DESIGN AND DEVELOPMENT OF SPIN-TORQUE-OSCILLATOR FOR MICROWAVE ASSISTED MAGNETIC RECORDING

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I. Introduction

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), has not been realized. The STO device for MAMR should have a size of 30-40 nm and be able to generate large $\mu_0 H_{ac} > 0.1$ T with a frequency over 20 GHz at a small current density $J < 1.0\times10^8$ A/cm^2 [1]. In addition, large oscillation cone angle of free layer is desired to maximize the $\mu_0 H_{ac}$. Such a device has not been realized experimentally due to the lack of fundamental understandings on the desired materials and structure of the STO. We have combined micromagnetic simulations to propose the desired material/design of STO for MAMR. The designed STO is developed and analyzed experimentally [2,3]. In this talk, we will first address how we developed STO device with size of below 40 nm that can oscillate OOP with frequency of over 20 GHz and large H_{ac} over 0.1 T. Thereafter, we will present desired material parameters to develop all-in-plane mag-flip STO.

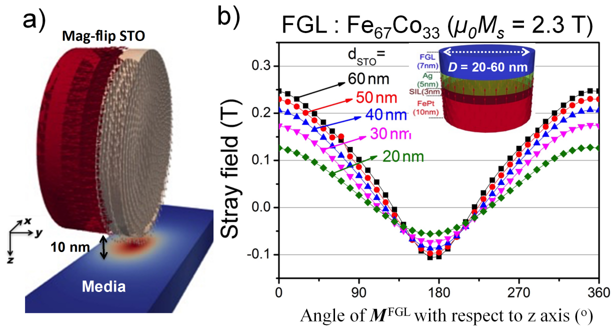

Figure 1: (a) Schematic illustration of STO and perpendicular recording media setup for ac field calculation $\mu_0 H_{ac}$, (b) calculated stray field distributions from STO's with different sizes, D = 20 to 60 nm.

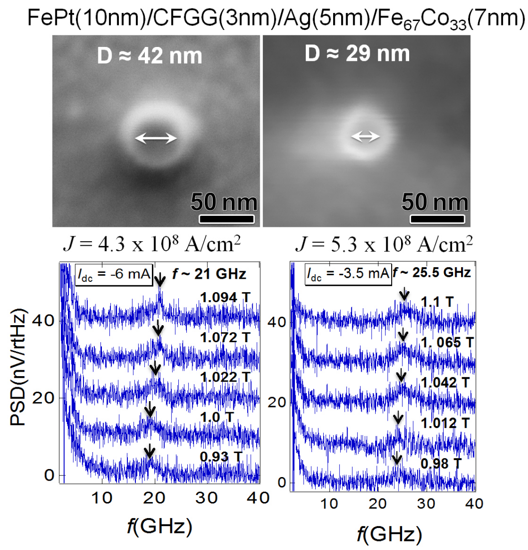

Figure 2: SEM image from two different STO device with $Co_2FeGa_{0.5}Ge_{0.5}$ SIL and $Fe_{67}Co_{33}$ FGL with diameters of 42 and 29 nm and corresponding rf power spectrum obtained at $J = 4.3\times10^8$ and 5.3×10^8 A/cm^2, respectively. Applied $\mu_0 H_{ext}$ at tilting angle $\theta_H \sim$ 4-5° are shown in each spectrum. $f \sim 21$ GHz and $f \sim 25.5$ GHz has been observed for $D = 42$ nm and $D = 29$ nm, respectively at $\mu_0 H_{ext} \sim 1.1$ T.

II. Experimental procedure and purpose of the study

We employed a micromagnetic simulation code, *magnum.fe*, which solves 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 [4]. This will allow us to directly simulate the effect of locally varying spin accumulations on the magnetization dynamics. We first designed the required materials for a mag-flip STO device. Mag-flip STO device consists of out-of-plane magnetized spin injecting layer (SIL) and in-plane magnetized field generating layer (FGL). We have shown that use of high spin polarized materials such as half metallic Heusler alloys in SIL is necessary to reduce bias current density required for oscillation of FGL [2]. However, developed device had large size of ~ 60nm, not suitable for MAMR. In this work, we designed the STO that can produce large H_{ac} with size of smaller than 40nm. The designed STO device was developed experimentally and oscillation behavior was studied by measuring the power spectra using a spectrum analyzer for the frequency range from 1 to 40 GHz. In order to reduce total thickness of the STO

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device, we also designed materials for another type of STO device, all in-plane mag-flip STO device, consisting in-plane magnetization SIL and FGL, that can generate large $\mu_0 H_{ac}$ with a frequency over 20 GHz in a small bias current density.

