Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 1084-1085

I-7-5

MBE Growth of Gd/Fe Multilayer on GaAs(001)

H. Miyagawa[1], S. Koshiba[1], N. Takahashi[2], N. Tsurumachi[1],
H. Shiraoka[1], K. Matsushita[1], S. Nakanishi[1] and H. Itoh[1]

[1]Faculty of Engineering, Kagawa University, 2217-20 Hayashi-cho, Takamatsu, Kagawa 761-0396, Japan
[2]Faculty of Education, Kagawa University, 1-1 Saiwai-cho, Takamatsu, Kagawa 760-8522, Japan
Phone: +81-87-864-2396 E-mail: miyagawa@eng.kagawa-u.ac.jp

1. Introduction

Magnetic layers grown on semiconductors have great attentions because of their application to spintronics devices, which utilize the novel phenomena such as spin injection or giant magnetic resistance. For best understanding of the mechanism of magnetism, it is important to grow magnetic layers with good crystal structure, and with good reproducibility. There are many reports in terms of magnetic layers with Transition Metal (TM) on GaAs-based semiconductors [1][2]. Though a lot of Rare Earths (RE) have large magnetic moments per atom than TM, there are less reports on magnetic layers of RE on semiconductors. Main reason of this is that there are large differences of both crystal structures and lattice constants between RE and GaAs. In order to overcome this limitation of lattice mismatch, we adapt a technique of ultra-short period superlattice, so-called 'digital alloys'. With this technique, one can control the macroscopic properties by growing the various phases with preferable lattice parameters. Many studies of Gd/Fe magnetic multilayer have been done on the focus of the spin alignment around interfaces and the magnetic coupling between each layers [3]. However, some of those studies have lack of analyses in terms of nano-scaled structures.

In this reports, we grow Gd/Fe multilayer on GaAs substrate using MBE technique and investigate the layer structure and the roughness at interfaces by means of X-Ray Diffraction (XRD) and Transmission Electron Microscopy (TEM).

2. Experimental

The Gd/Fe multilayer was grown on GaAs (001) substrate by MBE (sample(i)). We made two samples of only one magnetic layer of Gd or Fe as reference (sample(ii),(iii)). Gd was evaporated using Knudsen cell. Fe was evaporated by Electric Beam gun (EB-gun), EIKO Engineering MB-5031. Temperature of substrate is room temperature. The growth conditions for all samples are shown in Table 1.

In order to obtain crystal structures of samples, XRD measurements were performed with Shimadzu XRD-6100 using Cu K_α. Microscopic structures in samples were obtained from cross-sectional TEM observation using JEOL JEM-3010 with 300kV high voltage. Before TEM observation, the thicknesses of samples were reduced by Ion polishing with Ar beam. It is found that Gd/Fe multilayer phase is difficult to thin as compared to GaAs substrate and unevenness of thickness in multilayer made TEM observation difficult.

Table 1 Growth conditions of sample (i) Gd/Fe multilayer, (ii) Gd layer, and (iii)Fe layer, on GaAs (001) substrate.

Sample	Shutter Sequence	K-Cell Temp. (Gd rate)	EB-gun (Fe rate)
(i) Gd/Fe multilayer on GaAs(001)	Fe : 15 min G. I. : 0.5 min Gd : 4 min G. I. : 0.5 min (x20 cycles)	1400 °C (2.5 nm/min)	HV: 6.2 kV Filament: 7.8 A (1~1.3 nm/min)
(ii) Gd layer on GaAs(001)	–	1450 °C (3 nm/min)	–
(ii) Fe layer on GaAs(001)	–	–	HV: 6.2 kV Filament: 7.4 A (0.08 nm/min)

G.I.: Growth Interruption.

