3D MAGNETIC RECORDING BASED ON MAMR TECHNOLOGY

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I. BACKGROUND

Conventionally, hard disk drives (HDDs) store data in 2D pattern of the magnetization direction in magnetic recording media. To increase the recording density beyond the limit of 2D, 3D magnetic recording that uses a media with multiple recording layers will be required. In response to this situation, we have proposed and been working on 3D magnetic recording based on ferromagnetic resonance (FMR) excitation in a microwave field [1-6]. When each of multiple recording layers is designed to have a different FMR frequency, FMR excitation can be induced in a specific recording layer by tuning the frequency of the applied microwave field, and this FMR excitation can be utilized for layer-selective read/write operations. Our 3D magnetic recording is compatible with the structure of conventional HDDs consisting of a spinning recording medium and a flying head element. The major challenge, however, is how to generate a microwave field from a head element. This issue can be solved by employing microwave-assisted magnetic recording (MAMR) technology. MAMR uses a microwave field in inducing FMR excitation of the media magnetization to write in a high-anisotropy media material and has been extensively studied as a candidate writing method for next-generation 2D magnetic recording.

II. LAYER-SELECTIVE WRITING BASED ON MAMR

Figure 1(a) shows a schematic of layer-selective writing based on MAMR technology. A write head element has a spin-torque oscillator (STO) integrated in the gap between the write pole and the trailing shield. By applying a current to the STO, the STO magnetization oscillates and generates a microwave field. Note that this microwave field is a stray field from the oscillating STO magnetization and confined near the STO. No electromagnetic radiation is involved. Each recording layer consists of antiferromagnetically coupled (AFC) two magnetic layers (soft layer and hard layer) having a different perpendicular magnetic anisotropy (PMA). The AFC strength and PMAs are designed as follows. The soft layer has a PMA low enough to realize a spontaneous antiferromagnetic configuration in the remanent state, and the hard layer has a PMA high enough to ensure thermal stability. By employing the AFC structure, the dipolar interaction between the recording layers can be suppressed. Switching of the hard layer is induced by the head field and microwave field. After that, switching of the soft layer occurs spontaneously to make an AFC configuration. Switching behavior in a microwave field has been studied, and it has been shown that switching field decreases almost linearly as microwave-field frequency increases and abruptly increases at a critical frequency. Figure 1(b) schematically shows switching condition when the hard layer of three recording layer has a different FMR frequency, which suggests that layer-selective switching is possible by tuning microwave-field frequency.

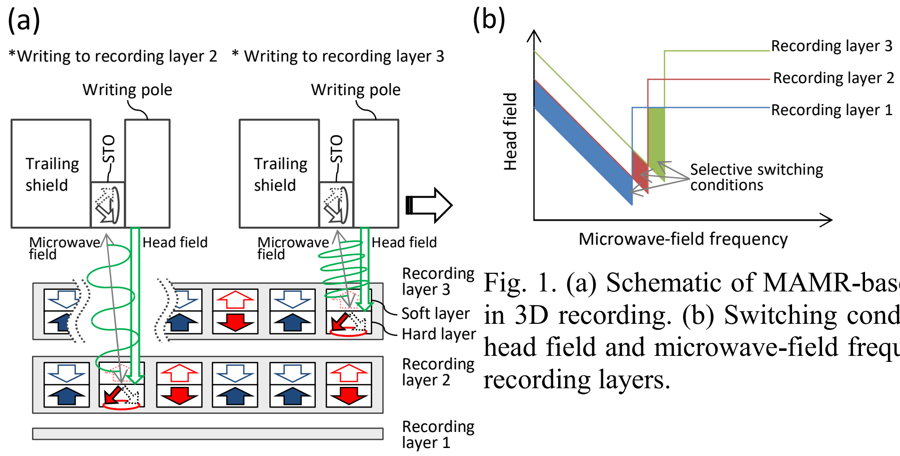

Fig. 1. (a) Schematic of MAMR-based layer-selective writing in 3D recording. (b) Switching condition as a function of the head field and microwave-field frequency in the case of three recording layers.

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III. READING BASED ON INTERACTION BETWEEN MEDIA MAGNETIZAION AND STO

Figure 2(a) shows a schematic of reading based on interaction between media magnetization and an STO. When the STO comes close to a recording magnetization (RM) in the media, they interact through microwave stray field, and magnetization oscillation is resonantly excited in the RM when the oscillation frequency of the STO is close to the FMR frequency of the soft layer. Different from the case of writing, this excitation does not induce switching but leads to a change in magnetization oscillation of the STO, which is used to read magnetization direction in RM. Because this method is based on FMR excitation and does not require a static stray field, it is applicable in 3D magnetic recording, and a recording layer can be selected by FMR frequency. Here, to investigate basic aspects of this method, readout from a sequence of single-layer 6 RM with staggered magnetization configuration is demonstrated by using a micromagnetic simulation. The oscillation frequency of the STO is set near to the FMR frequency of the soft layer with downward magnetization direction (down state). Figure 2(b) shows y-components of magnetizations as a function of time. That of the STO corresponds to a readout signal since the magnetization of the STO fixed layer is directed in y-direction. When the STO comes near to RM in down state, the magnetization oscillation of RM is excited, and the amplitude of STO oscillation is decreased owing to increased effective damping. On the other hand, when the STO is near RM in up state, the magnetization of RM is excited little, and the STO oscillation amplitude recovers. The changes of the STO oscillation occur in a few nanoseconds. By detecting these differences of oscillation change, the magnetization direction of RM can be distinguished.

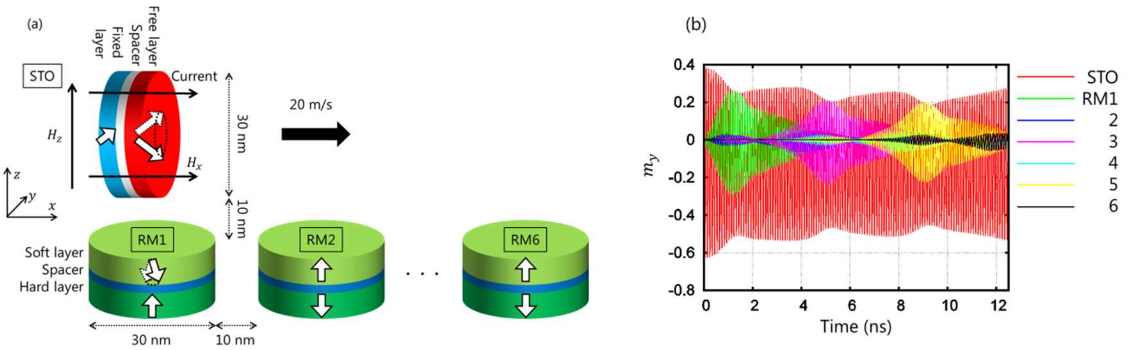

Fig. 2 (a) Schematic of reading based on interaction between recording magnetization (RM) and spin-torque oscillator (STO). At 0 ns, the STO is placed with its right surface at 10 nm left from the left edge of the first RM and moves rightward at a velocity of 20 m/s. (b) y-components of magnetizations as a function of time.

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