EXPERIMENTAL STUDY ON MICROWAVE-ASSISTED MAGNETIZATION SWITCHING: EFFECT OF MICROWAVE-FIELD POLARIZATION AND SUBNANOSECOND SWITCHING

H. Suto, T. Kanao, T. Nagasawa, K. Mizushima, and R. Sato
Corporate Research & Development Center, Toshiba Corporation, Kawasaki, Japan.
hirofumi.suto@toshiba.co.jp

I. BACKGROUND

Applying a microwave magnetic field to a magnet induces ferromagnetic resonance (FMR) excitation, which can decrease the switching field [1-4]. This switching scheme is called microwave-assisted magnetization switching (MAS) and attracts attention as a writing method in next-generation magnetic recordings such as microwave-assisted magnetic recording (MAMR) and three-dimensional (3D) magnetic recording. In MAMR, a microwave field induces excitation of media magnetization, which enables writing to a high-anisotropy media material required for high-density recording [2,3]. In 3D recording, multiple recording layers are stacked to increase the recording density. By designing each recording layer to have a different FMR frequency and by controlling the microwave-field frequency, magnetization excitation can be induced selectively in a target recording layer, which enables layer-selective writing by MAS [3,4]. When designing recording devices that utilize MAS, we must consider the frequency of the microwave field because FMR is a resonance phenomenon, and previous experimental studies have revealed the dependence of MAS on the microwave-field frequency [3]. In addition to the frequency, 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 magnetization precession. However, it has not yet been experimentally studied how the polarization affects MAS behavior. Other than these microwave-field properties, the timescale of MAS is practically crucial because it determines the writing rate. During MAS, magnetization excitation gradually grows until it reaches the amplitude required for switching; therefore a microwave field must be applied for a certain period of time. However, this timescale of MAS has not yet been studied, either. In this study, we report MAS of a nanomagnet with perpendicular magnetic anisotropy focusing on the microwave-field polarization and the timescale of MAS.

II. EXPERIMENTAL

Figure 1 shows the sample structure and the measurement setup. Switching of a perpendicularly magnetized nanomagnet with a 50 nm diameter is studied by applying a *z*-direction dc magnetic field and a microwave field. The microwave field is generated by introducing microwave signals to two CPWs that cross at a right angle above the nanomagnet. The microwave-field polarization is controlled by the phase delay between the two signals. When no microwave field is applied, the switching *z*-direction magnetic field (H_{sw}) of the nanomagnet is 7.1 kOe.

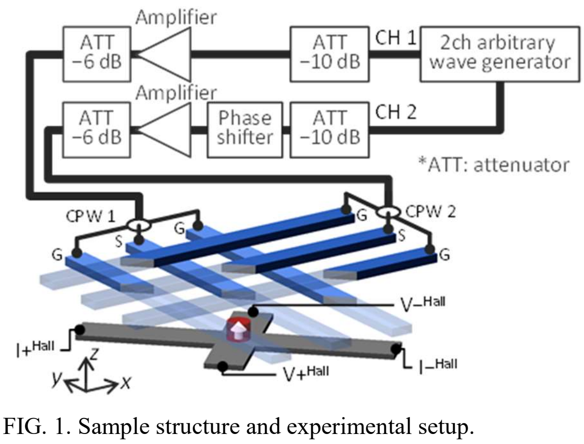

FIG. 1. Sample structure and experimental setup.

III. RESULTS AND DISCUSSION

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 circularly

Hirofumi SUTO

hirofumi.suto@toshiba.co.jp

polarized microwave field rotating clockwise in the *x*-*y* plane. This microwave field reduces the switching field only when the nanomagnet reverses from the down to up direction because the rotation directions of the microwave field and the magnetization precession coincide. At around 270°, the microwave field changes the rotation direction and MAS occurs only when the nanomagnet reverses in the opposite way.

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. H_{sw} decreases almost linearly with increasing the frequency and suddenly increases after the minimum, which is typical of MAS. 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). This result is consistent with the fact that an LP microwave field is the sum of two CP microwave fields that respectively rotate clockwise and counterclockwise and have half the field amplitude.

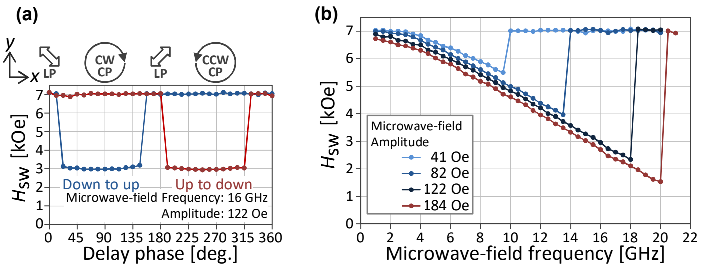

FIG. 2. (a) H_{sw} versus delay phase of the signal in CPW 1 with respect to that in CPW 2. Schematics above the plot depict the polarization of the generated microwave field. (b) H_{sw} versus microwave-field frequency in CP microwave fields.

Figure 3 shows the dependence of H_{sw} on the microwave-field duration. For 10 GHz to 18 GHz, H_{sw} is almost the same when the duration is equal to or larger than 0.5 ns showing that the FMR excitation saturates within this time scale. When the duration is smaller than 0.5 ns, H_{sw} increases gradually because the FMR excitation is still developing on this time scale. However, a large MAS effect still occurs for this short microwave field. When the duration is 0.1 ns (0.2 ns for 16 GHz), H_{sw} increases steeply and almost no MAS effect appears. For 20 GHz, which corresponds to the minimum H_{sw}, it takes 0.5 ns for the FMR excitation to become sufficient for MAS, which is slightly longer than other frequencies.

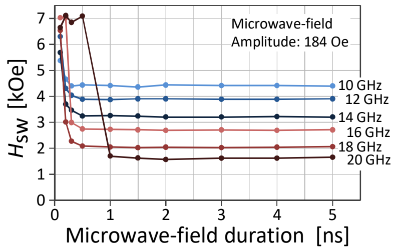

FIG. 3. H_{sw} versus microwave-field duration in CP microwave fields.

It was shown that MAS occurs when the rotation direction of the CP microwave field matches with that of the FMR precession of the nanomagnet. This result indicates that the microwave field polarization must be considered when MAS-based recording devices are designed. A large MAS effect from 7.1 kOe to 1.5 kOe was demonstrated showing that MAS is an effective method to write to a high-anisotropy media material. MAS was induced by a microwave field with a duration of 0.3 ns showing that a high writing rate can be achieved.

REFERENCES

[1] C. Thirion, W. Wernsdorfer, and D. Mailly, Nature Mater. **2**, 524 (2003).

[2] J.-G. Zhu, X. Zhu, and Y. Tang, IEEE Trans. Magn. **44**, 125 (2008).

[3] S. Okamoto, N. Kikuchi, M. Furuta, O. Kitakami, and T. Shimatsu, J. Phys. D: Appl. Phys. **48**, 353001 (2015).

[4] H. Suto, T. Nagasawa, K. Kudo, T. Kanao, K. Mizushima, and R. Sato, Phys. Rev. Appl. **5**, 014003 (2016).

This work is supported by Strategic Promotion of Innovative Research and Development from Japan Science and Technology Agency, JST.