3. Results and Discussion

XRD profile of (i) Gd/Fe multilayer is shown in Fig. 1. In Fig. 1, XRD profile of (ii) Gd layer is also shown. In the profile of sample (i), peaks from bcc Fe are observed, whereas peaks from polycrystalline Gd are not observed. A broad peak around GaAs (002) in the profile of sample(i) is possibly caused by Gd peaks that have strong intensities as shown around GaAs(002) in the profile of sample (ii). Satellite peaks due to the period of multilayer are not observed in the profile of sample (i), which may be because the period length is too large to detect as satellites in XRD profile.

In Fig. 2(a) and 2(b), the cross-sectional TEM images

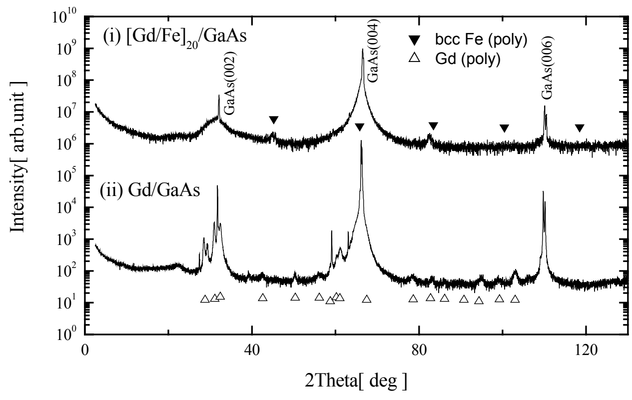

Fig. 1 XRD profiles of (i) Gd/Fe multilayer on GaAs and (ii) Gd layer on GaAs.

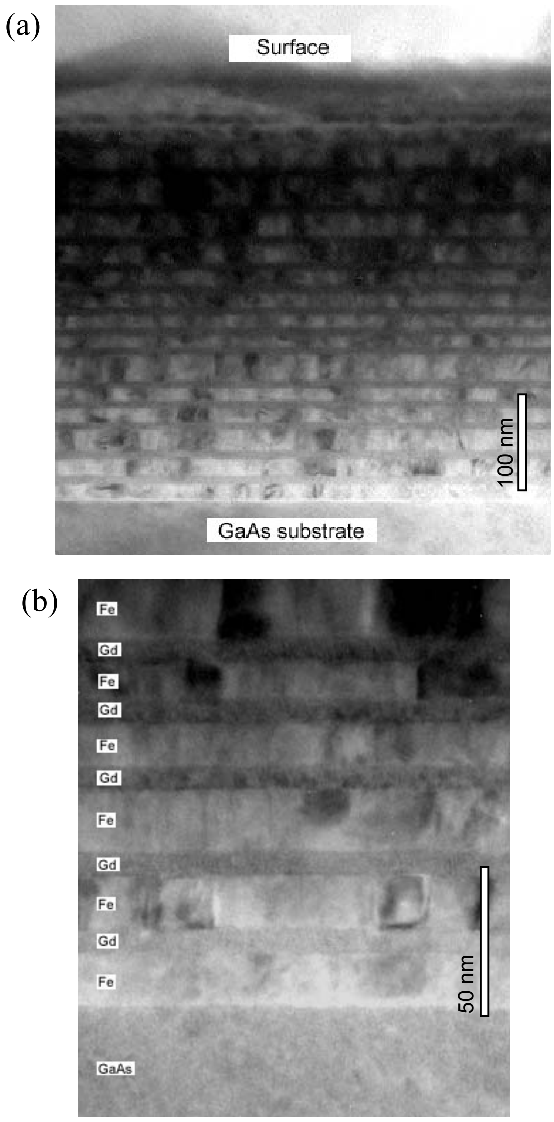

Fig. 2 Cross-sectional TEM images of Gd/Fe multilayer grown on GaAs(001). (a) Whole image of the multilayer. (b) Close-up of the area near GaAs substrate.

of Gd/Fe multilayer on GaAs(001) are shown. The structure of multilayer is obviously observed in Fig. 2. The period length of the multilayer is estimated as 25 nm, averagely. The thickness of each layer in Fig. 2 is not constant. This seems to arise from instability of the flux of Fe atoms evaporated by EB-gun. As shown in Fig. 2(b), Fe layer has dark areas and bright areas. This difference of contrast suggests that Fe layer is not single-crystallized and there are many crystal grains. The size of those grains are approximately 20~40 nm.

