Defense Technical Information Center Compilation Part Notice

ADP013032

TITLE: Epitaxial Growth and Characterization of MnAs/Si[111] Nanoscale Magnetoelectronic Heterostructures

DISTRIBUTION: Approved for public release, distribution unlimited
Availability: Hard copy only.

This paper is part of the following report:

TITLE: Nanostructures: Physics and Technology International Symposium [8th] Held in St. Petersburg, Russia on June 19-23, 2000 Proceedings

To order the complete compilation report, use: ADA407315

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP013002 thru ADP013146

UNCLASSIFIED

8th Int. Symp. "Nanostructures: Physics and Technology"
St Petersburg, Russia, June 19–23, 2000

Epitaxial growth and characterization of MnAs/Si(111) nanoscale magnetoelectronic heterostructures

A. G. Banshchikov, R. V. Pisarev, A. A. Rzhevsky, N. S. Sokolov,
Ahsan M. Nazmul† and M. Tanaka†
Ioffe Physico-Technical Institute, St Petersburg, Russia
† The University of Tokyo, Bunkyo-ku, Tokyo 113-8654, Japan

Abstract. Molecular beam epitaxy was used to grow thin (6-12nm) ferromagnetic MnAs films on a Si(111) substrate. The characterization of the film structural and magnetic properties was carried out using X-ray, RHEED, AFM and magneto-optical methods.

Introduction

In recent years, epitaxial ferromagnetic thin films on semiconductors have become a subject of intensive studies [1, 2]. It is expected that such systems can lead to a new class of devices which integrate magnetic, semiconducting and optical properties. Ferromagnetic manganese arsenide (MnAs) films on silicon (Si) and gallium arsenide (GaAs) substrates are attractive for such applications due to excellent magnetic properties and a high Curie temperature (40°C). Much progress has lately been made in the study of relatively thick MnAs layers [3, 4]. At present, many research groups focus their efforts on the growth of nanoscale ferromagnetic films on semiconductors because these can display new spin-dependent kinetic and magneto-optical phenomena [5].

In this paper we report on MBE growth, epitaxial structure and magnetic characterisation of MnAs nanoscale films.

1. Growth

Manganese arsenide thin films having the thickness (6–12) nm were grown in a conventional III–V MBE system (ULVAC MBC-508) with a Mn effusion cell. We used Si(111) substrates with 1.5° misorientation. After chemical treatment [6] and drying in N_2 gas flow, the Si substrates were introduced into the MBE growth chamber and annealed at ~900°C at As_4 flow for a few minutes. With the As_4 flow kept on, the MnAs epitaxial growth was started by supplying Mn flow. The typical growth rate was about 0.8 nm/min. The crystalline quality of the substrates and ferromagnetic film layers was monitored *in situ* by RHEED.

The structural characterization of the (6–12 nm) MnAs/Si(111) samples was made by X-ray diffraction measurements ($\theta - 2\theta$ method). The X-ray results for the B1118 film ($d = 10$ nm) are shown in Fig. 1. One can see MnAs[0001] (at 15.5°), MnAs[0002] (at 31.3°) and MnAs[0004] (at 65.3°) peaks in addition to intensive Si(111) and Si(222) peaks. These peaks indicate that the film grows epitaxially in the direction of c-axis. The average thickness (d) was defined as the amount of material deposited on the Si substrate.

The surface film morphology was measured with a Digital Instruments atomic force microscope operating in the contact mode. The surface morphology features for 3 films is depicted in Fig. 2. In Fig. 2(a), the thin film B1105 has a uniform distribution of MnAs across the substrate surface. Hexagon-like islands appear with increasing average

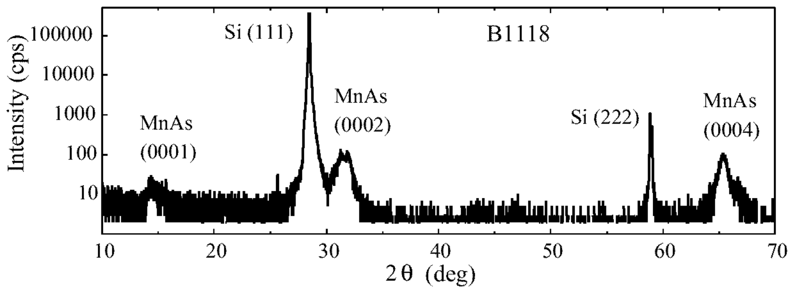

Fig. 1. X-ray diffraction spectrum of a MnAs film (B1118, d = 10 nm) grown on Si(111). The assignment of dominant peaks is shown.

