Examination of magneto-transport properties in $Mn_{4-x}Ni_xN$ acquired by experiment and ab-initio calculation

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【Introduction】 Mn_4N film is a notable candidate for the domain wall (DW)-motion devices such as non-volatile memory thanks to its perpendicular magnetic anisotropy and small spontaneous magnetization (≃ 80 kA/m)[1]. Our group has recently achieved DW-motion velocity of 900 m/s at the current density of 1.3×10^{12} A/m^2[1], one of the fastest and most efficient among the records on spin transfer torque-driven ones. Also, we found the magnetic compensation occurs in $Mn_{4-x}Ni_xN$ between x = 0.1~0.25[2], around which faster DW-motion is expected with lower power consumption. In our previous work, anisotropic magnetoresistance (AMR) and anomalous Hall effect (AHE) were measured for the deep understanding of the magneto-transport properties of $Mn_{4-x}Ni_xN$ films. In this work, we further pursued the relationship between the results of AMR and AHE. Also, ab-initio calculation for $Mn_{4-x}Ni_xN$ films was performed to acquire P-DOSs.

【Experiment】 $Mn_{4-x}Ni_xN$ samples (30 nm) were fabricated onto $SrTiO_3$(001) substrates by molecular beam epitaxy. AHE and AMR measurements were performed by physical properties measurement system (PPMS). Before measurements, film samples were processed into Hall bars with a width of 200 μm and a length of 3500 μm. DC current flew in [100] azimuth during the measurement. The magnetic field of 9 T was applied parallel to the plane.

【Results and Discussion】 Figure 1 shows the relationship between AHE conductivity (σ_{AHE}) and longitudinal conductivity (σ_{xx}) in $Mn_{4-x}Ni_xN$ (x = 0, 0.05, 0.15, 0.2). Note that these measurements were performed at temperatures (5~300K). σ_{xx} increased as the temperature decreased in all samples, typical metallic property.

The region of $\sigma_{xx} > 10^4$ Ω^{-1}m^{-1} is called *Good metal regime*[3]. In this region, σ_{AHE} is relatively constant relative against σ_{xx}. For samples of x = 0, 0.05, however, σ_{AHE} decreased with increasing σ_{xx} (temperature decreased). We attributed this decrease in σ_{AHE} to the emergence of tetragonal crystalline field confirmed by AMR measurements in our previous work[4]. Note that σ_{AHE} was consistent for x = 0.15 and 0.2, in which the tetragonal crystalline field was not suggested by AMR. This trend led to the conclusion that AHE in these samples under low temperature is dominated by intrinsic one, related to their band structures[3].

The region of $\sigma_{xx} < 10^4$ Ω^{-1}m^{-1} is called *Bad metal regime*[3]. In this region, σ_{AHE} is proportional to $\sigma_{xx}{}^{\alpha}$ (α = 1.4 ~ 1.8). All samples well followed this theory, indicating the origin of AHE is not clear due to a limited number of study in this regime[3]. However, the mixture of intrinsic AHE and enlarged extrinsic AHE due to phonon-scattering at high temperature is the possible answer to this question. The discussion in the results of ab-initio calculation will be talked as well.

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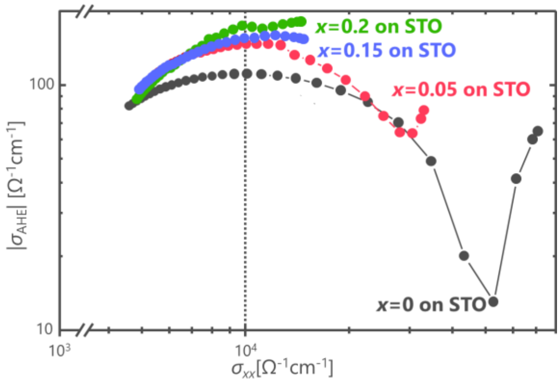

Figure 1. σ_{xx} dependence of σ_{AHE} in $Mn_{4-x}Ni_xN$ at various temperatures. A dashed line indicates the border of Good metal and Bad metal regime.