Experimental Study on Microwave-Assisted Magnetization Switching: Circularly Polarized Microwave Field and Varying-Frequency Microwave Field

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I. Background

Applying a microwave magnetic field to a magnet induces FMR excitation, and when this excitation is large enough, it can decrease the switching field. This switching scheme is called microwave-assisted magnetization switching (MAS) and attracts attention for its applications in next-generation magnetic recording such as microwave-assisted magnetic recording and three-dimensional magnetic recording. [1-4] The difficulty of generating a microwave field can be solved by employing a spin-torque oscillator (STO). The STO is a nanodevice, and the one with dimensions less than 30 nm has been reported. [5] By applying a dc current to the STO, the STO magnetization oscillates and generates a microwave field (stray field from the oscillating STO magnetization). This microwave field is confined near the STO, which is beneficial for manipulating magnetization in the nanoscale. In this presentation, for the implementation of the magnetic recording based on MAS, we investigate MAS focusing on two topics: circularly polarized microwave field and varying-frequency microwave field.

II Microwave-assisted magnetization switching in a circularly polarized microwave field

In order to understand MAS, the polarization of the microwave field, e.g. linear polarization (LP) where the field direction alternates in one direction and circular polarization (CP) where it rotates, must be considered. This is because FMR is a precessional motion of the magnetization and is most efficiently induced by a CP microwave field that rotates in the same rotation direction as the natural precession of the magnetization. The microwave field polarization is also important in applications using an STO because the polarization of the microwave field from the STO strongly depends on the oscillation trajectory of the STO magnetization. Here, we investigate MAS behavior of a Co/Pt multilayer perpendicular magnetic nanodot with a diameter of 50 nm in a microwave field with various polarizations. Figure 1 shows the measurement setup. We use a microwave field generated by introducing a microwave signal to the coplanar waveguide (CPW) because the frequency and the amplitude of the microwave field can be easily controlled. The sample has two CPWs crossing at a right angle above the nanomagnet. By introducing microwave signals with a tunable delay to the CPWs, microwave fields with a linear, elliptical, and circular polarization can be generated. Switching of the nanomagnet is detected by the anomalous Hall effect.

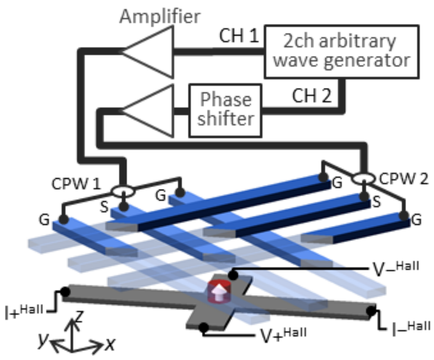

Fig. 1. Experimental setup.

Figure 2 (a) shows the dependence of the switching field on the delay phase between the microwave signals introduced to the two CPWs. When the delay phase is around 90°, the CPWs generate a CP microwave field rotating clockwise in the x-y plane. This microwave field reduces the switching field only when the nanomagnet reverses from the $-z$ to $+z$ direction because the rotation directions of the microwave field and the magnetization precession coincide. At around 270°, the microwave field rotates in the opposite direction and MAS occurs only when the nanomagnet reverses from the $+z$ to $-z$ direction. Next, we fix the phase delay to 90° to examine MAS in a CP microwave field. Figure 2(b) shows the dependence of the switching field on the microwave field frequency. The switching field decreases almost linearly with increasing the frequency and suddenly increases to the value without MAS. This kind of switching behavior is typical of MAS. [3] A large switching field decrease from 7.1 kOe to 1.5 kOe is demonstrated. In comparison with MAS in an LP microwave field, a CP microwave field induces the same MAS effect with half the microwave field amplitude (data not shown), thereby showing that a CP microwave field is efficient in MAS.

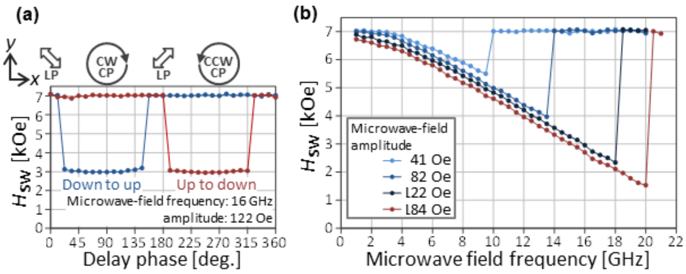

Fig. 2. (a) Switching field versus delay phase of the signal in CPW 1 with respect to that in CPW 2. (b) Switching field versus microwave field frequency in the CP microwave fields from CPWs 1 and 2.

III Microwave-assisted magnetization switching in a varying-frequency microwave field

The FMR frequency of a magnet is not constant but varies with the magnetization trajectory because of nonlinearity. When the magnet has a perpendicular anisotropy, the FMR frequency decreases as the FMR excitation evolves. This suggests that applying a microwave field with time-varying (decreasing) frequency induces larger FMR excitation because the frequency follows the varying FMR frequency, which is expected to enhance MAS effect. Recently, the use of varying-frequency microwave field was suggested by a micromagnetic simulation study, which reported that, in a certain configuration, an STO spontaneously changes its frequency to match the FMR frequency of a magnet because of the mutual stray fields. [6] Here, we investigate MAS in a varying-frequency microwave field. The experimental setup is similar to that shown in Fig. 1 except that only one CPW is used to generate an LP microwave field and that the anisotropy of the nanomagnet is smaller.

Figures 3(a) shows the dependence of the switching field on the microwave field frequency for constant-frequency MAS (CF-MAS). Switching behavior typical to MAS is obtained. Figures 3(b) shows the result for varying-frequency MAS (VF-MAS). The horizontal axis is the start frequency of the microwave field, and the frequency gradually changes to 0.02 GHz over a 10 ns time period. VF-MAS differs from CF-MAS in the following two aspects. (1) VF-MAS can achieve smaller switching field with the same microwave field amplitude, thereby showing that a varying-frequency microwave field enhances MAS effect. (2) After the abrupt increase, switching field becomes almost same as the minimum switching field of CF- MAS, which differs from CF-MAS where switching field increases to the value without MAS. The latter can be explained as follows. As the start frequency increases, the frequency changes at a higher rate, and when the magnetization excitation cannot follow the frequency change, the enhancement of MAS by a varying-frequency microwave field no longer occurs. When the enhancement disappears, switching occurs in the same manner as CF-MAS when the frequency decreases and matches the frequency at which CF-MAS occurs. Therefore, switching field becomes almost same as the minimum switching field of CF-MAS.

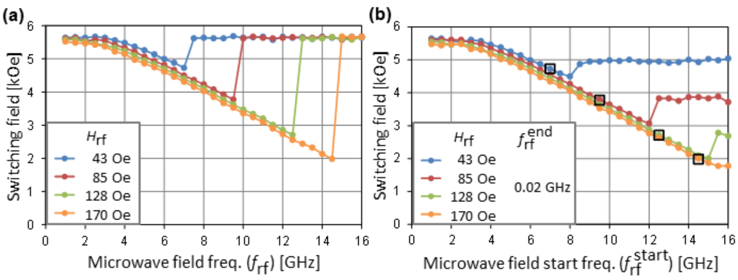

Fig. 3. (a) Switching field versus microwave field frequency for CF-MAS. (b) Switching field versus microwave field start frequency for VF-MAS. Open squares are the maximum microwave field frequency at which CF-MAS occurs, and corresponding switching field.

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