MAGNETO-OPTICAL CHARACTERIZATION OF EPITAXIALLY GROWN MANGANESE PNICTIDES

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Abstract - MnAs and MnSb thin films were grown on GaAs (100) substrates by hot-wall epitaxy (HWE) technique. Epitaxial growth with $(10\bar{1}1)$ axis parallel to GaAs (100) surface was observed in both films. Polar magneto-optical Kerr rotation and Kerr ellipticity spectra were measured in these samples. For MnAs, it is for the first time that reliable polar Kerr spectra were obtained.
KEYWORDS: MnAs, MnSb, epitaxial film, hot wall epitaxy, polar magneto-optical Kerr spectrum

Introduction

Manganese pnictides such as MnAs and MnSb are known to crystallize in NiAs-type structure and show ferromagnetism at room temperature, in which magnetic and magneto-optical properties have been studied from fundamental as well as aplicational view points.[1-3]

For MnSb, magneto-optical spectra in polycrystalline bulk materials were first reported by Buschow et al.[4] Magneto-optical spectra in a bulk single crystal were reported by our group, in which large Kerr rotation at short wavelength was first observed.[5,6]

On the other hand, only available data concerning magneto-optical effect of MnAs to date were those measured by Stoffel and Schneider.[7] They reported spectra of longitudinal magneto-optical Kerr effect in evaporated polycrystalline films, the spectral range of which was limited between 1.3 eV and 2.6 eV. The lack of reliable data on MnAs is due mainly to the difficulty in obtaining stable NiAs-phase single crystals at room temperature by suppressing the MnP-phase that exists in equilibrium phase diagram.

Quite recently, novel hybrid structures consisting of semiconductors and magnetic substances are attracting much interest as possible candidate materials for new functionality device application.[8] For this purpose, establishment of epitaxial growth technologies of magnetic thin films on semiconductor substrates are very important. Manganese pnictides such as MnAs and MnSb have been considered to be suited as magnetic materials for hybrid magnetic semiconductor system, since they consist of a transition element and a group V_b element, the latter being shared by III-V_b semiconductors and minimizing inter-diffusion of cations. [9,10]

In this study, we succeeded in epitaxial growth of MnAs and MnSb thin films with NiAs-type structure on GaAs (100) substrates by HWE technique and measured polar magneto-optical Kerr rotation and Kerr ellipticity spectra for wide photon energies between 1.2 eV and 5.3 eV. It should be noted that this is the first report of polar magneto-optical Kerr spectra in MnAs with well-defined NiAs structure.

Experimental Procedure

Crystal growth of MnAs and MnSb films were performed in a conventional HWE system. The growth apparatus, the growth conditions and the characterization methods were described previously in detail elsewhere.[11]

GaAs substrates used in this study were of vicinal (100) plane with a tilt angle of 2 degrees towards [011] azimuth. It is generally known that epitaxial growth occurs more easily by employing off-axis substrates than using just (100) GaAs substrates. The use of the off-axis GaAs has another merit that it suppresses the $\{10\bar{1}1\}$ twins which are often observed when using just (100) GaAs substrates. The substrate was set on a molybdenum holder using indium contacts in the HWE system. The chamber was then evacuated to

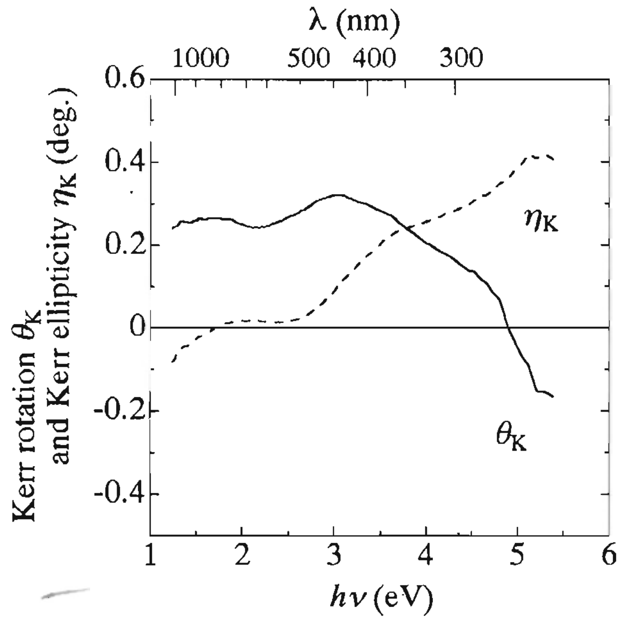

Fig. 2 Polar magneto-optical Kerr rotation and Kerr ellipticity spectra for $(10\bar{1}1)$ plane of MnAs thin film grown on GaAs (100) substrate.

