Solid solutions of MnSb as recording media in optical memory applications

V. Seshu Bai and K. V. S. Rama Rao

Citation: Journal of Applied Physics **55**, 2167 (1984); doi: 10.1063/1.333598
View online: http://dx.doi.org/10.1063/1.333598
View Table of Contents: http://scitation.aip.org/content/aip/journal/jap/55/6?ver=pdfcov
Published by the AIP Publishing

Solid solutions of MnSb as recording media in optical memory applications

V. Seshu Bai
School of Physics, University of Hyderabad, Hyderabad 500 134, India

K. V. S. Rama Rao
Department of Physics and Materials Science Research Centre, Indian Institute of Technology, Madras 600 036, India

We show in this paper that many of the difficulties, encountered in using the ferromagnetic MnSb films as storage media in memory devices employing the technique of laser Curie point writing and magneto-optic readout, can be overcome by forming solid solutions of MnSb with Fe, Co, In, and excess Mn, viz. $Mn_{1-x}Fe_xSb$, $Mn_{1-x}Co_xSb$, $MnSb_{1-x}In_x$ and $Mn_{1+x}Sb$ ($0 \leqslant x \leqslant 0.25$ or 0.3). Spins that are in basal plane of MnSb at 300 K are found to reorient to be along the film normal, from ferromagnetic resonance work, beyond a critical composition ($x_c = 0.16, 0.21, 0.16$, and 0.14 for the systems containing Co, Fe, In, and excess Mn, respectively) ensuring a large readout efficiency. Moreover, the lowering of Curie temperature for higher compositions can enable us to work with low power lasers which help to achieve sharper writing without diffusion of heat into neighboring domains. In addition, the absence of any crystallographic phase transformation in the temperature range of operation (unlike in MnBi) makes the MnSb alloys potentially more attractive for use as recording media.

PACS numbers: 85.70.Sq

I. INTRODUCTION

Introduction of optical technology for data storage in computers is potentially capable of improving the performance figure of merit by about 2–4 orders of magnitude, compared to conventional memory systems. This improvement results from the possibility of larger packing density of the storage medium, faster access times and the avoidance of head-crash problems.[1] The coherent property of the writing laser beam enables the data to be stored holographically, thus opening the possibility of parallel data processing.

Information can be stored and retrieved from thin magnetic films using the technique of laser Curie point writing (LCPW) and magneto-optic readout (MORO) respectively. The Curie point writing involves heating of the memory bit location above the Curie point of the film material and cooling it in a magnetic field. The sum of the closure flux and the applied magnetic field determines the direction of magnetization of the memory bit. The reading is accomplished by the Kerr effect or Faraday effect. The above method of storing and retrieving information needs a memory medium with the following properties.

The medium must have (i) sufficiently low Curie temperature to enable writing at lower laser power levels (ii) should, preferably, be usable at room temperature (iii) must have sufficiently high coercivity to avoid accidental erasure of information, (iv) should be stable over extended period of time and over almost indefinite number of write-read cycles, (v) must have a high recording density, and (vi) must provide adequate readout signal to noise ratio.

Thin films of MnBi have been studied extensively[2–4] as a memory medium employing the above technique. However, thin films of other intermetallic compounds such as MnSb, MnAs, CrTe, Mn_5Ge_3, MnGaGe, MnAlGe, etc., have been studied only to a much lesser extent.

MnSb and MnBi are isostructural with hexagonal NiAs-type crystal structure and have Curie temperatures of 588 and 633 K, respectively. The easy direction of magnetization in MnBi is along the film normal, i.e., parallel to c axis[5,6] resulting in a large Faraday rotation F and hence a large readout figure of merit $2F/\alpha$, where α is the optical absorption coefficient. The easy direction of magnetization in MnSb lies in the basal plane and hence in the film plane at room temperature leading to a lesser Faraday effect. This has caused the MnSb film to remain less attractive for optical memory applications.

MnBi undergoes a structural phase transformation from the low-temperature phase (ltp) to a high-temperature phase (htp) at 719 K. The htp MnBi can be prepared by quenching MnBi from above the transformation temperature and it has a lower Curie temperature (453 K) and larger Faraday rotation compared to the ltp MnBi. However, the htp MnBi is known to get converted to the ltp phase with a time constant of two years.[4] Even if one compromises the large Faraday rotation of htp MnBi and uses the ltp phase, a large number of write-read cycles are shown to transform the ltp phase into the htp phase.[4]

The absence of crystallographic phase transformation in MnSb makes it potentially attractive for optical memory applications provided the easy direction of magnetization can be changed from the basal plane to the c direction, ensuring a large readout figure of merit. In this paper we discuss our results on several solid solutions of MnSb and discuss how some of them are potential candidates for optical memory applications.

