強磁性金属合金におけるスピン異常ホール効果に関する第一原理計算

A first-principles study on spin anomalous Hall effect of ferromagnetic alloys

物材機構 〇三浦 良雄，名和 憲嗣，増田 啓介

NIMS, °Yoshio Miura, Kenji Nawa, Keisuke Masuda

E-mail: MIURA.Yoshio@nims.go.jp

Current-induced magnetization switching using spin-orbit torque (SOT) [1] has attractive much attention as a promising method for magnetization reversal in spin memory. The SOT is caused by spin current injection to ferromagnetic layers from non-magnetic layer attached to the bottom of the free layer of magnetic junctions due to the spin-Hall effect in nonmagnetic metals. While the SOT-induced switching leads to more efficient magnetization switching, the direction of spin quantum axis of injected electrons related to direction of torque is limited by the geometry of the device. Recently, Taniguchi *et al.*, proposed new type of SOT-induced switching[2,3], in which the non-magnetic layer is replaced by the ferromagnetic layer, and spin current due to spin anomalous Hall effects in the ferromagnetic layer can provide torque to magnetization of ferromagnetic upper layer through the non-magnetic spacer. According to Taniguchi's theory[2], the most important parameter to realize large SOT in ferromagnetic layers is a ratio of spin anomalous Hall conductivity (SAHC) σ_{xy}^{spin} to anomalous Hall conductivity (AHC) σ_{xy}, i.e. $\zeta=\sigma_{xy}^{spin}/\sigma_{xy}$. We investigate and discuss the intrinsic SAHC and AHC by using the firs-principles calculations and the linear response theory.

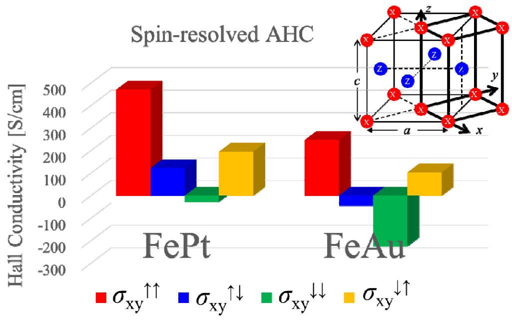

Fig.1: Spin-resolved anomalous Hall conductivity (AHC) of $L1_0$-FePt and FeAu.

We focused on the $L1_0$-type FePt and FeAu alloys. We assumed that the magnetization is directed parallel to the z-axis (*c*-axis), and the charge current flows along *x*-axis, and Hall current flows along *y*-axis. Figure 1 shows the spin-resolved AHC of $L1_0$-FePt and FeAu, where the AHC is given by $\sigma_{xy}=\sigma_{xy}^{\uparrow\uparrow}+\sigma_{xy}^{\downarrow\downarrow}+\sigma_{xy}^{\uparrow\downarrow}+\sigma_{xy}^{\downarrow\uparrow}$ and the SAHC is $\sigma_{xy}^{spin}= \sigma_{xy}^{\uparrow\uparrow}-\sigma_{xy}^{\downarrow\downarrow}$. In Fig. 1, FePt has large AHC σ_{xy}=761[S/cm], and SAHC of FePt is σ_{xy}^{spin}=498[S/cm]. The SAHC is smaller than that of the AHC, leading to the small ζ less than 1. This is attributed to positively large $\sigma_{xy}^{\downarrow\uparrow}$ and negatively small $\sigma_{xy}^{\downarrow\downarrow}$ because of large spin-flip scattering in Hall current of FePt. On the other hand, SAHC of FeAu is σ_{xy}^{spin}=472[S/cm], which is larger than that of the AHC σ_{xy}=79[S/cm], resulting in large ζ=5.9. The large ζ in FeAu is attributed to negatively large $\sigma_{xy}^{\downarrow\downarrow}$ and positively small $\sigma_{xy}^{\downarrow\uparrow}$, resulting from the suppression of spin-flip scattering due to the absence of majority-spin local density of states of Au *d* orbitals of FeAu. This work was supported by Grant-in-Aids for Scientific Research (S) (JP16H06332) from the JSPS.

[1] Miron, *et al.*, Nature **476**, 189 (2011).

[2] Taniguchi, *et al.*, Phys. Rev. Appl. **3**, 044001 (2015).

[3] S. Iihama, *et al.*, Nature electronics **1**, 120-123 (2018).