

# Magneto-optical spectra in MnSb and MnAs films prepared by atomic-hydrogen assisted hot wall epitaxy on GaAs

Katsuaki Sato\*, Hiroshi Ikekame, Masanori Akita, Yoshitaka Morishita

*Faculty of Technology, Tokyo University of Agriculture and Technology, Koganei, Tokyo 184, Japan*

## Abstract

Thin films of NiAs-type MnSb and MnAs were epitaxially grown on GaAs (1 0 0) and (1 1 1) substrates by an atomic-hydrogen assisted hot-wall technique. Polar magneto-optical spectra were measured between 1.2 and 6 eV. Crystal-orientation dependence of the spectra were clearly observed. © 1998 Elsevier Science B.V. All rights reserved.

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Structural and magnetic properties in manganese pnictides, MnAs and MnSb, have been known to be closely related to their electronic structures [1]. To elucidate the electronic structures optical and magneto-optical investigations are required. Concerning MnSb, magneto-optical investigations were carried out in polycrystalline [2] and single crystalline bulk materials [3]. However, these spectra are less reliable since they were obtained from the mechanically polished surface of samples cut from the bulk crystals. Therefore it is desirable to measure optical spectra in well-controlled single-crystal films. Epitaxial films of MnSb have been successfully prepared by molecular beam epitaxy (MBE) [4, 5] and hot-wall epitaxy (HWE) on GaAs substrates [6, 7]. Concerning MnAs, it is very difficult to obtain single crystals with a good stability, since the material undergoes two successive phase transitions when it is cooled down from the melting point to room temperature. It is reported that MnAs films prepared by MBE technique can be stabilized in NiAs-type structure and is free from the phase transitions [8].

We previously reported magneto-optical spectra in MnSb and MnAs epitaxial films prepared by HWE [7]. However, it was found from SEM and AFM observation that these films suffer three-dimensional growth which lead to the root-mean-square (RMS) surface roughness of

as large as 1000 Å. In order to improve the surface quality of the films we have introduced an atomic-hydrogen assistance technique which have been proved to be powerful in surface modification of semiconductor films [9].

The growth experiments were performed in a conventional HWE system using polycrystalline powders of the manganese-pnictide compounds as source materials. For substrates we employed single crystals of GaAs with (1 0 0) or (1 1 1) orientations. We used atomic hydrogen for cleaning of the substrate, as well as for enhancing two-dimensional growth of the epitaxial layer. The atomic hydrogen was generated by flowing pure hydrogen molecules (H<sub>2</sub>) through a tungsten filament heated above 1600°C placed inside an Al<sub>2</sub>O<sub>3</sub> tube and then introduced to the vicinity of the substrate surface.

Prior to the film growth the surface of the GaAs substrate was cleaned by irradiation of the atomic hydrogen for 15 min at substrate temperature of 430 C. The hydrogen pressure was 10<sup>-5</sup> torr. After the treatment the substrate was cooled down to 350 C for growth of the magnetic films. MnSb films were deposited on the GaAs (1 0 0) and (1 1 1) substrates with atomized hydrogen. Typical deposition time was 3 h, at which the film thickness of approximately 2000 Å was obtained. Surface morphology was studied using a Digital Instruments Nano-scope II AFM, which elucidated that introduction of atomic hydrogen results in a drastic improvement of surface quality; i.e., reduction of the RMS roughness from 1000 to 44 Å. The details of the atomic-hydrogen assisted HWE technique are described elsewhere [10].

\* Corresponding author. Fax: +81-423-87-8151; e-mail: satokats@cc.tuat.ac.jp.

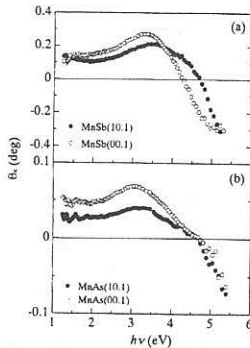


Fig. 1. (a) Polar magneto-optical Kerr rotation spectra from the (10.1) (closed circles) and (00.1) surface (open circles) of MnSb prepared by the atomic-hydrogen assisted HWE technique on GaAs substrates. (b) The corresponding spectra from the (10.1) (closed circles) and the (00.1) (open circles) surfaces of MnAs on GaAs.

The same technique was applied to the growth of MnAs films on GaAs substrates. In this case the source and substrate temperatures were chosen to be 700°C and 400°C, respectively. The typical growth rate was about 0.05 Å/s and the thickness of films obtained was approximately 1000 Å.

The orientation of the epitaxial films was found to depend strongly on the crystal orientation of the substrate: The surface orientation of the MnSb and MnAs films was (10.1) on GaAs (1 0 0) and (00.1) on GaAs (1 1 1)<sub>B</sub>. In MnAs films on GaAs (1 0 0) surface, a small trace of (10.2) plane was observed in the X-ray diffraction.

Spectra of polar magneto-optical Kerr rotation and ellipticity were measured in these films at room temperature for both (10.1) and (00.1) surfaces, with the magnetic field up to 1.7 T. With the largest applied field MnSb films showed a saturation behavior in a Kerr hysteresis curve, while MnAs films showed an incomplete magnetic saturation. In Fig. 1a and Fig. 1b are plotted Kerr rotation spectra in MnSb and MnAs, respectively. Kerr ellipticity spectra are not shown for simplicity. Spectral features of the Kerr rotation in MnSb are considerably different from those in bulk crystals [2, 3]. The smallness of the Kerr rotation in MnAs may be ascribed to the incomplete magnetic saturation. The Kerr rotation peak for the (10.1) surface is located at lower energies than for the (00.1) surface in both materials. Similar orientation dependence of the magneto-optical effect was already reported in epitaxial MnSb film and is consistent with the present study [5].

Spectra of the off-diagonal elements of conductivity tensor were calculated from the measured magneto-optical spectra using the optical constants obtained from

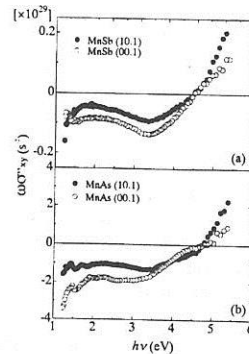


Fig. 2. Imaginary part of off-diagonal conductivity multiplied by angular frequency in (a) MnSb/GaAs and (b) MnAs/GaAs. Closed circles and open circles denote spectra from (10.1) and (00.1) surfaces, respectively.

reflectivity spectra and are illustrated in Fig. 2a and Fig. 2b. No distinct orientation dependence was found in off-diagonal conductivity spectra of both films. We therefore conclude that anisotropic features of Kerr rotation in MnSb and MnAs result mainly from the anisotropy in diagonal part of conductivity tensor, the latter being consistent with theoretical calculations [11].

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