II. OBSERVATIONS

The systems $Mn_{1-x}Fe_xSb$ ($0 \leqslant x \leqslant 0.3$), $Mn_{1-x}Co_xSb$ ($0 \leqslant x \leqslant 0.3$), $MnSb_{1-x}In_x$ ($0 \leqslant x \leqslant 0.25$) and $Mn_{1+x}Sb$ ($0 \leqslant x \leqslant 0.25$) were prepared and studied in our laboratory using thin films coated on coverglass substrates under a vacuum of 10^{-6} Torr. X-ray diffraction studies confirmed that the films were of single phase with the NiAs type crystal

 0021-8979/84/062167-03$02.40

structure of MnSb. Magnetization measurements were made using an oscillator technique described elsewhere.[7] The reorientation of the magnetization from the basal plane to the c direction was detected using the ferromagnetic resonance (FMR) technique. Exchange coupling constants (A) were obtained using the spin wave resonance (SWR) technique. The results are summarized in Figs. 1–4. Preparation of the solid solutions and further experimental details are available in our publications.[8,9]

III. DISCUSSION

We have already mentioned that though MnSb is structurally stable unlike MnBi, the major drawback of MnSb is that at room temperature the spins lie in the basal plane, i.e., in the film plane, thus failing to provide full utilization of the readout figure of merit. In pure MnSb the spins reorient to the c direction only above 520 K.[10]

Just as the crystalline anisotropy in single crystals, the strain-anisotropy from magnetostriction plays the dominant role in the polycrystalline films. It can be seen from Fig. 1 that the strain-anisotropy field $3\lambda_s\sigma/M_s$ (λ_s, M_s are the saturation values of magnetostriction constant and magnetization, respectively, and σ is the planar stress isotropic in the film plane), obtained from ferromagnetic resonance work, undergoes a change in sign from negative to positive at a critical composition, $x_c = 0.16$, 0.21, 0.16, and 0.14 for the systems $Mn_{1-x}Co_xSb$, $Mn_{1-x}Fe_xSb$, $MnSb_{1-x}In_x$ and $Mn_{1+x}Sb$, respectively. The critical compositions are the compositions at which the direction of magnetization changes over to the c direction from the basal plane at room temperature (300 K).[11] In other words, the spin reorientation temperature of MnSb (520 K) comes down to 300 K at the critical compositions of the solid solutions. The magnetization remains oriented along the c direction for $x > x_c$ at 300 K, ensuring a large Faraday rotation. FMR investigations on $Mn_{1-x}Cu_xSb$[12] and $MnSb_{1-x}Sn_x$[13] suggest that reorientation of spins to c direction does not occur at room temperature even up to 30 at. % of Cu and 20 at. % of Sn respectively. The alloys with higher concentrations of Cu and Sn are found to show the presence of other phases in x-ray photographs.

The optical absorption coefficient α and the coercive field H_c of MnSb and MnBi are found to be of the same order of magnitude.[14] Another parameter of importance is the do-

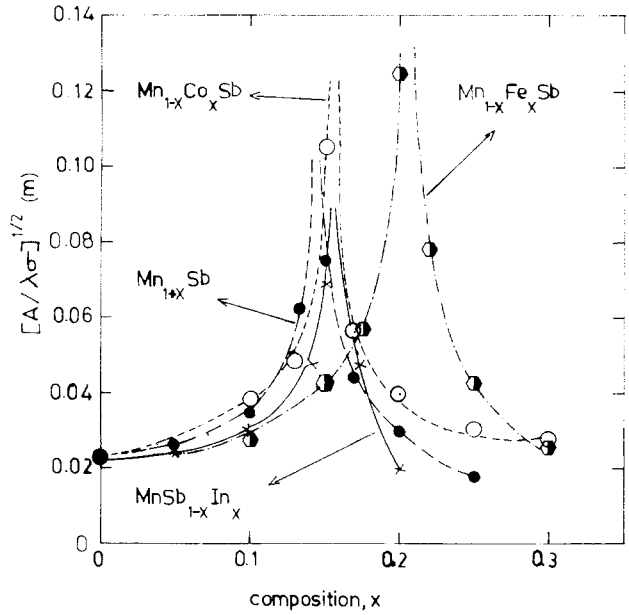

FIG. 2. Variation of $(A/\lambda\sigma)^{1/2}$ with composition of (a) (Mn,Fe)Sb, (b) (Mn,Co)Sb, (c) Mn (Sb,In) and (d) Mn-Sb at 300 K. The discontinuity at $x = x_c$ is a result of λ being zero at this composition.

