Theory of Microwave Assisted Magnetization Reversal

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Microwave assisted magnetization reversal (MAMR) has been attracted much attention from viewpoints of both fundamental physics and practical application such as a high-density magnetic recording. The basic idea of MAMR is that microwave having the frequency close to ferromagnetic resonance (FMR) frequency efficiently excites an oscillation of the magnetization around the easy axis and assists the magnetization reversal by a small direct field[1)]. A quantitative analysis on a relation between the switching field and microwave frequency has been made by using the Landau-Lifshitz-Gilbert (LLG) equation in a rotating frame[2)]. In the rotating frame, the microwave field is converted to a direct field proportional to the microwave frequency. This additional field in the rotating frame has been considered as an origin of the reduction of the reversal field[3)]. We should, however, point out that this theoretical view is insufficient to understand the mechanisms of MAMR. According to this physical picture, the reversal field is expected to be monotonically decreased with increasing the microwave frequency because the magnitude of the additional field is proportional to the frequency. The numerical simulation of MAMR, however, revealed the existence of a critical frequency, where the reduction of the reversal field is observed only for the frequency lower than the critical value[1)]. As can be seen in this example, it seems that the physical mechanism of MAMR is still not fully understood yet.

In this work, we present a theory of MAMR based on the LLG equation in the rotating frame[4,5)]. We notice that the microwave field in the rotating frame provides not only the direct field but also a torque pointing in the direction of the damping torque. Interestingly, this damping-like torque prevents the switching. In addition, this torque can be mathematically regarded as a spin-transfer torque[6)]. Using this analogy between MAMR and spin-transfer phenomena, we derived equations determining the switching fields in both low and high frequency regions separated by the critical frequency[4)]. A quantitative agreement between our theory and macrospin simulation guarantees the validity of our study. The analytical formula of the critical frequency is also obtained as[5)]

$$f = \frac{\gamma}{2\pi} H_{\mathrm{K}} \frac{\left(H_{\mathrm{ac}}/H_{\mathrm{K}}\right)^{2/3}}{\sqrt{1-\left(H_{\mathrm{ac}}/H_{\mathrm{K}}\right)^{2/3}}} \left[2-\frac{5}{3}\left(H_{\mathrm{ac}}/H_{\mathrm{K}}\right)^{2/3}\right], \tag{1}$$

where γ, H_{ac}, and H_{K} are the gyromagnetic ratio, magnitude of the microwave field, and magnetic anisotropy of the recording bit. The present works[4,5)] provide a comprehensive picture of MAMR, and will be useful for designing magnetic devices utilizing MAMR.

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