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Anomalous Nernst Effect in NiMnSb Half-Heusler Alloy Thin Film

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Abstract

We report the anomalous Nernst effect (ANE) in a NiMnSb half-Heusler alloy thin film deposited on a MgO(001) substrate. Both ANE and Seebeck effect show an extreme sensitivity to in-plane thermal gradient by producing a reckonable electrical response under a small temperature difference of 3 K. Reasonably large Nernst angle (θ_{ANE}) is observed at low temperatures.

1. Introduction

The anomalous Nernst effect (ANE): thermally induced transversal voltage in the direction perpendicular to both the temperature gradient and the magnetization is a complimentary probe to the spin-orbit coupling phenomena in the field of spin caloritoronics [1-3]. The ability of ANE to generate the pure spin current and spin-polarized current by a thermal gradient has attracted many researchers for the last two decades [1-3]. On the other hand, the half-metallic Heusler alloys are of intense research interest because of their exclusive properties due to the semiconducting behavior of the minority band with a gap at the Fermi level and leading to 100% spin polarization of conduction electrons [4-8].

This exceptional property may direct the spontaneous thermoelectric effects in half-metallic Heusler alloys, which augment the interest to investigate the thermoelectric effects in half- Heusler alloys.

In this paper, we present a thorough investigation of the Seebeck and the anomalous Nernst effects (ANEs) in a NiMnSb half-Heusler alloy thin film.

2. Experimental

A thin film of half-Heusler NiMnSb with a thickness of 20 nm was deposited by co-sputtering Ni and MnSb targets using DC-sputtering on a MgO (001) single crystalline substrate at room temperature. After deposition, the NiMnSb film was annealed at 300°C. The composition of the deposited NiMnSb thin film was evaluated to be $Ni_{1.01 \pm 0.02}Mn_{0.98 \pm 0.02}Sb_{1.01 \pm 0.02}$ by an inductively coupled plasma (ICP) analysis, which confirms the ideal stoichiometric composition for the half-Heusler compound [5].

In order to measure the ANE, the NiMnSb thin film was patterned into a Hall bar structure using an optical lithography and ion-milling process. The typical lateral size of NiMnSb thin film channel was 2 mm × 5 mm, whereas the distance between two voltage (V_{xy}) probes was 2 mm. The cryostat of physical property measurement system (PPMS) was used to obtain low temperature and magnetic field.

To create the in-plane thermal gradient across the structure (as shown in Fig. 1a) along the x-axis a ceramic heater at one (Hot) end and a Cu-heat sink at the other (Cold) end were used. The pre-calibrated Pt-100 temperature sensors were used to sense the temperature difference across the structure, whereas the transverse output voltage (V_{xy}) was measured by a nanovoltmeter.

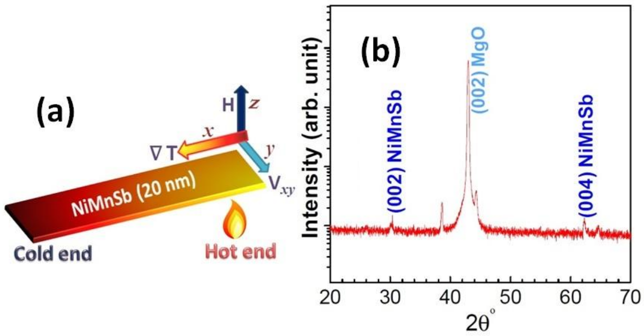

Fig. 1 (a) Sketch of the device used to measure ANE, (b) XRD (θ-2θ-scan) pattern of a 20 nm thick NiMnSb thin film deposited on a MgO (001) substrate.

3. Results and Discussion

The structural properties were characterized by X-ray diffraction (XRD) (θ-2θ-scan) pattern, as shown in Fig. 1b. The diffraction peaks from NiMnSb (002) and (004) superlattices were clearly observed.

