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Magnetocaloric Effect and Magnetoelastic Properties of NiMnGa and NiMnSn Heusler Alloy Thin Films

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Abstract

Series of NiMnSn and NiMnGa Heusler alloys thin films of different compositions were obtained by DC magnetron sputtering in order to achieve strong magnetocaloric effect in the temperature range close to the room temperature. The maximal magnetocaloric effect was found in the temperature range 320-350 K, with the maximal entropy change -ΔS ranges from 1.4×10^4 erg/gK to 2.7×10^4 erg/gK. Strain modulated ferromagnetic resonance technique was used to determine magnetoelastic properties of the films. Magnetoelastic constants of an order of 10^6 erg/cm^3 were found.

Keywords: Heusler alloys, magnetocaloric effect, magnetoelastic properties, magnetocrystalline anisotropy

1. Introduction

The NiMnSn and NiMnGa Heusler alloys have attracted much attention because of large magnetocaloric effect and potential applications in magnetic refrigeration devices [1, 2, 3] In these compounds the martensitic transformation, with the change of the crystallographic symmetry from cubic (austenitic phase) to tetragonal (martensitic phase) occurs [4], and the magnetocaloric effect is very large at the points when both the martensitic and ferromagnetic transitions take place close to one another [5]. The martensitic transformation in Heusler alloys is also correlated with the phenomenon of magnetically driven shape memory [6] and giant strains reaching 10% [7]. Although the giant strains are observed in strong magnetic field (of an order of 10 kOe), the large magnetic field induced strains are undesirable from the viewpoint magnetic refrigeration technique, because they may cause the device deformation as well as energy dissipation in alternating magnetic field. Hence, the control of both magnetocaloric and magnetoelastic effects is necessary for such applications.

DC magnetron sputtering technique is a very convenient technique to obtain magnetic thin films. For this reason, we used this technique to obtain the NiMnSn and NiMnGa films of different compositions in order to achieve strong magnetocaloric effect at room temperature.

Strain modulated ferromagnetic resonance (SMFMR) [8] is a unique technique which enables determination of magnetoelastic properties of magnetic thin films. We used this technique to determine the magnetoelastic properties of the films with strong magnetocaloric effect. In previous work [9], we used this technique to study magnetoelastic properties of a series of epitaxially grown $Co_2Fe_{0.4}Mn_{0.6}Si$ and $Co_2FeGa_{0.5}Ge_{0.5}$ Heusler alloys thin films. In present work, we use this method to determine the magnetoelastic properties of the NiMnSn and NiMnGa Heusler alloys films with strong magnetocaloric effect at room temperature.

2. Experimental technique

The NiMnSn and NiMnGa magnetic thin films were deposited on amorphous SiO_2 substrates and/or photoresist coated crystalline Si plates (for thin foils) in room temperature by means of DC magnetron sputtering from pure element sources (Ni, Mn, Ga and Sn). The chemical composition of these alloys oscillated in the Mn-rich region of Ni-Mn-X ternary phase diagram (38-47 at. %) with the amount of Ga or Sn in the range of 14-21 and 10-26 atomic percent respectively. Samples were annealed at the temperature of 775 K for 5 hours in vacuum. Their composition, structure and magnetic properties were studied with the use of SEM/EDX, XRD and SQUID magnetometer technique.

The samples with the maximal magnetocaloric effect were chosen to study magnetoelastic properties. We studied magnetoelastic properties of five NiMnSn samples (Sn04, Sn05, Sn06, Sn09, and Sn10) and two NiMnGa samples (Ga22, Ga24). The main features of the five NiMnSn samples including composition, thickness of the magnetic layer and crystallographic structure, at room temperature, are summarized in Table 1. The x-ray patterns of the samples are shown in Fig.1. The lines corresponding to the martensitic and austenitic phases are marked by the symbols.

Depending on composition, we observed the presence of both austenitic and martensitic phases, and the samples have either polycrystalline or texturized structure (see in Tab.1). All samples except for Sn05 were on SiO_2 substrate. The sample Sn05 was detached from the substrate before performing the studies of magnetoelastic properties.

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