Gd-doped III-Nitride Diluted Magnetic Semiconductors for Circular-Polarized Semiconductor Lasers

H. Asahi, S. Hasegawa, Y.K. Zhou, Shuichi Emura

The Institute of Scientific and Industrial Research, Osaka University, 8-1 Mihogaoka, Ibaraki, Osaka 567-0047, Japan, Email: asahi@sanken.osaka-u.ac.jp

1. Introduction

Diluted magnetic semiconductors (DMS) are important for the application to semiconductor spintonic devices such as circular polarized laser diodes (CP-LDs). CP-LDs can be fabricated using the DMS as an active layer or a cladding layer. Bhattacharya et al. [1] reported the fabrication of CP-LDs using GaMnAs DMS layer as spin-polarized carrier supplying layer and the observation of CP light at a low temperature of 80 K because of the low Curie temperature of GaMnAs. To fabricate practical CP-LDs, room temperature ferromagnetic DMS is a requisite. We have reported, for the first time, the observation of ferromagnetic characteristics even at high temperatures (>400 K) for the rare-earth Gd-doped GaN (GaGdN) [2]. We also studied the magnetic and optical properties of the InGaGdN layers and the InGaGdN/GaGdN superlattice structures aiming at the fabrication of CP-LDs [3].

2. Results

We have grown Gd-doped InGaN (InGaGdN) and their superlattice (SL) and multi-quantum well (MQW) structures by plasma-assisted molecular beam epitaxy (PA-MBE) and observed room temperature ferromagnetic characteristics as well as photoluminescence (PL) emission. InGaGdN layers exhibited photoluminescence emission at room temperature and its peak wavelength was red-shifted with the increase of In composition.

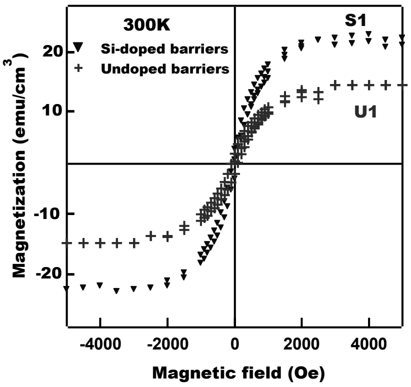

Fig. 1 *M-H curves measured in-plane at 300 K for the InGaGdN/GaN SLs with and without Si doping into wide bandgap GaN layers.*

Clear hysteresis and saturation were observed in the magnetization versus magnetic field curves at room temperature for the InGaGdN layers. Si co-doping into InGaGdN layers increased the electron carrier concentration and enhanced the magnetization. In the InGaGdN/GaN SL samples, enhanced magnetization was also observed. Si doping into wide bandgap GaN layers in these SL structures further increased the magnetization, where InGaGdN layers were not doped with Si. All these results can be understood with the carrier-mediated ferromagnetism.

To realize the CP-LDs, vertically magnetized DMS layers are essentially required. We have grown the GaGdN nanorod structures and studied the magnetization characteristics. By forming the nanorod structures and changing the nanorod aspect ratio, the vertically magnetization was improved, though not sufficient at present.

Table 1 *Residual magnetization (M_r) ratio for the GaGdN nanorod structures as a function of nanorod aspect ratio (height/diameter). M_s is saturation magnetization.*

	Ga flux (Torr)	Gd (%)	Aspect ratio (H/D)	M_r ratio $(M_r/M_s)_\perp/(M_r/M_s)_{//}$
A	1x10^{-9}	1.2	20	0.97
B	2x10^{-9}	2.2	8	0.94
C	3x10^{-9}	8.7	5	0.28

3. Summary

In summary, InGaGdN and their heterostructures with and without Si doping were grown and carrier-mediated ferromagnetism was confirmed. By growing the GaGdN nanorod structures, the vertically magnetization was improved, which is required to fabricate CP-LDs.

4. Open Questions

- How to improve the magnetic hysteresis loop properties to obtain large residual magnetization?
- How to realize the perfect vertical magnetization characteristics to use in CP-LDs?

References

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