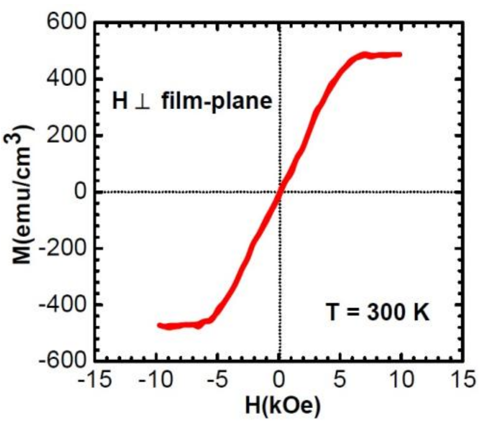

Fig. 2 The out-of-plane magnetization as a function of applied magnetic field (H) at 300 K.

The out-of-plane magnetization as a function of applied magnetic field was measured at room temperature using a vibrating sample magnetometer (VSM). From the magnetization curve, the saturation magnetization (M_s) and saturated magnetic field (H_s) are found to be about 500 emu/cm^3 and 6 kOe, respectively.

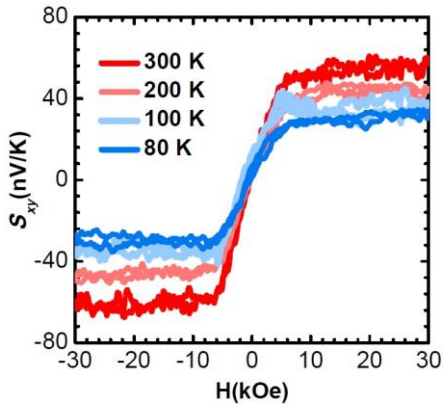

Fig. 3 Magnetic field dependence of the transverse Seebeck coefficient measured at different temperatures with in-plane applied thermal gradient of 3 K.

Figure 3 shows the magnetic field dependence of the transverse Seebeck coefficient (S_{xy}) with measured at different temperatures, when the applied magnetic field is perpendicular to the x-y plane, for the thermal gradient of 3 K, applied along the x-axis to the sample. The observed saturation magnetic field for V_{ANE} is the same as that observed in magnetization data (see Fig. 2 and Fig. 3).

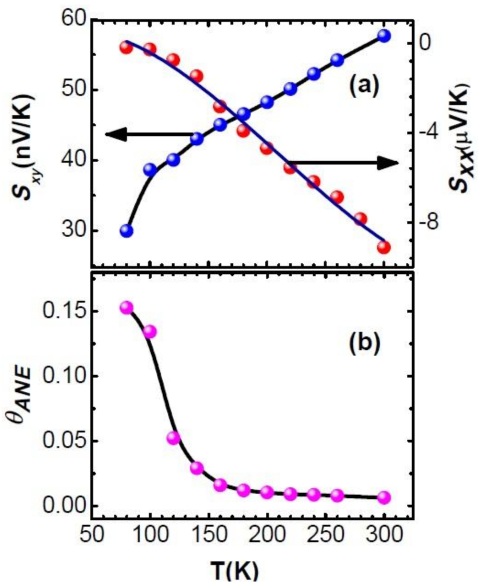

Fig. 4 (a) Temperature dependence of ANEs (left axis) and Seebeck (right axis) effect, (b) Temperature dependence of Nernst angle (θ_{ANE}).

In ferromagnets, the electromotive force (E) induced by spin-polarized current through ANE can be described as [1]:

$$E = -S_{xy} \times \nabla T = \theta_{ANE} S_{xx} \times \nabla T \qquad \text{----- (1)}$$

where S_{xy} is the transverse Seebeck coefficient, S_{xx} is the longitudinal Seebeck coefficient, and θ_{ANE} is the anomalous Nernst angle.

Figure 4a shows the temperature dependence of S_{xy} (left axis) and S_{xx} (right axis). It is observed that S_{xy} simply decreases with decreasing temperature till 100 K, and drops faster below 100 K. The temperature dependence of θ_{ANE} is shown in Fig 4b as calculated from eq. 1. It is observed that θ_{ANE} increases with decreasing temperature. Most importantly, the θ_{ANE} is found to be significantly enhanced and become 10 times below 100 K.

This is probably associated with particular properties in NiMnSb leading to a low temperature anomaly [7,8]. However, distinct mechanism of this anomaly has not clarified yet. More precise measurements and intensive discussion are needed.

4. Conclusions

In summary, we have investigated the temperature dependence of the anomalous Nernst effects in NiMnSb half-Heusler alloy thin film grown on a MgO substrate. A significantly enhanced Nernst angle was observed at low temperature.

Acknowledgements

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