Effect of Transmitted Spin from Head Poles in MAMR

Ikuya Tagawa

Electrical and Electronic Engineering, Tohoku Institute of Technology, 3-1 Yagiyama-Kasumicho, Sendai 982-8577, Japan

In microwave assisted magnetic recording (MAMR), it is still a challenge to obtain stable oscillation of magnetization in the spin torque oscillator (STO). In this paper we point out that one possible problem in practical MAMR heads is oscillation disturbance by transmitted spins from the head poles, i.e. the main pole and trailing shield, and also discuss the requirements for good STO oscillation. We propose structure design candidates with a short spin-diffusion length material and with a negative spin-polarization material to obtain a larger microwave assist field generated from the STO using micromagnetics simulation.

Key words: microwave assisted magnetic recording, spin torque oscillator, spin diffusion length, negative polarization, micromagnetics simulation

1. Introduction

Microwave assisted magnetic recording (MAMR) is one of the most promising technologies for next-generation hard disk drives (HDD) \(^1\),\(^2\), Western Digital and Toshiba have made encouraging announcements on their introduction plans of MAMR into production-level HDD within this or next year \(^4\),\(^5\).

In MAMR, a high frequency assist field from a spin-torque oscillator (STO) in the write gap of a recording head is utilized to reduce the magnetization switching field of the recording medium. Since uniform and stable oscillation of the magnetization is one of the most important factors for the STO in MAMR, there are many papers discussing material and shape design of the STO itself \(^6\),\(^7\). In contrast, there is probably no paper discussing the effect of the transmitted spin between the STO and the head main pole or between the STO and the head trailing shield. In this paper, we focus on the impact of these spins.

2. Modeling

A commercial micromagnetics software (Fujitsu Examag v2.1) is used, in which the Landau-Lifshitz-Gilbert (LLG) equation (1) with the spin transfer torque term (2,3) is solved.

\[
(1 + \alpha^2) \frac{dM}{dt} = -M \times (H + \gamma H_{ST}) - \frac{\gamma}{M_s} M \times [M \times (\alpha H - H_{ST})] \tag{1}
\]

Transmitted ST: \(H_{ST} = \frac{hP \beta}{2eM_s \delta} (1 - Pm)(1 - P'm) \tag{2}\)

Reflected ST: \(H_{ST} = \frac{hP \beta}{2eM_s \delta} (1 - Pm)(-1 + P'm) \tag{3}\)

Here, \(\alpha, \gamma, P, h, J, e, M_s, \) and \(\delta\) are the damping constant, gyromagnetic factor, spin polarization, Dirac constant, spin-injection current density, electron charge, saturation magnetization, and calculation cell thickness, respectively. The effective field due to spin transfer torque is calculated as \(H_{ST}\), where \(m\) is a unit magnetization vector, and \(m'\) and \(m\) mean the polarization and the magnetization in the adjacent layer, respectively. The direction of \(m'\) is the same as \(m\) in the case for transmission spin and is opposite to \(m\) for reflected spin, respectively.

![Fig. 1 Pole tip area views of the MAMR head model in (a) down-track section, (b) air-bearing surface, (c) cross-track section.](image)

| Table 1 Material parameter used in the simulation. |
|-----------------------------------------------|
| \(H_k (\text{T})\) | Head TS | STO FGL | STO SL | Media SUL |
|-----|--------|--------|--------|-----------|
| 2.4 | 1.6 | 1.6 | 1.6 | 1.6 |
| \(A (\text{erg/cm}^2)\) | - | 2 \times 10^{-6} | 2 \times 10^{-6} | 2 \times 10^{-6} | 2 \times 10^{-6} |
| \(P_s\) polarization | 0.5 | 0.5 | 0.5 | 0.5 | - |
| \(t (\text{nm})\) | - | 8 | 2 | - | - |

*\(A\) cross-track direction
Fig. 1 shows the dimensions of the MAMR head model used in this analysis, in which the STO is assumed as a flat rectangular solid. The main pole (MP) and trailing shield (TS) are divided into hexahedron meshes to calculate the spin transfer torque between the MP and the STO, or the TS and the STO, due to software requirement. The STO consists of a spin injection layer (SIL) and a field generation layer (FGL). The SIL is located to the MP side of the FGL. The microwave assist field (MA field) is evaluated 5 nm below the trailing edge of the MP.