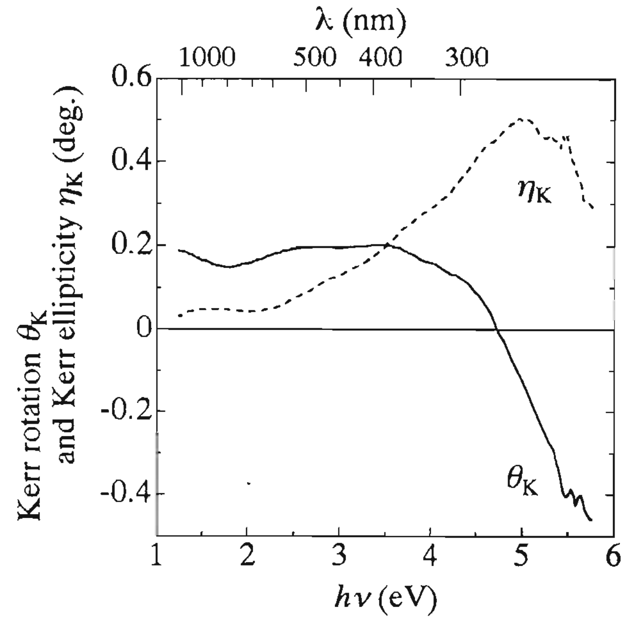

Fig. 3 Polar magneto-optical Kerr rotation and Kerr ellipticity spectra for $(10\bar{1}1)$ plane of MnSb thin film grown on GaAs (100) substrate.

The peak value of Kerr rotation was about 0.33 deg., the value being larger than the rotation (0.20 deg.) of MnSb at the same photon energy (see Fig. 3). Reflectivity values of both MnAs and MnSb films at 3 eV are as large as 30 %, which iscomparable to that of TbFe at the same photon energy.. Therefore MnAs can be regarded as a promising material for magneto-optical applications.

Polar magneto-optical Kerr rotation and ellipticity spectra for $(10\bar{1}1)$ MnSb thin film grown on GaAs (100) substrate are shown in Fig. 3 The Kerr rotation crosses zero at 4.8 eV and shows a rapid increase of rotation above the photon energy. The rotation reaches as large as 0.4 deg at 5.5 eV. The spectral shape is quite similar to that reported in the MBE-grown $(10\bar{1}1)$ MnSb film by Akinaga et al. [10]

It is found that spectral shape of the film was almost the same as that of the bulk single crystal except for the difference in the higher energy region where the ellipticity takes a larger value and the rotation shows a steeper slope than those in the bulk sample.[6] Improvement of Kerr effect in higher energy region may be ascribed to the reduced scattering in the surface of the epitaxial film compared with the polished surface of the bulk crystal.

Comparison of Figs. 2 and 3 suggests that the spectral features are not so much different between those two compounds, although a slight shift of structures are observed. This means that the electronic transitions associated with the magneto-optical effect of these compounds are quite similar to each other. Theoretical calculations based on the energy band structure is necessary for further discussion.

Conclusion

MnAs and MnSb thin films were found to grow epitaxially by HWE technique on GaAs (100) with the growth direction $[10\bar{1}1]$. Polar magneto-optical Kerr rotation spectra obtained in the MnSb thin film are good agreement with those in the MBE-grown films. Reliable polar Kerr spectra were obtained for the first time in MnAs films with NiAs structure.

a pressure of 10^{-7} Torr, in which thermal cleaning of the substrate was carried out at 580 °C for 5 minutes. After the cleaning process the substrate was cooled down to a desirable temperature in order to grow MnAs or MnSb thin films.

