetic field[1], the photoluminescence of the erbium dopant, which cause the ferromagnetism, show distinct differences between fields applied in the growth direction or against it. This asymmetry is most pronounced for the samples with the highest tensile strain and absent for a strain-free sample grown on GaN. This indicates that the magnetic states of the ions are coupled to the electronic states of the host.

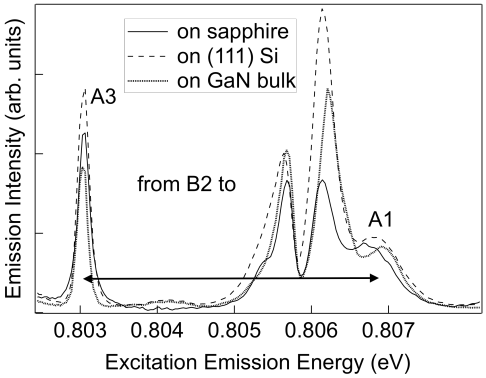

Fig. 1: Emission spectra taken for different samples. The distance between the peaks labeled A1 and A3 is a good measure for the intrinsic strain

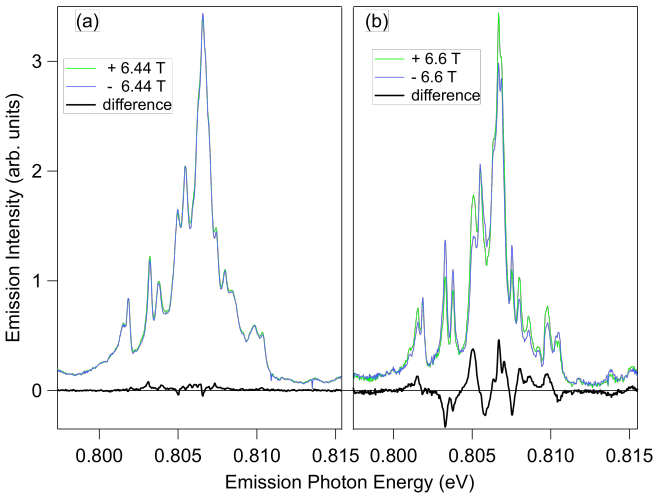

Fig. 2: Emission spectra under magnetic fields applied along or against the growth direction for samples grown on (a) GaN and (b) sapphire.

Open Questions:

(1) What is the mechanism of the coupling between electronic states of the Er ions with the host
(2) Does the same mechanism apply to other ions as well
(3) Does the same mechanism apply to other strain directions
(4) What is the optimal strain ?

Conclusion

Our results show that the magnetic states of Er in GaN are coupled to the host through the presence of the strain. This coupling may be mediated by the electric fields induced by strain and the resulting changes in the band structure of the host, which in is modified under application of an magnetic field. Our results also hold promise for use of strain to control the magnetic properties of GaN:Er films for spintronic applications.

References:

[1] see e.g.: O. Brandt, S. Dhar, L. Pérez and V. Sapega. Chapter 8 in Rare-Earth Doped III-Nitrides for Optoelectronic and Spintronic Applications, (ed. K.P. O'Donnell, V. Dierolf, Springer-Verlag, Berlin, Heidelberg, New York, 2010).

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