Other magnetic properties are summarized in Table 1. Here, $\alpha$, $A$, $P$, and $t$ are the damping constant, magnetic exchange constant, spin polarization factor, and layer thickness, respectively. An alternating current with 1 Gbps frequency and 0.1 AT (Ampere*Turns) is applied to the head coil.

3. Impact of spins from head poles

3.1 Ideal case

Fig. 2 shows a typical magnetization distribution in the STO and the head poles when a good oscillation is observed, where no spin-polarized current is assumed between the STO and the MP or the TS. This is a gap area view from the media side. The FGL magnetization tilts towards the cross-track direction, which indicates good rotation. On the other hand, the SIL magnetization is opposite to the MP and TS magnetization, which is required for good FGL oscillation.

Fig. 3 shows (a) time response waves of the down-track ($H_x$), the cross-track ($H_y$), and the perpendicular ($H_z$) fields, respectively, at the MA field observation point, and (b) Fourier amplitude spectra. $H_x$ shows a strong microwave oscillation which is superposed on the ordinary head field whose frequency is much lower than the MA field. $H_y$ also shows oscillation because of the rotational field in plane. The Fourier spectra show clear peaks at about 27 GHz, whose magnitudes are about 1.4 kOe in $H_x$ and 0.4 kOe in $H_y$, respectively. The MA field amplitude is defined as an averaged value of these two curves.

3.2 Practical problem

Fig. 4 illustrates the structure design difference between (a) the original idea of MAMR and (b) a practical MAMR head design, in which a sectional view of the gap area including the STO is shown. In the original idea, separate electrodes are connected to the STO directly. In contrast, the main pole (MP) and the trailing shield (TS) are used as electrodes in practical MAMR heads because the write gap is too narrow to

Table 2 Spin diffusion length estimation.

| Type                        | Diffusion Length |
|-----------------------------|------------------|
| Long spin diffusion length  | $> 100$ nm       |
| non-magnetic metal (Ag, Cu, Al, etc.) |                   |
| Short spin diffusion length | 5 - 50 nm        |
| non-magnetic metal (Cr, W, Pt, etc.) |                   |
| Ferromagnetic metal (Fe, Ni, Co, etc.) | 5 - 50 nm        |
fabricate additional electrodes inside. In this situation, spins transmitted from the MP to the SIL are undesirable because they work to align the SIL magnetization with the MP magnetization.

The spin diffusion length in non-magnetic metals is usually not very short, i.e. >100 nm in long spin diffusion length metals and >5 nm in short diffusion length metals $^{8}$ as summarized in Table 2. Therefore, the effect of transmitted spin from the MP should not be negligible.

Fig. 5 shows (a) the magnetization distribution when all the transmitted and reflected spins are taken into account among the FGL, the SIL, the MP and the TS, and (b) the time response waves of the write field including the MA field. In contrast to the ideal case of Fig. 2 and Fig. 3, both the SIL and FGL magnetization has aligned with the MP magnetization and no oscillation is observed in the time response waves.

4. Requirement for good oscillation

4.1 What’s required

The problem here is the effect of the transmitted spins from the MP when electrons flow from the MP to the TS. To improve this, the spin-polarized current should be blocked. To do this, materials with a very short spin diffusion length, for example heavier atomic weight non-magnetic metals, should be used.

| Table 3 Spin polarization examples. |
|-------------------------------------|
| **Polarization**                     |
| High polarization Heusler alloy (Co$_2$FeGe$_2$S$_3$, etc.) | 0.7 |
| Lower polarization metal (Ni, Co, etc.) | 0.2 ~ 0.3 |
| Negative polarization metal (FeN, CoFeN, NiFeN, etc.) | -0.5 (?) |

Fig. 6 Head designs (a) with the MP spin barrier layer by short diffusion length material, and (b) with the negative polarization TS and opposite electron flow.