The evaporation sources were prepared as follows; for the case of MnSb, polycrystalline MnSb compound was synthesized from elements of Mn and Sb by normal freezing technique, the details of which were described in our previous paper.[5] For MnAs, element materials of Mn and As were used.

The growth temperatures are given in Table 1. Growth rates were maintained at about 0.1 Å/s, and typical thickness of the thin film was 1500 Å.

Table 1 Temperature conditions for HWE growth.

	Source temperature	Substrate temperature
MnSb	700 °C	400 °C
MnAs	Mn: 700 °C As: 250 °C	400 °C

Characterization of these films were carried out as follows; structural properties were studied by X-ray diffractometry (XRD) using a Rigaku RAD-IIc diffractometer (Cu Kα-line). Compositions were analyzed by means of electron probe microanalysis (EPMA) using a JEOL JXA-8900R microanalyzer. Reflectivity spectra were measured using Hitachi U-3410 spectrophotometer. Kerr hysteresis loops and polar magneto-optical Kerr rotation and Kerr ellipticity spectra were measured at room temperature for photon energies region from 1.2 eV to 5.3 eV using a specially designed Kerr spectrometer developed in our laboratory.[12]

Results and Discussion

XRD patterns of MnSb films obtained by the present study showed only the diffraction lines which can be assigned to reflection from the $(10\bar{1}1)$ plane of hexagonal NiAs structure. In MnAs, however, the $10\bar{1}1$ diffraction line happens to appear very close to the 200 diffraction of GaAs. The epitaxial relationship was confirmed using another diffraction line $10\bar{1}2$ of MnAs. These XRD results suggest epitaxial growth of MnAs and MnSb with $(10\bar{1}1)$ parallel to the (100) surface of GaAs substrate. The same epitaxial relationship was reported in samples prepared by molecular beam epitaxy (MBE).[9,10] EPMA results for MnAs and MnSb thin films provided a stoichiometric composition within an experimental error.

Prior to the measurement of magneto-optical spectra, Kerr hysteresis loops were evaluated. As illustrated in Fig. 1 magnetic saturation was approximately realized in both MnAs and MnSb thin films. It has been known that easy axis of magnetization in Mn-pnictides with stoichiometric composition is perpendicular to c-axis of NiAs structure at room temperature. Since c-axis makes an angle with the plane-normal in our growth condition, the observed magnetization curves are consistent with known magnetic behavior of these materials.

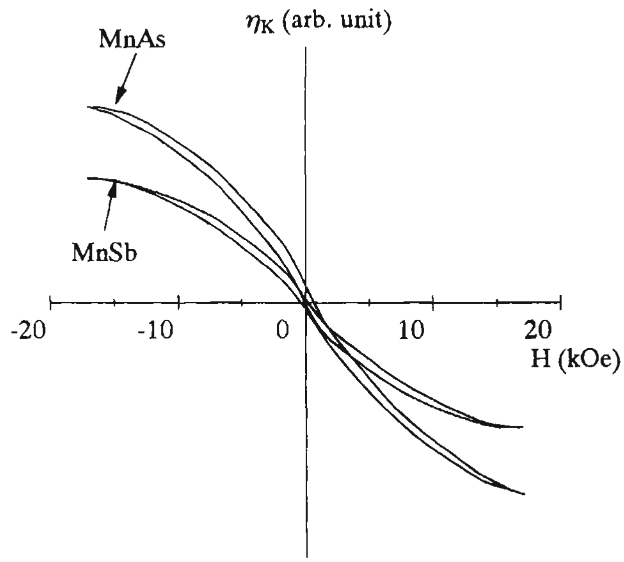

Fig. 1 Polar Kerr hysteresis loops in MnAs and MnSb films obtained by HWE on GaAs (100) substrates.

Polar magneto-optical Kerr rotation and Kerr ellipticity spectra for $(10\bar{1}1)$ MnAs thin film grown on GaAs (100) substrate are shown in Fig. 2. The Kerr rotation reaches the maximum value around 3.0 eV (400 nm), and crosses zero around 4.9 eV where the Kerr ellipticity takes a maximum value.

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