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Magneto-optical properties of tin substituted MnSb films

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Polycrystalline films of Sn-substituted MnSb have been prepared from bulk by Flash evaporation. The Faraday rotations and optical absorption coefficients of $MnSb_{1-x}Sn_x$ ($0 \leqslant x \leqslant 0.3$) films are measured in the visible region. Room temperature specific saturation rotation F, decreases with increasing Sn concentration at all wavelengths while the optical absorption coefficient α (uncorrected for reflection) does not show any significant change. The Magneto-optic figure of merit ($2F/\alpha$) for different compositions and wavelengths are estimated for evaluating these films as beam-addressable storage elements.

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I. INTRODUCTION

Magneto-optical properties of magnetic material in thin-film form have been of considerable interest since thermomagnetic recording was demonstrated on MnBi. Materials for magneto-optic file application must have large magneto-optic rotation for read out and high optical absorption for the thermomagnetic writing process. If in addition, the file has to operate without the use of any refrigeration or temperature biasing, then the material requirement imposes an additional condition that the Curie temperature should be as close to room temperature as possible.

The compound MnSb possesses NiAs-type structure and the magnetic properties of this compound have been found to be devoid of instabilities associated with first-order phase transitions near the Curie temperature as in MnAs and MnBi. The specific Faraday rotations and optical absorption coefficients are large enough for these to be considered as potential magneto-optic file element. Since it has a large Curie temperature of about 300 °C and also since its magnetic properties are sensitive to the presence of interstitial cations, Sawatzky *et al.*[1] attempted to populate the bipyramidal interstitial positions with excess manganese and were able to bring down its Curie temperature to about 90 °C. But their attempts failed as the new compound $Mn_{1+x}Sb$ ($0 \leqslant x \leqslant 0.2$) reverted back to the stoichiometric MnSb phase on thermal cycling through their Curie temperatures. They also found from their result on the systems of $Mn_{1.1}Co_{0.1}Sb$ and $Mn_{1.1}Ni_{0.1}Sb$ that this instability of the bipyramidal site is not limited to excess manganese. Later Vijayaraghavan *et al.*[2] were able to prepare compounds of MnSb with different lower Curie temperatures by substituting the manganese of the octahedral interstitial sites by copper which resulted in the films of the composition $Mn_{1-x}Cu_xSb$ ($0 \leqslant x \leqslant 0.3$). These films were found to be devoid of the instabilities associated with $Mn_{1+x}Sb$. Thus having obtained a technique for preparing MnSb of lower curie temperatures we attempted to substitute tin, but this time in place of antimony. We report here on the preparation of vacuum deposited $MnSb_{1-x}Sn_x$ films. The experimental technique involved in the film preparation, the results of magneto-optical, optical and temperature variation of Faraday rotation are discussed. These are later analyzed for evaluating them for beam-addressable magnetic memory devices.

II. FILM SYNTHESIS AND CHARACTERIZATION

Films of $MnSb_{1-x}Sn_x$ were prepared for the composition range from $x = 0$ to $x = 0.3$ by flash evaporation in the same way as described in Ref. 3 using bulk materials of these alloys which were supplied by Professor Hashimoto of Japan. The substrates were optically flat glass plates thoroughly cleaned ultrasonically and subsequently cleaned by ion bombardment just before deposition. They were kept at room temperature and during deposition the vacuum was better than 5×10^{-6} torr. Film thickness was determined using quartz oscillator thickness monitor calibrated with the aid of optical interferometer.

The structure and the composition of the films were investigated by electron microscopy, x-ray diffraction and electron microprobe analysis. All the films studied (up to a thickness of 5000 Å) were found to be polycrystalline and of single phase with no significant preferred orientation. Figure 1 shows a transmission electron diffraction (TED) pattern of a Sn 0.2 film. The lattice constants of all the films were in

