Design and development of all-in-plane spin-torque-oscillator for microwave assisted magnetic recording

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Microwave assisted magnetic recording (MAMR) is a promising technology to overcome the stagnated areal density increase of hard disk drives. However, its most essential part, spin-torque-oscillator (STO) specific to the MAMR application, has not been established. The STO device for MAMR should have a diameter smaller than 40 nm, total thickness smaller than 25 nm, and a capability to generate large magnetic flux, μ_0H_{ac} > 0.1 T, with a frequency over 20 GHz at a small current density J<1.0×10^8 A/cm^2 [1]. We have recently demonstrated experimentally mag-flip STO, that can oscillate with resonance frequency of 21-25.5 GHz and produce an μ_0H_{ac} of 0.15 T [2,3]. However, the main disadvantage of the mag-flip STO is its large thickness due to the need for ~10 nm out-of-plane magnetized FePt. In addition, the required J for oscillation of mag-flip STO is over 4.3 × 10^8 A/cm^2 that needs to be substantially reduced for the practical application [3]. In this study, we numerically demonstrate the potential of the all-in-plane STO, which composes in-plain magnetized spin-injection layer (SIL) and field-generating layer (FGL), that can possess smaller thickness and driving current density compared to the mag-flip STO.

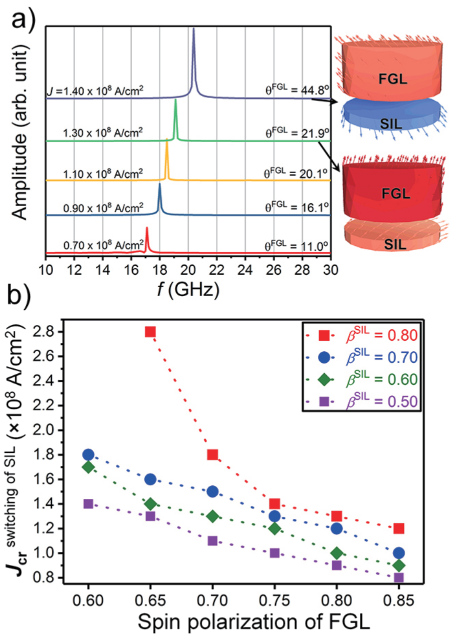

Figure 1: (a) RF spectrums calculated from $\boldsymbol{M}_x$ oscillation of FGL for β^{SIL} = 0.80 and β^{FGL} = 0.75 for different J. The oscillation cone angle of FGL is also shown. (b) Critical current density required for the magnetization switching of SIL as a function of β^{FGL} and varied β^{SIL}.

Micromagnetic simulations showed that the magnetization direction of SIL can be switched to the opposite direction to that of the applied external magnetic field by use of spin-transfer-torque that results in oscillation of FGL with a large cone angle at a reduced J. An example is shown in Fig. 1 (a) in which when the current density increases from 1.3×10^8 A/cm^2 to 1.4×10^8 A/cm^2, magnetization of SIL switches opposite to the applied magnetic field direction. Thereafter, increase of resonance frequency to 20GHz and increase of oscillation cone angle to ~45^o. We designed SIL to reduce the critical current density, J_{cr}, required for the magnetization switching of SIL. The materials with a smaller μ_0M_s and spin polarization (β) in SIL results in reduction of J_{cr} and enables STO to oscillate with frequency of above 20 GHz with a large out-of-plane oscillation cone angle of 45-50^o. The validity of this finding was studied experimentally by developing STO with different SIL materials; Heusler $Co_2Fe(Al_{0.5}Si_{0.5})$ and $Fe_{67}Co_{33}$. The former showed B2 crystal structure with a large spin polarization and latter has A2 crystal structure with smaller spin polarization. The magnetization configuration of SIL and FGL in STO with ~60 nm diameter is investigated experimentally based on the field dependent resistance change measured at room temperature and low temperature and discussed based on the micromagnetic simulations. We also found that large β of FGL is beneficial to reduce J_{cr} as shown in Fig. 1 (b). We studied the underlying physics for this based on the spin accumulation in SIL for different spin polarization of FGL. By increase of β^{FGL}, more reflected spins from FGL/Ag interface toward to SIL layer with opposite direction to the magnetization of SIL was realized that will be beneficial for magnetization switching of SIL. We will discuss how the magnetization switching of SIL lead to an increase of oscillation cone angle of FGL, reduction of J for oscillation of STO, and an increase of oscillation frequency.

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References: [1] Takeo A. *et al.*, Intermag Conference 2014 (AD-02). [2] Bosu S. *et al.,* Appl. Phys. Lett. **108**,072403 (2016). [3] Bosu S. *et al.,* Appl. Phys. Lett. **108**,072403 (2017).