Relation between Emission Power and Diameter of Spin Torque Oscillator: Micromagnetic Simulation Study

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Introduction

The spin torque oscillators (STOs) are considered as the important devices, because the STOs are expected to be applied in many fields, such as a microwave generator or a magnetic field sensor. Therefore, the development of the STOs with the high emission power and the high Q-factor is in high demand. It has, however, been reported that the emission power of a nano-pillar STO reaches to maximum around 300nm in the diameter [1]. Wang *et al.* have speculated that the frequency of each magnetization oscillation of the free layer is same but the phase of that is different above 300nm in the diameter, which decreases the emission power of the STOs. To elucidate this phenomenon, it is important to study the spatial magnetization dynamics of the STOs which show the decrease in the emission power at the large diameter.

Method

To investigate the mechanism of the decrease in the emission power, we analyze the STOs which have various diameters, by using micromagnetic simulations. The schematic picture of the model of STOs is shown in Fig. 1. To consider the current induced spin transfer torque effect, the magnetization dynamics is described by the Landau-Lifshitz-Gilbert-Slonczewski equation [2]:

$$\frac{\partial \boldsymbol{M}}{\partial t} = -\frac{\gamma}{1+\alpha^2}\boldsymbol{M}\times\left(\boldsymbol{H}_{eff} + H_s\alpha\boldsymbol{p}\right) - \frac{\gamma}{1+\alpha^2}\frac{1}{M_s}\boldsymbol{M}\times\boldsymbol{M}\times\left(\alpha\boldsymbol{H}_{eff} - H_s\boldsymbol{p}\right),$$

where $\boldsymbol{M}, \gamma, \alpha, \boldsymbol{H}_{eff}, \boldsymbol{p}, M_s$ are the magnetization vector, the gyro magnetic constant, the damping constant, the effective field, the unit vector of magnetization of the reference layer and the saturation magnetization respectively. Here, H_s is the strength of the spin torque: $H_s = p_0\hbar J\{2e\delta(M_s - \lambda\boldsymbol{M}\times\boldsymbol{p})\}^{-1}$,where $p_0, \hbar, J, e, \delta, \lambda$ are the spin polarization factor, the reduced Plank constant, the current density, the elementary charge, the thickness of the layer, and the angle coefficient respectively.

Simulation Results

Fig. 2 shows the relation between the diameter of the STOs and the emission power obtained by the simulations. These results indicate that the peak of the emission power exists around 300nm in diameter. This is consistent with the reported experimental results [1]. Fig. 3 shows the snapshot of magnetization states in the models, diameters of which are 200nm and 400nm respectively. In 200nm, although magnetization state is different between the center region and the edge region, the magnetization dynamics is relatively coherent. In contrast, the magnetization dynamics in the diameter of 400nm is rather chaotic. We will address the mechanism which causes such degradation of the emission power and the physical properties which enhance the emission power.

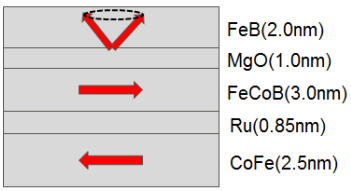

Fig. 1. Simulation model of STO. The red arrows show the schematic dynamics of magnetization during the oscillation.

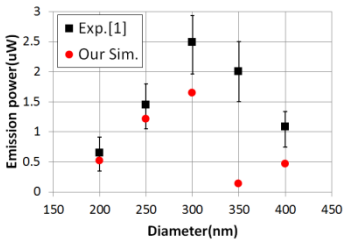

Fig. 2. Relation between the diameter and the emission power. The red circles and black squares show our simulation results and experimental results obtained by [1], respectively.

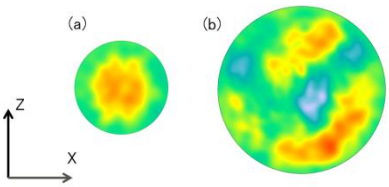

Fig. 3. Magnetization states of the FeB layer whose diameter is (a) 200nm and (b) 400nm respectively. The color indicates the value of the X component of the magnetization vectors.

References

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[2] T. Taniguchi, *et al.* Appl. Phys. Express (2013)