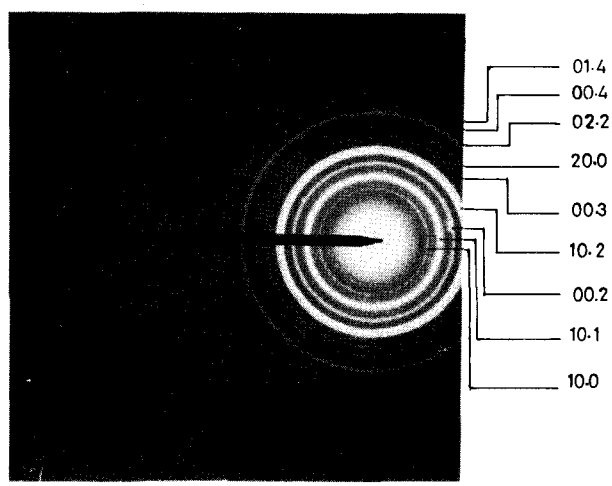

FIG. 1. Transmission electron diffraction pattern of a 500-Å-thick $MnSb_{0.8}Sn_{0.2}$ film, taken at 80 kV. This shows that the film is composed of one phase of the NiAs structure.

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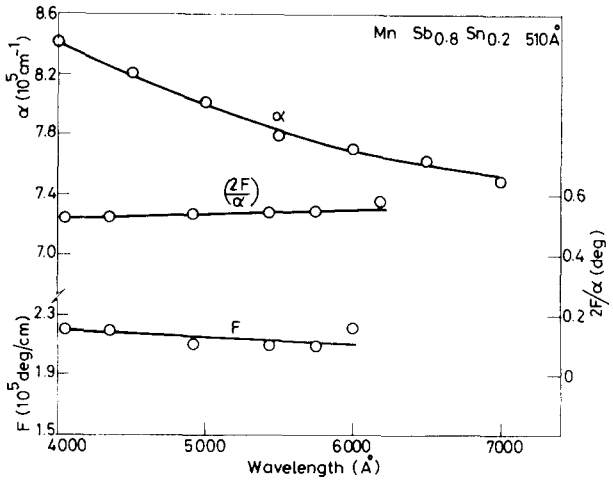

FIG. 2. Dispersion of specific Faraday rotation F, optical absorption coefficient α and figure of merit $(2F/\alpha)$ for $MnSb_{0.8}Sn_{0.2}$ film. The thickness of the film was 510 Å.

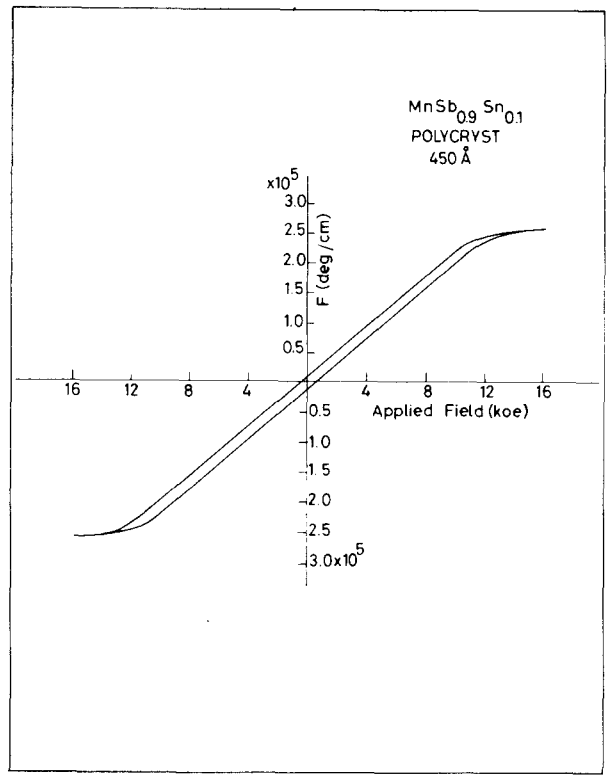

FIG. 3. Room-temperature polar Faraday rotation at 6328 Å as a function of applied magnetic field.

agreement with that of the bulk. The x-ray diffraction data on films approximately 5000 Å thick also agrees well with the x-ray pattern of the corresponding powder specimens. The composition was independently determined by an electron probe using bulk standards. The composition was almost retained in all the films investigated and there was reasonable uniformity in composition throughout the area scanned. All the films obtained were smooth, metallic in appearance, and were highly reflecting. We also found that it was not possible to control the film composition when the tin content exceeded 30 atomic percent; for beyond this composition we noticed segregation of tin from the alloy.