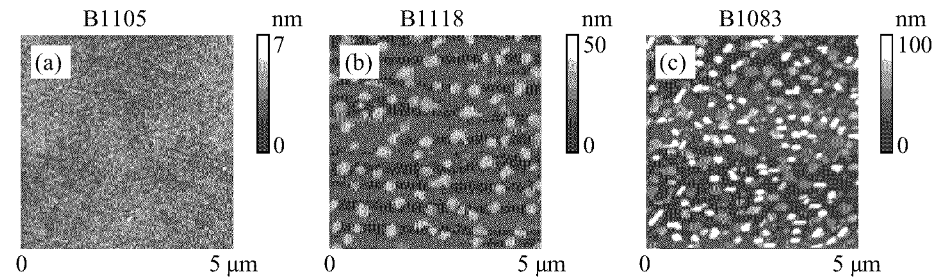

Fig. 2. AFM images of MnAs films: (a) B1105 (350°C; 1.2; 6 nm), (b) B1118 (400°C; 1.2; 10 nm), (c) B1083 (350°C; 2.0; 12 nm). In brackets: the substrate temperature, As_4-to-Mn flow ratio and the average thickness, respectively.

thickness (for B1118 and B1083), as can be seen in Fig. 2(b),(c). In Fig. 2(b), the islands have heights up to 50 nm and lateral dimensions in the range from 50 nm to 100 nm. Figure 2(c) demonstrates a tendency for larger island sizes up to the heights of 50–100 nm.

2. Magneto-optical studies

The magneto-optical Kerr rotation effect was measured in the longitudinal and polar geometry [7] when linearly polarized light was reflected by the films. The measurements were carried out at the wavelengh of 0.63 μm (He–Ne laser) in a magnetic field up to 0.7 T at room temperature. The measurement sensitivity of rotation was $\sim 5''$. Figure 3(a) shows the Kerr hysteresis loops measured in the longitudinal geometry in the B1083 and B1105 films. The loops are saturated. Figure 3(b) demonstrates the azimuth dependence of the Kerr rotation magnitude in the B1083 film. The dependence is mostly isotropic. The measurements in the polar geometry using a solenoid to create a field of 0.05 T have shown that the value of the polar effect in different films is by about a factor of ten smaller than in the longitudinal geometry and no saturation is reached. Figure 4(a) illustrates the dependence of the longitudinal Kerr effect on the average film thickness.

3. Discussion and conclusions

The measurements of Kerr hysteresis loops clearly indicate the ferromagnetic character of the MnAs films. The azimuthal dependencies of the Kerr effect show that the films can be

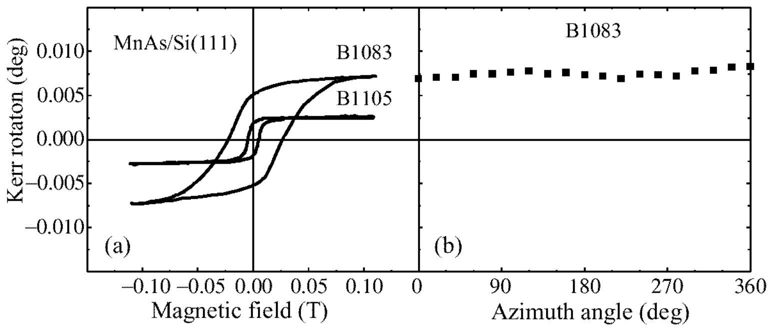

Fig. 3. (a) The Kerr hysteresis loops in the longitudinal geometry for p-polarized light at the incidence angle of $\varphi \approx 15^\circ$ in the B1083 and B1105 films. (b) The azimuth dependence of the longitudinal Kerr rotation in the B1083 film.

