Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp306-307

Characterization of GaGdN/AlGaN/GaGdN Triple-layer Structures with High Gd Concentration for Tunneling Magnetoresistance Devices

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1. Introduction

III-V based diluted magnetic semiconductors (DMSs) have been widely studied for their interesting magnetic properties. In several years, various materials have been investigated, for example, GaMnAs [1], GaMnN [2], and transition metal or rare earth elements doped materials [3-9]. One of the most effective applications using DMSs is tunneling magnetoresistance (TMR) devices. There are many reports about TMR fabrication by these DMSs materials [10-14]. Realizing such TMR devices requires DMSs materials showing ferromagnetism at room temperature (RT).

GaGdN is one of the promising materials showing ferromagnetism at RT, in which GaN is doped with rare earth element Gd as a magnetic dopant [7,8]. In order to make its magnetic properties better toward the fabrication of devices, it is necessary to increase the concentration of Gd without segregation of any secondary phases and generation of defects. In this presentation, we will report the growth of the GaGdN layers with high Gd concentration and their structural analyses performed by x-ray diffraction (XRD) measurement and transmission electron microscope (TEM). Based on the findings, we will also present the fabrication of TMR structures consisting of GaGdN layers with high Gd composition and an AlGaN barrier layer.

2. Experimental

GaGdN samples and TMR samples were grown by radio-frequency plasma-assisted molecular beam epitaxy (RF-MBE) on GaN templates, which have a MOCVD-grown 2 μm-thick GaN layer on sapphire (0001) substrate. Figure 1 shows the sample structures of these GaGdN and TMR samples. First, the substrate surfaces of all the samples were thermally cleaned at 700 °C for 15 minutes. During the growth, RF power was kept at 180 W and nitrogen flow rate 1.5 sccm.

In GaGdN samples, Ga beam equivalent pressure (BEP) was kept at 1.5×10^{-7} Torr, and the substrate temperature at 700 °C. After the growth of a GaN buffer layer for 5 min, a GaGdN layer was grown for 60 min, followed by the deposition of a GaN cap layer for 1 min. Three samples A, B and C were grown by varying the Gd cell temperatures of 1100 °C, 1125 °C and 1150 °C, respectively.

All the triple-layer TMR samples were grown with a Ga BEP of 1.0×10^{-7} Torr and a substrate temperature of 600 °C in order to obtain GaGdN layers both with higher Gd concentration and without the segregation of secondary phases. An AlGaN barrier layer sandwiched between GaGdN layers with different Gd compositions was grown for 26 s with an Al BEP of 1.0×10^{-8} Torr. The respective two GaGdN layers were grown for 30 min at different Gd cell temperatures of 1100 °C and 1150 °C (sample D), or at 1100°C and 1125°C (sample E). Finally, a GaN cap layer was grown for 10 min.

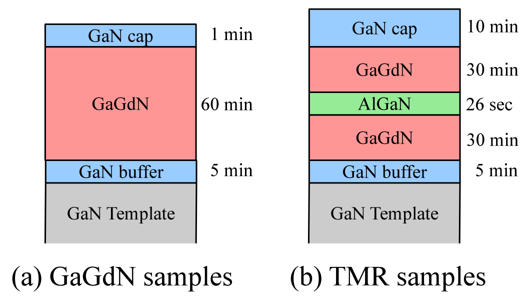

Fig. 1. Sample structures of (a) GaGdN and (b) triple-layer TMR samples.

3. Results and Discussion

Figure 2 shows the cross sectional TEM images for samples A and B. Neither dislocation nor secondary phase segregation was observed except for threading dislocations that originate from the GaN templates. By contrast, dislocations were generated at the interface of GaGdN and GaN buffer layer of sample C (not shown), while no segregation of secondly phase was observed in the dislocation-free regions. From energy-dispersive x-ray measurement, the concentrations of Gd for samples A, B, and C were calculated as 2.5, 4.5 and 8.0 %, respectively.

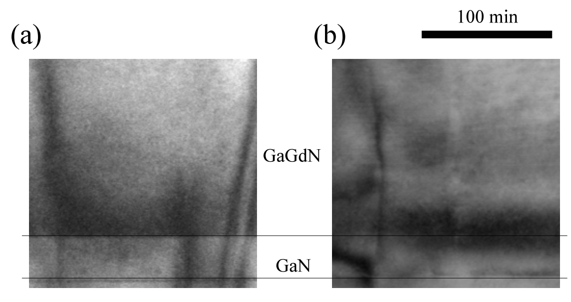

Fig. 2. Cross sectional TEM images for the GaGdN/GaN regions of samples (a) A and (b) B.