Fig. 7 Injection current dependencies of (a) the MA field amplitude and (b) its frequency; in the case of no spin b/w STO and MP/T, 50% reduced spins b/w STO and MP, all spins b/w STO and MP&T, and negative polarization “P” TS, respectively.
Instead of blocking the MP spin, there is another idea which is to utilize negative polarization materials \(^9\), shown in Table 3, which can flip the direction of the transmitted spin.

Fig. 6 shows proposed designs of layer structures with (a) a very short spin-diffusion length metal between the SIL and the MP, and (b) with a negative polarization metal for the TS, respectively. The electrons flow to the MP from the TS in the case of the negative polarization TS.

4.2 Effect of spin control

Fig. 7 shows the injection current dependence of (a) the MA field amplitude and (b) its frequency. When there is no spin-polarized current between the STO and the MP or the TS (●), clear oscillation is obtained and the MA field amplitude increases according to the increase of injection current. The oscillation frequency is about 25 GHz and almost independent of the injection current.

When the spin-polarized current is reduced by 50% between the STO and the MP (○), a reasonably large MA field is observed. In contrast, no oscillation is obtained when all the spin-polarized current flows between the STO and the MP and the TS, even at large injection current (▲).

On the other hand, when the TS has negative polarization and the electrons flow in the opposite direction, i.e. to the MP from the TS, the injection current response is even better (□). A MA field of more than 0.8 kOe is obtained even for an injection current of less than 4×10\(^8\) A/cm\(^2\), though the MA field saturates at about 0.9 kOe.

These results clearly show the importance of a spin barrier layer with very short spin-diffusion length and also the effect of negative polarization material.

5. Conclusion

We discussed the impact of transmitted spins from the head poles, i.e. main pole and trailing shield. The impact is significant if the spin diffusion length is not sufficiently short. The transmitted spins disturb the magnetization oscillation in the spin-torque oscillator.

The necessity of a spin barrier layer with a very short spin-diffusion length was also shown, together with the effect of an alternate design with a negative polarization material.

Studies of negative polarization materials are not very popular now, but there are a couple of academic reports from Toshiba and from Tohoku University \(^9,10\) for instance. The new designs proposed here look to be very attractive solutions to managing the problem of transmitted spin from the head poles.

References

1. J.-G. Zhu, X. Zhu and Y. Tang: IEEE Trans. Magn., 44, 125 (2008)
2. Y. Tang and J. G. Zhu: IEEE Trans. Magn., 44, 3376 (2008)
3. I. Tagawa, M. Shiimoto, M. Matsubara, S. Nosaki, Y. Urakami and J. Aoyama: IEEE Trans. Magn., 52, 3101104, (2016)
4. http://innovation.wdc.com/game-changers/why-mamr.html (2017)
5. https://www.anandtech.com/show/14077/toshiba-hdd-smr-mamr-tdmr-and-hamr (2019)
6. Y. Nozaki, N. Ishida, Y. Soeno, and K. Sekiguchi: J. Appl. Phys., 112, 083912 (2012)
7. Y. Kanai, K. Yoshida, S. Greaves, H. Muraoka: IEEE Trans. Magn., 53, 3000211 (2017)
8. Jack Bass and William P Pratt Jr.: J. Phys. Cond-Mat., 19, 183201 (2007)
9. M. Tsunoda, Y. Komasaki, S. Kokado, S. Isogami, C. Chen and M. Takahashi.: Appl. Phys. Express 2, 083001 (2009)
10. M. Shimizu, K. Koi, S. Murakami, N. Fujita, K. Yamada, and A. Takeo: The 39th annual conference on Magnetics in Japan, 10pE-3 (2015)

Received Oct. 2, 2019: Accepted Nov. 1, 2019