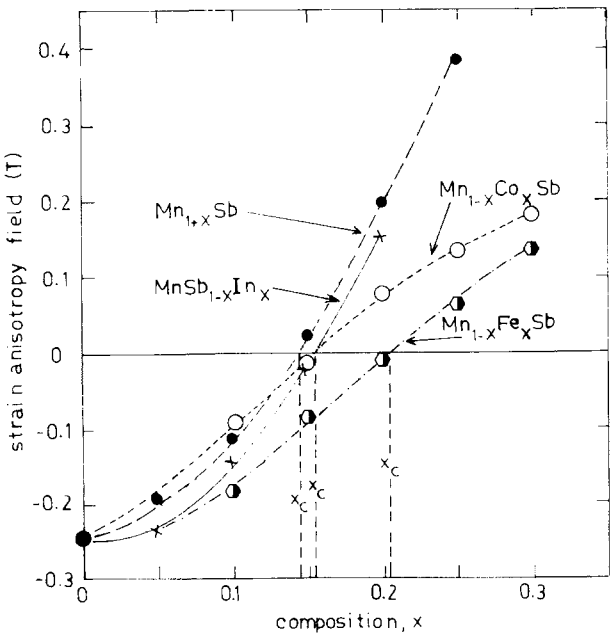

FIG. 1. Strain-anisotropy field ($3\lambda_s\sigma/M_s$) as a function of composition in (a) (Mn,Fe)Sb, (b) (Mn,Co)Sb, (c) Mn(Sb,In) and (d) Mn-Sb at 300 K. The change in sign at $x = x_c$ is a result of reorientation of spins from film plane at $x < x_c$ to be along film normal at $x > x_c$.

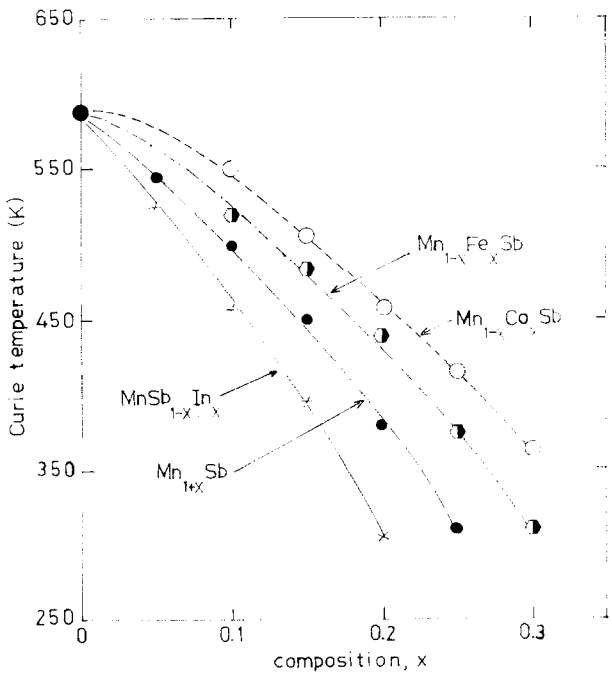

FIG. 3. Curie temperature (T_C) as a function of composition in (a) (Mn,Fe)Sb, (b) (Mn,Co)Sb, (c) Mn(Sb,In) and (d) Mn-Sb systems.

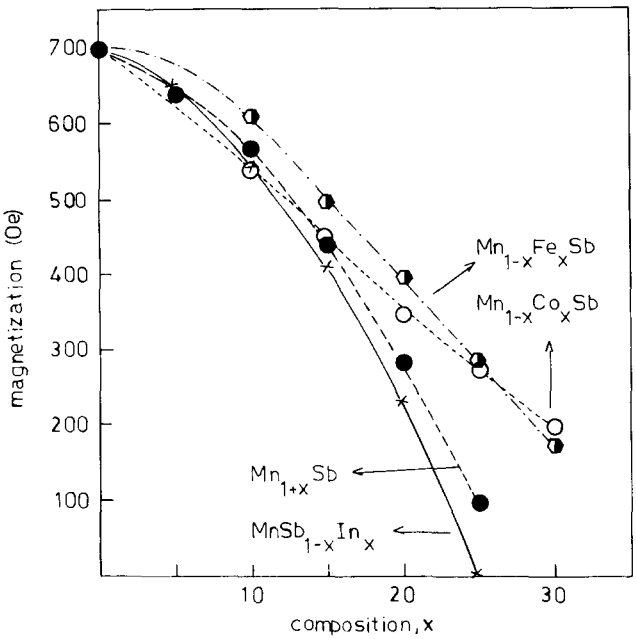

FIG. 4. Variation in saturation value of magnetization at 300 K with composition of (a) (Mn,Fe)Sb, (b) (Mn,Co)Sb, (c) Mn(Sb,In) and (d) Mn-Sb solid solutions.