III. RESULTS

A. Faraday rotation measurement

The polar Faraday rotation of the film was measured at room temperature in air within few hours after deposition using a spectropolarimeter described elsewhere.[4] A well concentrated and collimated beam of light from a high-pressure Xe arc lamp was made monochromatic by a set of interference filters having a high transmittance and spectral half width of about 100 Å. The monochromatic beam, 4 mm in diameter on a film surface, was allowed to pass through a nicol prism before entering the film and the transmitted beam was modulated by a mechanical chopper analyzer and detected by a photomultiplier tube. Rotation angle was measured within an accuracy of $\frac{1}{2}$ minute of arc. The thicknesses of films ranged between 400–600 Å, for films of higher thicknesses had low light transmittance and hence low sensitivity of detection. Again thinner films were avoided because their pin holes might lead to errors in the measurement of Faraday rotation. Figure 2 shows the variation of saturation Faraday rotation of an Sn 0.2 film with wavelength, recorded at room temperature. It can be seen that Faraday rotation remains almost constant. This was true at all dopant concentrations of tin in the film. The values of Faraday rotation measured at a wavelength of 6328 Å for all compositions are listed in Table I. The room temperature polar Faraday rotation as a function of applied field is shown in Fig. 3 for a Sn 0.1 film. The remnance in the polar configuration is very low, less

TABLE I. Comparison of magneto-optical properties of potential magneto optic memory materials.

Material	$T_c(K)$	Absorption coefficient α_{6328} cm^{-1}	Saturation Faraday rotation F_{6328}(deg/cm)	Figure of merit $(2F/\alpha)_{6328}$deg	Ref.
Mn_5Ge_3	310	$4.5\times10^5(U)$	1.9×10^5	0.85	6
CrTe	334	$1.8\times10^5(C)$	0.5×10^5	0.55	5
Fe_5Si_3	390	$3.7\times10^5(C)$	1.3×10^5	0.70	8
MnSb	585	$6.7\times10^5(U)$	2.3×10^5	0.70	1
MnSb0.9Sn0.1	575	$7.7\times10^5(U)$	2.6×10^5	0.70	
MnSb0.8Sn0.2	540	$7.6\times10^5(U)$	2.2×10^5	0.60	Present work
MnSb0.7Sn0.3	363	$7.4\times10^5(U)$	0.9×10^5	0.25	

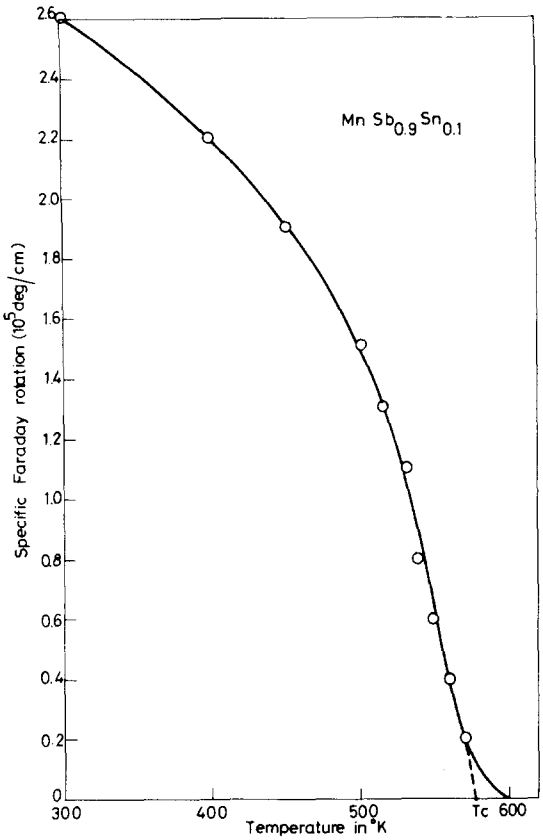

FIG. 4. Temperature dependence of specific Faraday rotation for a 450-Å-thick $MnSb_{0.9}Sn_{0.1}$ film. The Curie temperature T_c is 575 K.

than 10% of saturation value and the hysteresis loops are typical hard direction loops indicating that the easy axis of magnetization lies in the plane of the film. Saturation rotation is reached in applied fields greater than about 10 K Oe for all compositions.

