ABSTRACT
Ni-Mn-Ga ferromagnetic shape memory thin films were deposited onto well cleaned substrates of Si (100) and glass at two different sputtering powers of 25W and 45W in argon atmosphere at 0.015 mbar. The structural, magnetic and magneto-resistive properties of the deposited films were systematically investigated. The sputtering target Ni$_50$Mn$_{30}$Ga$_{20}$ (at.%) used in the present work has been prepared by vacuum induction melting technique. The prepared thin films were post annealed at a temperature of 600°C for 1 h in vacuum. The composition and structure of the films were studied by energy dispersive x-ray analysis and x-ray diffraction techniques. The magnetic properties were studied using vibrating sample magnetometer and a.c. magnetic susceptibility. Magneto-resistive properties were measured using four-probe set-up attached with vibrating sample magnetometer. Pristine thin films are quasi crystalline while the annealed films show good crystallinity and ferromagnetism at room temperature. It was observed that the annealed films deposited at 25 W show austenite phase whereas the films deposited at 45 W show mixed phases of both austenite and martensite. Maximum magnetic transition temperature of the films investigated was found to be 327 K which is in consistent with the results of a.c. magnetic susceptibility. The thermo-magnetic curves reflect only magnetic transition and no signature of structural transition observed. The magneto-resistive properties of the thin films are found to be isotropic with a maximum negative magneto-resistance value of -0.6% at an applied magnetic field of 2.0 Tesla.

Keywords: NiMnGa shape memory thin films; Magnetic and magneto-resistive properties; Magnetic susceptometer.

Abbreviations: MEMS - Microelectro Mechanical Systems; MR - Magneto Resistive; VSM - Vibration Sample Magnetometer

1. INTRODUCTION

Heusler NiMnGa is a multifunctional smart magnetic material capable of producing large magnetic field induced strain ~10% and negative magneto-resistance ~5% making it suitable for shape memory magnetic-actuation and magneto-resistive applications (Hakola et al., 2004; Andriy Vovk et al., 2005; Liu et al., 2008; Banki et al., 2007; Koike et al., 2007). The material also possesses other technologically interesting properties viz. magneto-caloric properties used for magnetic cooling, which other ferromagnetic shape memory alloys cannot fulfill (Soderberg et al., 2008). Despite the unique properties and multifunctional applications of NiMnGa bulk alloy, its brittleness is a major drawback which limits its potential use in effective actuation applications as the bending stress causes fracture failure in the material. Thin films of NiMnGa have been proposed to solve this problem as they can be bent by deforming stresses without fracture (Makoto Ohtsuka et al., 2004; Makoto Ohtsuka et al., 2008). NiMnGa thin films have already been successfully implemented in first prototypes of MEMS devices such as micro valves and micro scanners. Although considerable work has been carried on bulk alloy of Ni-Mn-Ga, systematic studies on the preparation and characterization of Ni-Mn-Ga thin films (Ahn et al., 2001; Dong et al., 1999; Dong et al., 2004; Wuttig et al., 2000; Wu et al., 2002; Castano et al., 2003; Chemenko et al., 2008; Kohl et al., 2006; Kohl et al., 2004; Liu et al., 2006; Dubowiak & Goscińska, 2007) are not much. In the present work, NiMnGa thin films were prepared by d.c. magnetron sputtering technique at two different sputtering powers of 25 and 45 W at 0.015 mbar argon pressure and their structural, magnetic and magneto-resistive properties were systematically investigated.

2. MATERIALS AND METHODS

The mixture of 99.9% pure Ni, 99.999% pure Mn and 99.999% pure Ga of required composition was melted using an alumina crucible under argon atmosphere by vacuum induction heating technique. The melt is transferred into a steel mould of 50mm inner diameter to obtain the bulk alloy. The as-cast bulk alloy was hot isostatically pressed to overcome the problem of porosity and low density. The sputtering targets of 50mm diameter and 1mm thick were prepared by EDM wire cutting from bulk alloy. The composition of the sputtering target is Ni$_{50}$Mn$_{30}$Ga$_{20}$. Thin films of NiMnGa were deposited onto well cleaned Si (100) and glass substrates in a d.c magnetron sputtering system (12"MSPT, HIND HIVAC, Bangalore). Thin films were deposited at a constant argon pressure of 0.015 mbar and sputtering powers of 25W and 45W respectively. The films were subjected to post-deposition heat treatment at 600°C for 1h in vacuum. The structural, magnetic and magneto-resistive (MR) properties of the thin films were systematically investigated. The chemical composition in the thin films has been determined using energy dispersive x-ray analysis and the structural characteristics have been...
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Structural, magnetic and magneto-resistive properties of sputter deposited Ni-Mn-Ga ferromagnetic shape memory thin films.
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Table 1 Magnetic properties of d.c. magnetron sputter deposited Ni-Mn-Ga thin films

<table>
<thead>
<tr>
<th>Film ID</th>
<th>Composition (at.%)</th>
<th>Substrate</th>
<th>Magnetization $M_s$ (emu/cc)</th>
<th>$H_c$ (Oe)</th>
<th>$T_c$ (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMGC1 (25W)</td>
<td>Ni$<em>{57.3}$Mn$</em>{27.3}$Ga$_{15.3}$</td>
<td>Si (100)</td>
<td>52</td>
<td>63</td>
<td>43.51</td>
</tr>
<tr>
<td>NMGC1 (25W)</td>
<td>Ni$<em>{57.3}$Mn$</em>{27.3}$Ga$_{15.3}$</td>
<td>Glass</td>
<td>208</td>
<td>220</td>
<td>38.23</td>
</tr>
<tr>
<td>NMGC3 (45W)</td>
<td>Ni$<em>{59.1}$Mn$</em>{27.4}$Ga$_{13.5}$</td>
<td>Si (100)</td>
<td>148</td>
<td>135</td>
<td>17.75</td>
</tr>
<tr>
<td>NMGC3 (45W)</td>
<td>Ni$<em>{61.0}$Mn$</em>{27.8}$Ga$_{11.2}$</td>
<td>Glass</td>
<td>332</td>
<td>297</td>
<td>33.31</td>
</tr>
</tbody>
</table>