III. Results and discussion

Figure 1 shows calculated stray field produced from an STO device located 10nm far from center of perpendicular recording media. The STO device has $Fe_{67}Co_{33}$ as FGL with $\mu_0 M_s \sim 2.3$ T. The stray field from this STO is shown in Fig. 1(b) for diameters of ~ 20 to 60 nm. $\mu_0 H_{ac}$ varies from 0.12 T for $D \sim 20$ nm to 0.25 T for $D \sim 60$ nm when the angle of OPP mode is considered its maximum, i.e, $\varphi = 90°$. Therefore, as of requirement for MAMR, $Fe_{67}Co_{33}$ FGL with even D ~30 to 40 nm could generate substantially large $\mu_0 H_{ac} \sim 0.15$ to 0.2 T. Figure 2 shows SEM images of developed STO devices with diameters of ~42 and 29 nm. These mag-flip STO contain $Co_2FeGa_{0.5}Ge_{0.5}$ (CFGG) SIL to reduce the bias current density required for oscillation [2]. $Fe_{67}Co_{33}$ was used as FGL. The rf power spectrums obtained at applied external magnetic fields of ~1.0 T, shown in Fig. 2, indicates that these devices can oscillate with $f \sim 21$ and 25.5 GHz around $\mu_0 H_{ext} \sim 1.1$ T for D~ 42 and 29 nm, respectively. However, required current density for these oscillations *are* still higher than the requirements for practical MAMR, which could be reduced by improving the chemical ordering as well as spin polarization of SIL. Nevertheless, increase of spin polarization of 3nm thick SIL is one challenge. Recently, Zhu et al. proposed by all-in-plane mag-flip STO, one can reduce the critical current density for oscillation [5]. We designed the optimum materials parameters for all-in-plane mag-flip STO device that can result in reduced current density for out-of-plane oscillation. Figure 3 (a) shows our designed all-in-plane mag-flip STO device consisting a thin SIL and 14nm thick FGL. Electrons are pumped from bottom to top and due to the reflection of electrons from FGL/Ag, the SIL switches and transmitted down-spin electrons lead to oscillation of FGL. Unlike the conventional mag-flip STO device, we found that the spin polarization of FGL play very important role in J_c required for switching of SIL and OOP oscillation of FGL. As shown in Fig. 3, by increase of spin polarization of FGL, J_c can be substantially reduced. The underlying mechanism is shown in Fig. 4. Fig. 4 (a) shows the STO device and 3D spin accumulation in Z direction in the model when all the layers are magnetized OOP under 1 T external magnetic field. Fig. 4 (b) shows distribution of $\boldsymbol{S}_z$ from SIL toward FGL for different spin polarization of FGL. It was found that by increase of β^{FGL}, we get more reflected down spins from FGL/Ag interface that will be beneficial for switching of SIL and OOP oscillation of FGL, resulting in smaller J_c. In this talk, we will introduce optimum material parameters for SIL and FGL that can minimize bias current density for OOP oscillation of FGL. In addition, we will introduce our recent experimental results on development of all-in-plane mag-flip STO device.

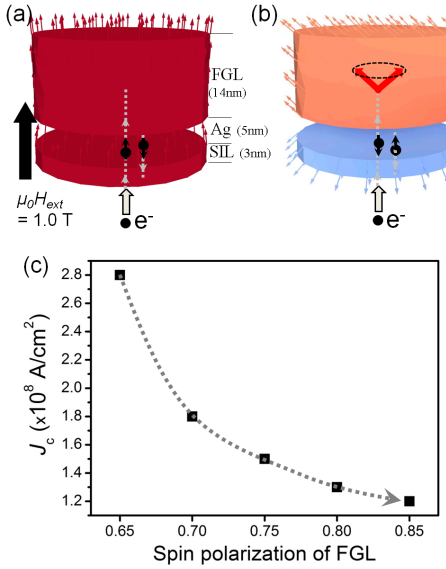

Figure 3: (a) and (b) Schematic illustration of all-in-plane mag-flip STO and OOP oscillation of FGL while magnetization of SIL is switched, (b) calculated critical current density for switching of SIL and OOP oscillation of FGL versus spin polarization of FGL.

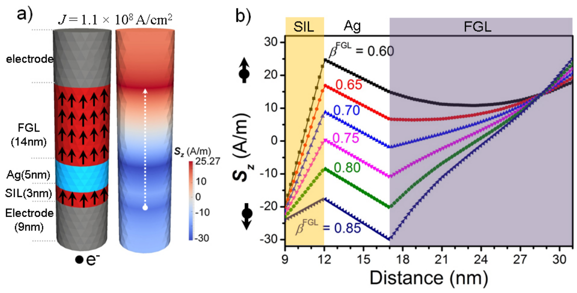

Figure 4: (a) All-in-plane mag-flip STO device magnetized OOP upon applying 1T external magnetic field and spin accumulation in Z direction ($\boldsymbol{S}_z$) for J = 1.1×10^8 A/cm^2(b) calculated line contour of $\boldsymbol{S}_z$ from SIL toward FGL for different spin polarization of FGL.

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