The effect of oxidation and deposition of films on different substrates were also studied. In respect of oxidation, it was found that no significant change in Faraday rotation was noticed even after a few weeks of exposure to highly humid atmosphere. Again, depositing the film with a thick protective layer of silicon monoxide, we found that there was no significant change in Faraday rotation upon several thermal cyclings through the Curie temperature for all the films investigated. Also no significant change in the specific Faraday rotation of the films was noticed when they were deposited on different substrates like rock salt, quartz etc.

B. Absorption coefficient measurements

The uncorrected room-temperature optical-absorption coefficient α defined by $I = I_0 \exp(-\alpha t)$ was measured using a CARL ZEISS DMR 21 spectrophotometer calibrated with known standards for reducing possible instrumental errors. To avoid multiple reflections of light in the magnetic layers all the films for which absorption coefficient was measured had thickness of about 500 Å. The variation of α with wavelength for an Sn 0.2 film is shown in Fig. 2. Although the α's are uncorrected for reflection, reflection and absorption due to substrate was taken care of by keeping a film-free substrate in the reference beam. As in various other intermetallics like CrTe,[5] Mn_5Ge_3,[6] etc., the absorption is quite featureless except for a gradual rise in α near ultraviolet as the metallic absorption edge is approached. For these measurements only films which showed similarity in composition, crystallographic structure, and specific Faraday rotation values for several thicknesses were used. The values of α at the wavelength of 6328 Å for different concentrations of tin are given in Table I.

C. Temperature variation of Faraday rotation

The Curie temperature T_c of all the films were determined using the temperature variation of Faraday rotation. The setup consists of a glass furnace heater, wound noninductively, where the films are kept and whose temperature could be controlled to within $\pm$ 3 °C. A thick coating of silicon monoxide was given to the films to prevent them from getting oxidized during measurement. Figure 4 shows the temperature dependence of specific Faraday rotation of an Sn 0.1 film. T_c for this film was found to be 575 K and it decreased with increasing Sn concentration, reaching a value of 360 K for Sn = 0.3, in agreement with the result of Hashimoto *et al.*[7] The values of T_c for all the compositions studied are tabulated in Table I.

IV. CONCLUSION

Thin films of the compound $MnSb_{1-x}Sn_x$ ($0 \leqslant x \leqslant 0.3$) possess some features which are not found in other similar materials reported as potential candidates for magneto-optic memory applications. Efficient use of a laser for thermomagnetic writing in magnetic films requires that the materials have large absorption coefficient at the laser wavelength. When one laser is used for both writing and reading, the wavelength of the beam must be properly selected to reach a compromise for the magnitudes of the material properties. It is commonly accepted that $(2F/\alpha) \gtrsim 1°$ is required for adequate read-out. In conjunction with the requirements for α, which is $\alpha \geqslant 10^5$ cm^{-1}, this means that $F \gtrsim 10^5$ deg/cm and both α and F are achievable at room temperature and in the convenient visible laser wavelength region. That the dispersion curves of both Faraday rotation and figure of merit for all compositions are almost flat shows that these materials have the advantage of being used in any visible laser wavelength. Also, as required, the optical absorption coefficients, like Faraday rotations, for all compositions are relatively high, consistent with the metallic character of the films. But since the easy direction of magnetization is in the plane of the film and the remnance normal to the film is essentially zero, magneto-optical read-out using the Faraday effect is possible only with oblique light beam incidence. Under these conditions the available read signal is reduced relative to the polar configuration by an amount dependent on the angle of incidence, on the refractive index and absorption coefficient of the material. This is a common feature for all materials having the easy direction of magnetization in the plane of the film. Again Curie temperature T_c of about 588 K for MnSb could be brought down to as low as 363 K by changing the concentration of tin in MnSb. Thus the Curie temperature

could be tailored to suit the specifications of a laser beam addressable file. A comparison of the pertinent magneto-optical properties of $MnSb_{1-x}Sn_x$ at a wavelength of 6328 Å with other similar materials reported as potential candidates for magneto-optic memory applications and whose easy direction of magnetization is in the plane of the film, is given in Table I. The absorption coefficients are either corrected (c) or uncorrected (u) for reflection. A study of the table indicates that Sn-doped MnSb compares favorably with other materials from the standpoint of laser beam thermomagnetic writing. Again considering the ease of preparation, stability, relatively lower Curie temperatures and comparable figure of merit, $MnSb_{1-x}Sn_x$ films look attractive for magneto-optic file applications.

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