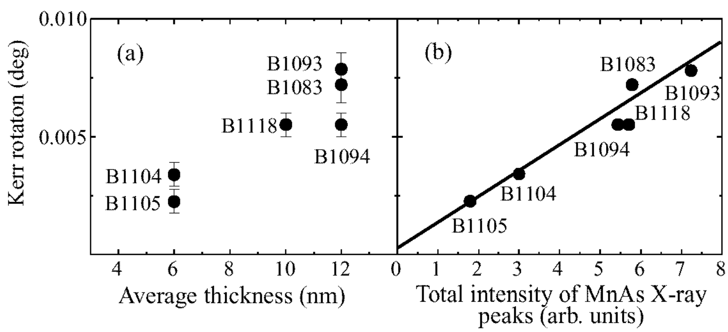

Fig. 4. The longitudinal Kerr rotation as a function (a) of the average film thickness; (b) of the total intensity of MnAs X-ray peaks.

characterized as having "easy plane" anisotropy with magnetization in the film plane. Since MnAs has the hexagonal NiAs sructure, this type of anisotropy apparently follows from the (111) orientation of the substrate, which provides a high epitaxial growth symmetry. The dependence presented in Fig. 4(a) can be understood taking into account the fact that the films studied are much thinner than the light penetration depth into the sample. In this case, the Kerr effect is proportional to the thickness of the magnetic layer. An analysis of the AFM images shows that the Kerr rotation magnitude depends on the film morphology. The effect is larger in films where MnAs islands display hexagon-like patterns and where the dimensions of the islands are larger. We suggest that these islands form the magnetic fraction of the film. To prove this suggestion, we have replotted the data of Fig. 4(a) as a function of the magnetic fraction evaluated from the total intensity of MnAs X-ray diffraction peaks normalized to the integral Si substrate peak intensity. The results are presented in Fig. 4(b). The data in Fig. 4(b) are well described by the linear dependence crossing the thickness axis close to zero.

Thus, we have grown thin (6–12 nm) MnAs films on Si (111) by MBE. X-ray diffraction analysis has shown that the MnAs growth plane is (0001). The film surface morphology was studied by AFM. The AFM images indicate that MnAs hexogon-like islands are formed on the Si substrate. The magneto-optical studies have shown that the films are ferromagnetic with the "easy-plane" type of anisotropy. The combined analysis of RHEED, X-ray diffraction, AFM and magneto-optical studies allows us to conclude that hexagon-like islands form the magnetic fraction and can be attributed to MnAs.

Acknowledgements

This work was supported by RFBR, Program "Physics of Solid State Nanostructures" and the Japan Society for the Promotion of Science (JSPS) Research for the Future Program.

References

[1] G. A. Prinz, *Science* **250**, 1092 (1990).

[2] *Magnetic Films* & Surfaces, 15th Int. Conf. Digest. Kyoto (August 4-8, 1997).

[3] K. Akeura, M. Tanaka, M. Ueki and T. Nishinaga, *Appl. Phys. Lett.* **67**, 3349 (1995).

[4] K. Akeura, M. Tanaka, T. Nishinaga and J. De Boeck, *J. Appl. Phys.* **79**, 4957 (1996).

[5] H. Ohno, F. Matsukura, T. Omiya and N. Akiba, *J. Appl. Phys.* **85**, 4277 (1999).

[6] T. Takahagi, A. Ishitani, H. Kuroda, Y. Nagasawa, H. Ito and S. Wakao, *J. Appl. Phys.* **68**, 1 (1990).

[7] J. Shoenes, *Magneto-optical properties of metals, alloys and compounds*, in Materials Science and Technology, eds R. W. Cahn *et al.*, vol 3, 1990.