Figure 3 shows the reciprocal space mapping (RSM) around GaN ($\bar{1}015$) of sample B by high-resolution XRD (HRXRD). The RSM reveals that an in-plane strain between GaN and GaGdN is not relaxed, and the GaGdN layer is still coherently grown on GaN. The RSM around GaN ($\bar{1}015$) of sample C (not shown) revealed that with increasing the Gd cell temperature to 1150 °C, GaGdN was partially relaxed. This is consistent with the TEM results that dislocations were generated at the interface of GaGdN and GaN buffer layer of sample C.

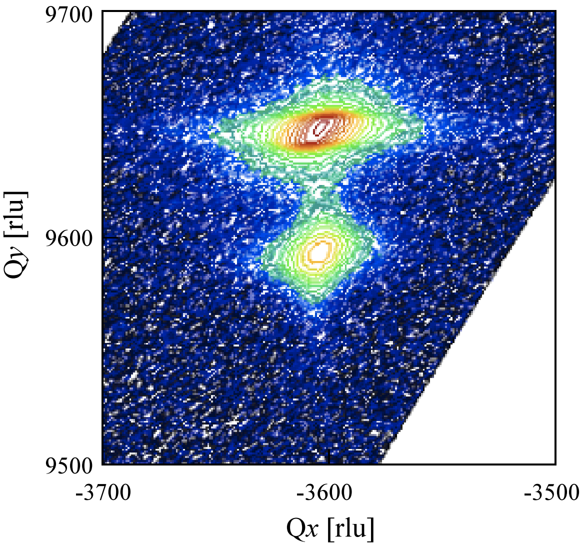

Fig. 3. RSM around GaN ($\bar{1}015$) of sample B. The upper peak is GaN ($\bar{1}015$), and the lower one is GaGdN ($\bar{1}015$).

We have examined whether or not the growth temperature affects such lattice relaxation in GaGdN layers grown at a Gd cell temperature of 1125 °C, and have found that the lattice relaxation does not occur at 650 °C while the lattice is easy to be relaxed for the higher growth temperature. Based on these results, the TMR structure samples were grown at 600 °C and with a Ga BEP of 1.0×10^{-7} Torr.

Figure 4 shows ω - 2θ scans around GaN (0002) of sample D and E. In each sample, two peaks appear at the lower diffraction angle than GaN (0002). This indicates that there exist two GaGdN layers with different Gd concentrations. The higher peaks correspond to the GaGdN layers grown at a Gd cell temperature of 1100 °C, and the lowers are due to the layers at 1150 °C for sample D and at 1125 °C for sample E. From these diffraction peaks, Gd concentrations of GaGdN layers for sample D (E) are calculated as 3.0 and 12.0 % (3.0 and 5.0 %).

4. Summary

HRXRD and TEM were used to characterize the GaGdN layers grown by varying Gd cell temperature and growth temperature. At a growth temperature of 700 °C, GaGdN layers grown with a Gd cell temperature below 1125 °C were coherently grown on GaN templates. With decreasing the growth temperature to 650 °C, GaGdN layers grown with a Gd cell temperature of 1125 °C was still coherently grown. Based on the results, we demonstrated the growth of GaGdN/AlGaN/GaGdN trilayer-structures with large difference in Gd concentration between the GaGdN magnetic semiconductor layers.

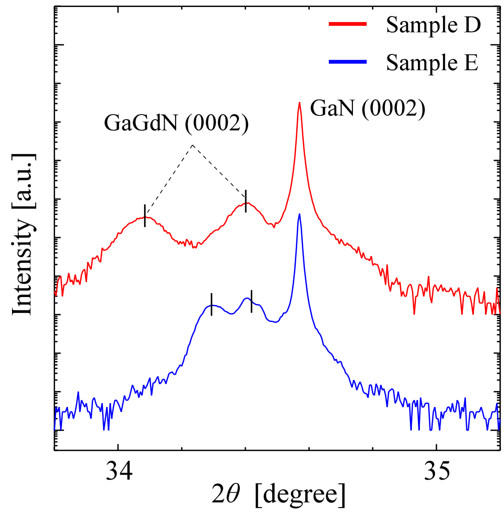

Fig. 4. HRXRD ω - 2θ scans around GaN (0002) of samples D and E.

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