Growth of Sn-doped Mn_4N epitaxial films and evaluation of their properties at room temperature

Univ. of Tsukuba [1], °T. Yasuda[1], T. Komori[1], H. Mitarai[1], T. Horiuchi[1], K. Toko[1] and T. Suemasu[1]
E-mail: ytrp108@gmail.com

[Introduction]

Ferrimagnetic Mn_4N (Fig. 1) film is a promising candidate for various spintronics devises thanks to their small magnetization (M_s ~ 100 kA/m) and clear perpendicular magnetic anisotropy (K_u = 0.1 MJ/m)[1]. Ni-[2,3] and Co-doped[4] Mn_4N films have magnetic compensation (MC) points which was revealed by the sign reversal of anomalous Hall resistivity and X-ray magnetic circular dichroism spectra. Using Ni-doped Mn_4N films, our group demonstrated ultrafast domain wall motion (v_{DW} = 3,000 m/s[5]) driven only by spin-transfer torque at room temperature (RT) thanks to the angular momentum compensation around the MC point. Additionally, In-doped Mn_4N[6] films show ferrimagnetic-to-ferromagnetic transition by their composition. In this work, we focus on Sn-doped Mn_4N ($Mn_{4-x}Sn_xN$) film. In the $Mn_{4-x}Sn_xN$ bulks, the MC point was suggested at low temperature[7]. However, there have been no reports about such films. Therefore, we grew $Mn_{4-x}Sn_xN$ epitaxial films and evaluated their properties.

[Experiment]

25-nm-thick $Mn_{4-x}Sn_xN$ epitaxial films (x = 0.0–1.4) were fabricated on the MgO(001) substrates by molecular beam epitaxy using radio-frequency nitrogen plasma and solid sources of Mn and Sn. Both the longitudinal and transverse resistivity (ρ_{xx} & ρ_{xy}) were measured with van der Pauw method by a physical property measurement system (Quantum Design) at RT. The obtained ρ_{xy} were divided into ordinary Hall resistivities (ρ_{OH}) and anomalous Hall resistivities (ρ_{AH}). While ρ_{OH} is proportional to the magnetic field, ρ_{AH} is proportional to the magnetization, which saturates under the high magnetic field. Therefore, we eliminated the contribution of ρ_{OH} by the slope of ρ_{xy}-H loops at high field regime to derive ρ_{AH}.

[Results]

Figure 2 shows the ordinary Hall coefficient (R_H) and the anomalous Hall angle (θ_{AH} (= ρ_{AH}/ρ_{xx})) of $Mn_{4-x}Sn_xN$ films as a function of Sn composition, x. The sign of R_H reversed between x=0.4 and 0.5. It suggests that the dominant career-type changed from electrons (R_H < 0) to holes (R_H > 0) with increasing x. We label the composition at which the sign of R_H reversed as x_{cc}. Moreover, the sign reversal of θ_{AH} was observed three times at the composition except x_{cc}, indicating that it was not caused by career-type change. Although similar results were also obtained in Ni-[2], Co-[4] and In-[6] doped Mn_4N, this was the first report that the multiple sign reversals of θ_{AH} were confirmed in Mn_4N-based compounds. The origin of the reversals seems to be the change of magnetic structures such as MC and ferrimagnetic-to-ferromagnetic transition.

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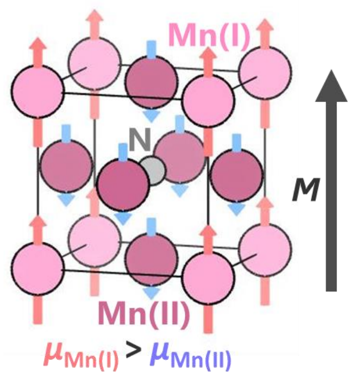

Fig. 1 Schematic images of antiperovskite crystalline and magnetic structure of ferrimagnetic Mn_4N.

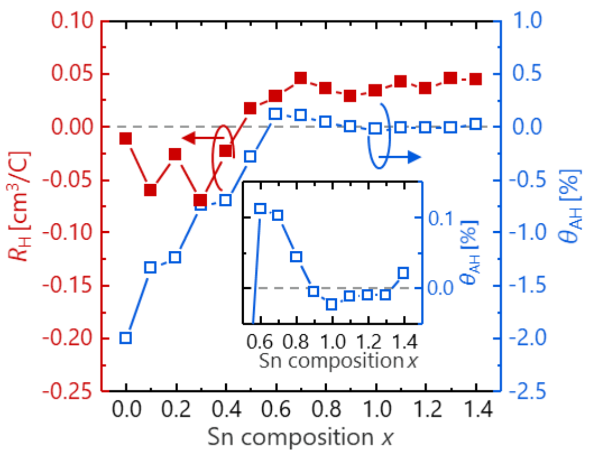

Fig. 2 Ordinary Hall coefficient R_H and anomalous Hall angle θ_{AH} of $Mn_{4-x}Sn_xN$ films. (inset: the enlarged part of θ_{AH} for $x \geq 0.6$.)