main size. Domain size d is related to the exchange coupling constant and anisotropy field through the relationship[15] $d \propto (A/\lambda\sigma)^{1/2}$. Figure 2 shows a plot of $(A/\lambda\sigma)^{1/2}$ versus composition. Among the solid solutions with $x > x_c$, i.e., with spins oriented along the c direction, the domain size decreases with increase of x. The discontinuity at $x = x_c$ is a result of λ being 0 at that composition. The smaller the domain size, the larger the packing density of memory bits on a film and hence the solid solutions with large x are preferable from this point of view.

Figure 3 shows that the Curie temperature (T_C) of all the solid solutions get reduced gradually with composition, to considerably lower values compared to that of MnSb. This enables the choice of a composition with Curie temperature low enough to prevent the neighboring domains from getting destroyed or erased during a writing process (using a laser beam), but sufficiently higher than room temperature to prevent accidental erasure of recorded information. The required power levels of the writing laser would also be lower.

Figure 4 shows that the saturation magnetization (M_s) values at 300 K of the solid solutions are also lowered with x, leading to a lower Faraday rotation and thus to a lower read-out figure of merit. This would necessitate a compromise to be made taking into consideration other parameters discussed above when choosing a suitable composition for memory applications. In Table I we give the relevant properties of some potential candidates for optical memeory applications and compare their properties with those of MnSb and MnBi. These solid solutions show promise of replacing MnBi, which poses difficulties due to the structural phase transformation, as recording media in optical memory devices and merit further investigations.

TABLE I. Properties of solid solutions proposed as more promising storage media compared to MnSb and MnBi, for optical memory applications.

Material	T_c (K)	Spin direction	$[A/\lambda\sigma]^{1/2}$ (m)	M_s (Oe)
MnSb	588	basal plane	0.023	700
MnBi (ltp)[a]	633	c-direction	...	570
MnBi (htp)	453	c-direction	...	440
$Mn_{0.75}Fe_{0.25}Sb$	376	c-direction	0.043	285
$Mn_{0.8}Co_{0.2}Sb$	458	c-direction	0.040	345
$Mn_{0.75}Co_{0.25}Sb$	415	c-direction	0.030	270
$Mn_{0.7}Co_{0.3}Sb$	363	c-direction	0.028	195
$MnSb_{0.82}In_{0.18}$	348	c-direction	0.034	315
$Mn_{1.2}Sb$	380	c-direction	0.030	280

[a] MnBi undergoes structural transformation from htp to ltp in course of time and from ltp to htp after repeated write-read cycles, see text.

[1] A. H. Eschenfelder, J. Appl. Phys. **41**, 1372 (1970).
[2] H. J. Williams, R. C. Sherwood, F. G. Foster, and E. M. Kelley, J. Appl. Phys. **28**, 1181 (1957).
[3] D. Chen, J. F. Ready, and G. Bernal E., J. Appl. Phys. **39**, 3916 (1968).
[4] D. Chen, G. N. Otto, and F. M. Schmit, IEEE Trans. Magn. **MAG-9**, 66 (1973).
[5] C. Guillaud, Ph.D. thesis, University of Strasbourg, France, 1943.
[6] B. W. Roberts, Phys. Rev. **104**, 607 (1956).
[7] K. V. S. Rama Rao, V. Seshu Bai, C. Ramasastry, N. Weiden, and A. Weiss, J. Magn. Magn. Mater. **36**, 180 (1983).
[8] V. Seshu Bai and K. V. S. Rama Rao, J. Phys. F. **13**, 695 (1983).
[9] V. Seshu Bai and K. V. S. Rama Rao, Phys. Status Solidi A **73**, K303 (1982).
[10] W. J. Takei, D. E. Cox, and G. Shirane, Phys. Rev. **129**, 2008 (1963).
[11] V. Seshu Bai, K. V. S. Rama Rao, and C. Ramasastry, IEEE Trans. Magn. **MAG-17**, 2724 (1981).
[12] K. V. S. Rama Rao, T. Rajasekharan, V. Seshu Bai, and C. Ramasastry, Phys. Status Solidi A **45**, K51 (1978).
[13] M. Hashimoto, J. Ishii, and K. Kambe, J. Phys. Soc. Jpn. **37**, 277 (1974).
[14] E. Sawatzky and G. B. Street, IEEE Trans. Magn., **MAG-7**, 377 (1971).
[15] K. W. Stewart, *Ferromagnetic Domains* (Cambridge University, London & New York, 1954).