Table 2 Magnetic-resistance properties of Ni-Mn-Ga thin films

<table>
<thead>
<tr>
<th>Film ID</th>
<th>Composition (at.%)</th>
<th>Substrate</th>
<th>B &amp; J direction</th>
<th>Resistivity $\rho$ ($\mu\Omega$·cm)</th>
<th>MR</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMGC1 (25W)</td>
<td>Ni$<em>{57.4}$Mn$</em>{27.3}$Ga$_{15.3}$</td>
<td>Si (100)</td>
<td>Parallel</td>
<td>891</td>
<td>-0.46</td>
</tr>
<tr>
<td>NMGC1 (25W)</td>
<td>Ni$<em>{57.4}$Mn$</em>{27.3}$Ga$_{15.3}$</td>
<td>Glass</td>
<td>Perpendicular</td>
<td>878</td>
<td>-0.51</td>
</tr>
<tr>
<td>NMGC3 (45W)</td>
<td>Ni$<em>{59.1}$Mn$</em>{27.4}$Ga$_{13.5}$</td>
<td>Si (100)</td>
<td>Parallel</td>
<td>1236</td>
<td>-0.34</td>
</tr>
<tr>
<td>NMGC3 (45W)</td>
<td>Ni$<em>{61.0}$Mn$</em>{27.8}$Ga$_{11.2}$</td>
<td>Glass</td>
<td>Perpendicular</td>
<td>229</td>
<td>-0.30</td>
</tr>
</tbody>
</table>

Figure 1
XRD patterns of the annealed Ni-Mn-Ga thin films

Figure 2a
M(H) hysterisis loops of annealed Ni-Mn-Ga thin films (25W)

Figure 2b
M(H) hysterisis loops of annealed Ni-Mn-Ga thin films (45W)

Figure 2c
M(H) hysterisis loops of annealed Ni-Mn-Ga thin films (45W)
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3. RESULTS AND DISCUSSION
3.1 Structural analysis of NiMnGa thin films

The atomic constituents in the thin films deposited on glass and silicon substrates are given in Table 1. The structural characteristics of the pristine and post-heat treated thin films were studied by x-ray diffraction. Pristine Ni-Mn-Ga thin films are quasi-crystalline, whereas annealed films are good crystalline. The presence of well defined peaks in diffractograms of annealed (600°C/1h) thin films shown in Fig.1 confirm the atomic ordering upon annealing. The diffraction patterns reveal the austenite phase of the annealed films deposited at 25W and the development of martensite for the films deposited at 45W. The presence of γ-phase was also observed in heat treated thin films deposited at 45W. Similar observations were also been made by Makoto Ohtsuka (2008) and Chung (2004) in NiMnGa thin films.
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3.3. Magneto-resistive properties of the thin films

Films show good soft magnetic properties, characterized by narrow hysteresis loop, low coercivity and high magnetic saturation. Thermo-magnetic curves obtained for the annealed thin films are shown in Fig.3, which provides the information about magnetic transition (Tc) and the values are given in Table 1. Even though information on the magnetic Curie transition temperature was observed from the thermo-magnetic curves, the presence of structural transition temperature could not be identified. This may be due to small change in its magnetization during such structural transition in thin films. The curves of a.c. magnetic susceptibility obtained for the films deposited at 25W and 45 W are shown in Figs 4a and 4b respectively. The values of Tc observed from a.c susceptibility measurements for the heat treated thin films (45 W) are in good agreement with the values obtained from thermo-magnetic curves (Table 1).

4. CONCLUSIONS

NiMnGa bulk alloy was synthesized using induction melting technique and the sputtering targets were prepared from the bulk alloy. Thin films were prepared at two different sputtering powers of 25 and 45 W at argon pressure of...
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0.015 mbar using d.c. magnetron sputtering technique and their structural, magnetic, magneto-resistive and a.c. magnetic susceptibility properties were systematically investigated. Pristine thin films are found to be quasi-crystalline and paramagnetic. Well crystalline and ferromagnetic natures of the thin films were restored by post deposition heat treatment. Maximum magnetic transition temperature and maximum negative magneto-resistance values of the films investigated were found to be 327K and -0.61% respectively.

SUMMARY OF RESEARCH
1. Heusler Ni-Mn-Ga alloy is a good ferromagnetic shape memory material but brittle in nature which limits its potential applications
2. For the development of miniaturized actuators, Ni-Mn-Ga thin films are good candidates due to their high MFIs and bending nature
3. In this present work Ni-Mn-Ga films were prepared at different sputtering environments and their physical properties were investigated
4. Results reveal that the annealed films are soft ferromagnetic showing magnetic transition and no evidence of structural transition
5. Maximum magnetic transition and maximum negative magneto-resistance of the films were found to be 327 K and -0.61% respectively.

FUTURE ISSUES
Even though signature of structural transition is absent from the thermo magnetic curves, the XRD reveals the formation of martensitic microstructure for the films deposited on si(100) which could be further addressed

DISCLOSURE STATEMENT
There is no financial support for this proposed work.

ACKNOWLEDGMENTS
The support and contribution extended by Dr. M. Manivel Raja, DMRL, Hyderabad and all others who helped in this work are gratefully acknowledged.

REFERENCES


RELATED RESOURCE