Realizing oscillation of all-in-plane spin-torque-oscillator for microwave assisted magnetic recording

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Microwave assisted magnetic recording (MAMR) is considered as one of the most promising candidates for next generation higher areal density magnetic recording technology. For MAMR writer, spin torque oscillator (STO) is required that should have a size of 30-40 nm and be able to generate large $\mu_0 H_{ac}$ > 0.1 T with a frequency of 20-30 GHz at a small current density J<1.0×10^8 A/cm^2 [1]. Recently, we have designed and demonstrated so called all-in-plane STO for MAMR that consist of a spin-injection-layer (SIL) and a field-generating-layer (FGL) with a metallic spacer [2,3]. As shown schematically in Fig. 1, electrons are injected from SIL to FGL while the magnetization of the SIL and FGL are saturated to the out-of-plane by the external magnetic field. The main merit of this device over the conventional mag-flip STO is its smaller thickness and potential for reducing the current density required for oscillation [2,3]. However, since both SIL and FGL oscillate during operation of STO, the oscillation behavior of each layer is not well understood. To address this, we employed micromagnetic simulation, *magnum.fe*, and solved the coupled dynamics of magnetization (***m***) and spin accumulations (***s***) simultaneously using the time dependent 3D spin diffusion equations and the Landau Lifshitz Gilbert (LLG) equation, respectively [2]. We considered FeNi as SIL and FeCo as FGL with the same 7 nm thickness separated with 5 nm thick Ag spacer and studied oscillation behavior of each layer [2,3].

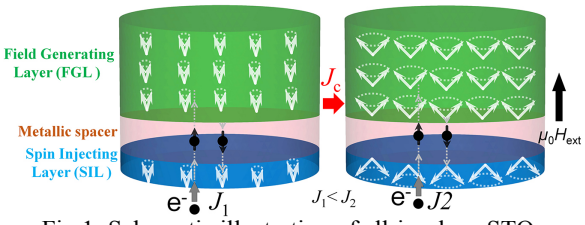

Fig.1: Schematic illustration of all-in-plane STO.

Figure 2(a) shows the calculated resonance frequency (f) versus applied current density (J) at different external magnetic fields, $\mu_0 H_{ext}$ of 0.8 and 1.0 T. f is calculated from the magnetization dynamic of FeCo as FGL (f_{FeCo}) and FeNi as SIL (f_{FeNi}) and compared to f calculated from the change of the device resistance (f_{MR}) during oscillation. A blue shift can be seen in f_{FeCo} upon increase of J while a red shift can be seen in f_{SIL} and f_{MR}. Note that by increasing $\mu_0 H_{ext}$, a larger oscillation frequency can be seen in FGL and SIL. Fig. 2 (b) shows oscillation cone angle for SIL and FGL as a function of J for different $\mu_0 H_{ext}$. OPP mode oscillation in FGL was seen while the magnetization direction of SIL is opposite to $\mu_0 H_{ext}$ and magnetization direction of FGL. By an increasing the external magnetic field, the oscillation cone angle of SIL gets closer to the direction of $\mu_0 H_{ext}$ but with the opposite direction. The reason was found to be increase of spin-transfer-torque in SIL with opposite direction to the external magnetic field. The obtained results will be compared with the oscillation behavior of STO device developed experimentally.

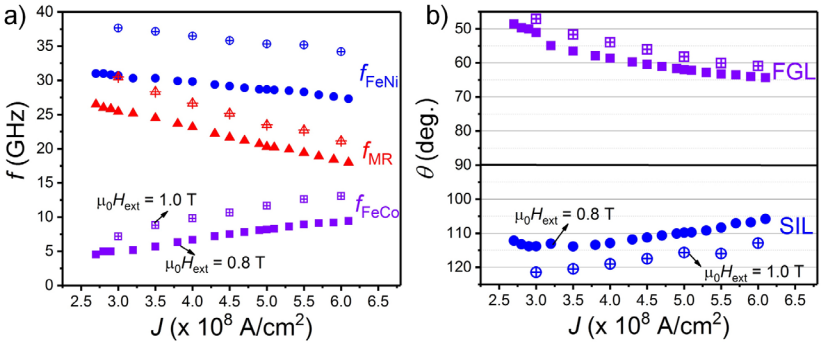

Fig. 2: (a) Oscillation frequency calculated from MR change of STO, and compared to that of magnetization dynamics of FeNi (SIL), FeCo (FGL) for different $\mu_0 H_{ext}$ of 0.8 and 1.0 T versus current density (J). (b) Oscillation cone angle of SIL and FGL versus J for different $\mu_0 H_{ext}$ of 0.8 and 1.0 T.

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[1] A. Takeo et al. Proc. Of the digest of Intermag conference, AD-02, 13M, 2014.

[2] H. Sepehri-Amin *et al.* JMMM 476 (2019) 361-370. [3] W. Zhou *et al.* Appl. Phys. Lett. **114** (2019) 172403.