Detection of vector orientation of magnetic field by a ferromagnetic Fe-Sn device

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With a rapid increase in demand of magnetic-field detection and visualization, various types of magnetometry has been contributed to a board range of application from scientific areas to industry. Among them, three-dimensional detection of the magnetic-field direction is highly demanded for position, angle and rotation detections, which play a key role for industrial and appliance automatization. For realization of three-dimensional magnetic-field sensor, detections of field strength and field direction are necessary to determine the vector orientation of magnetic field. We have demonstrated that the anomalous Hall effect (AHE) of the sputtered Fe-Sn nanocrystalline ferromagnetic films is applicable to detection of the magnetic-field strength owing to a sizeable sensitivity comparable to semiconductor Hall sensors at ambient condition [1,2]. In this study, detection of the field direction was examined in an on-chip Hall-bar device constituted by a SiO_x-capped 4-nm-thick Fe-Sn thin film grown on the Al_2O_3(0001) substrate. The Hall-bar-shaped channels are aligned along azimuthal angles $\phi = 90^o$ (channel 1) and 45^o (channel 2) in the same device plane as shown in Fig. 1(a). In addition to the AHE, we observed anisotropic magnetoresistance (AMR) and unidirectional magnetoresistance (UMR), which can be utilized for detection of in-plane component of the magnetic field (***H***).

The device characterizations were performed by a lock-in technique with a typical modulation frequency (f) of 13 Hz and in a superconducting vector magnet. Figure 1(b) shows Hall resistance R_H^{ω} as a function of the z-component and polar angle (θ) of ***H***. The R_H^{ω} was almost linearly dependent on θ owing to AHE, indicating that the value of θ was uniquely determined. Figures 2(c) and 2(d) show ϕ dependences of first and second harmonic components of the resistance of the channel 2 (R_2^{ω}) and 1 ($R_1^{2\omega}$), which corresponds to AMR and UMR, respectively (Fig. 1(a)). AMR clearly obeyed sinusoidal function $\sin 2\phi$. In contrast, UMR follows $\sin(\phi + 45^o)$, which possesses double period of AMR. Although the amplitude of UMR is as small as in the order of mΩ, the signal output is large enough for determination of polarity [3]. In the talk, we will present independent determination of θ and ϕ using signals of AHE and AMR, and sign of UMR, which evidences an applicability of the ferromagnetic Fe-Sn films for a functional three-dimensional magnetometry. **References** [1] Y. Satake *et al*., Sci. Rep. **9**, 3282 (2019). [2] J. Shiogai *et al*,. Appl. Phys. Express **12**, 123001 (2019). [3] J. Shiogai *et al*., in preparation.

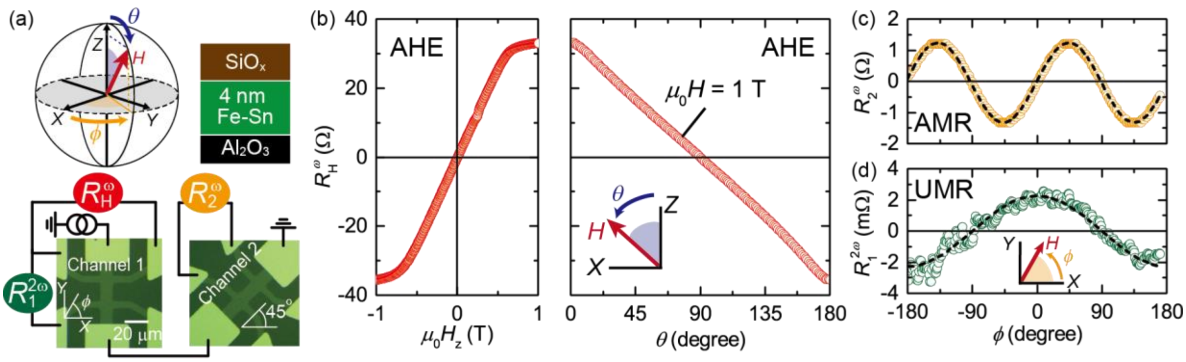

Figure 1 (a) Measurement setup for magnetic field detection by a Fe-Sn nanocrystalline film. (b) Hall resistance (R_H^{ω}) as a function of perpendicular magnetic field (H_z) and polar angle (θ) (c) First and (d) second harmonics signals from longitudinal resistance as a function of an azimuthal angle (ϕ). Dashed lines indicate fits to $\sin 2\phi$ and $\sin(\phi + 45^o)$, respectively.