Fig. 3(a) and 3(b) show TEM image at interfaces between Fe and Gd layers, and those between Fe layer and GaAs substrates, respectively. In Fig.3(a), there are some atomic fringe patterns along lateral direction in Gd layer. This means Gd tends to grow with a certain crystal orientation. High-resolution (HR) images at interfaces between Fe and GaAs substrate of sample (i) and (iii) are shown in Fig. 4(a) and (b), respectively. HR image of sample(i) in Fig 4(a) shows the amorphous layer at interface between Fe and GaAs substrate, which is expected to be Ga oxide. This oxide layer disturbs the growth with the lattice match. In Fig. 4(b), HR image of sample (ii) shows that there is good lattice matching between Fe layer and the substrate, and that the atomic fringe pattern of Fe layer is parallel to the growth direction. It is important to remove completely the oxide layer at the surface of GaAs substrate before growth of Fe layer.

Magnetic properties of samples, such as magnetizations or magneto-optical Kerr effects, depend on the thickness of each layer, the grain size of polycrystalline phase, and the roughness at interfaces. Results of magnetic measurement and the dependence of crystal structure on magnetic properties are presented in the conference.

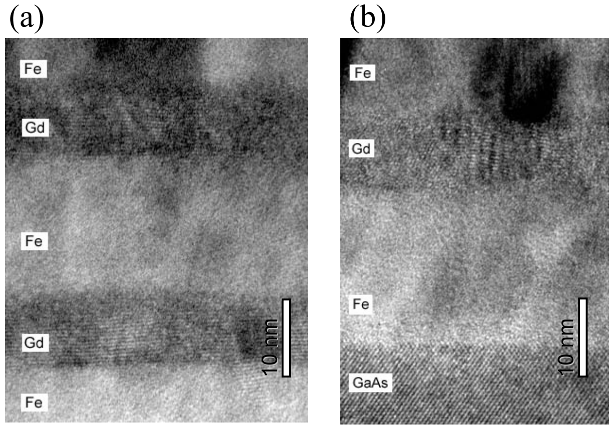

Fig. 3 (a) TEM image of interfaces between Fe and Gd layers. (b) TEM image of area near the GaAs substrate.

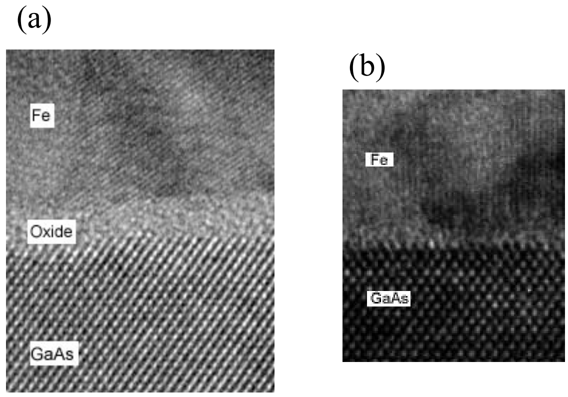

Fig. 4 TEM images of the interface between Fe layer and GaAs substrate. (a) Sample (i), Gd/Fe multilayer. (b) Sample (ii). Fe layer grown with slow-rate.

References

[1] M. Tanaka, J. P. Harbison, M. C. Park, Y. S. Park, T. Shin, G. M Rothberg, J. Appl. Phys. **76** (1994) 6278

[2] S. Hirose, S. Haneda, M. Yamaura, K. Hara, H. Munekata, J. Vac. Sci. Technol. B **18** (2000) 1

[3] M. Sajieddine, Ph. Bauer, K. Cherifi, C. Dufour, G. Marchal, R. E. Camley, Phys. Rev. B **49** (1994)