Study of the reduced magnetic field required for thermally assisted magnetization reversal

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Abstract. The reduced magnetic field required for thermally magnetization reversal discussed in this paper. Study of thermally assisted magnetization reversal conduct by using micromagnetic simulation. The magnetic dot size of the simulation was 50 nm × 50 nm × 20 nm. The perpendicular anisotropy constant was 2 × 10⁶ erg/cm³. Initial condition was set single domain configuration. Then a sufficiently thermal pulse was used to get stochastic effect so that the magnetization along to the induce field direction for pico second duration. The results show that the reduced magnetic field mechanism seem to be temporary antiferromagnetic configuration before single domain configuration in alinging along to field direction. The same mechanisms observed for modify of thickness dot particles. The require magnetic field of 145 Oe in thermally assisted magnetization reversal open a posibility for MRAM application.

1. Introduction
Nowadays, the availability of a high density memory is required for realization of a high speed devices electronic in information technology. Memory-based magnetic materials or magnetic random access memory (MRAM) is one of the candidates because they are non-volatile and no-endurance time. In order to realize a high density of MRAM, a magnetic material should be patterned in nano-meter order scale. To overcome the thermal stability of magnetic materials at the nanoscale meter, a high perpendicular anisotropy magnetic to be as one as potential candidate. Whereas thermally assisted of selected storage cell memory during read-write process is one promising procedure to reduced a magnetic field require for reversal [1-4].
Although the system of termally assited magnetization reversal (TAMR) has been proven to reduce the field required for magnetization reversal, however the reduced field mechanism so far not completely understood [5-7]. In the early development of TAMR, the degree of randomness of the magnetic moment due to heating process is considered as a main factor for the lowering in the magnetic field required for reversal. Here, the energy barrier decrease with increasing temperature within result a few of the magnetic field require for reversal. However, the evaluation TAMR with constant stiffness variations in order to modify the degree of randomness of the magnetic moment on the magnetic material with perpendicular asiotropy showed different results. Furthermore, magnetization reversal also have a chance to occur under zero-field cooling in TAMR scheme.

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In this paper, the reduced mechanism of magnetic field require for magnetization reversal is studied by micromagnetic simulation. A several different thickness of nano dot cell memory were modified to obtained the minimal field required for switching. The TAMR of ultra thin of nano dot cell memory become a major atention at this study.

2. Experimental procedure

The reduced mechanism of magnetic field require for aligning to along field in thermally assited magnetization reversal (TAMR) has been studied by micromagnetic simulation [bp, JMMM 2009]. In initial, magnetization set a uniform direction, then magnetic field and heating pulse enter so that randomly magnetized state as a stochastic result of pulse heating is realized. It should be note that for all calculations, a duration pulse of heating is shorter than magnetic field and magnetization reversal process perform in field cooling from near Curie Temperature to room temperature for pico secon order. The thermal fluctuation effect is taken into account in the Landau-Lifshit-Gilbert (LLG) equation by using fluctuation dissipation effect [4]. The probability aligning of magnetic state owing same direction to magnetic field direction at field cooling writing process was performed for 20 different series of randomly magnetic state. The perpendicularly anisotropy magnetic is considered as a storage cell memory with $K$ is $3 \times 10^5$ erg/cc and $4\pi M_S$ is 2.10 kG. The moderate $T_C$ of 372.9 K was used the whole simulation. The magnetic dot size is $50 \text{nm} \times 50 \text{nm} \times 20 \text{nm}$. The second-power temperature dependence with the reduced magnetization was assumed for both the exchange stiffness constant, $A$ and the perpendicular crystalline anisotropy, $K$.

3. Results and Discussion

Figure 1. (a) Reversal probability (magnetization aligning along to field direction) versus magnetic field $H$ calculated for 20 randomly magnetized state; (b) the magnetic field require for thermally assisted magnetization reversal (TAMR) $H_{SW}$ as a function of the magnetic dot thickness.

Figure 1a show the reversal probability versus a magnetic field calculated for 20 randomly magnetized state in TAMR scheme. In case ultra thin dot of 5 nm, reversal probability show a step-like curve. Reversal probability calculation is equal zero within the increase of magnetic field untill given the $H$ of 1200 Oe. Then the reversal even is attained for calculated 20 different randomly magnetized state.
when the $H$ is equal 1250 Oe. It seem that the entire magnetized state configurations of magnetic dot aligning to along field direction do simultaneously. In contrast for both the thickness of 7.5 and 30 nm, the reversal probability increase gradually with increasing the magnetic field $H$ and reversal even attain when the probability is equal 1. The experimental result indicate that the whole magnetized state configurations of magnetic dot do not simultaneously response to magnetic field for aligning along to field direction in TAMR scheme. Calculation for the entire thickness variation of a perpendicular anisotropy magnetic dot films, the magnetic field require for TAMR $H_{SW}$ as a function of the magnetic dot thickness as depicted in Figure 1b. The $H_{SW}$ increase with in decreasing the thickness of the magnetic dot and the highest $H_{SW}$ of 2050 Oe attain at the thickness of 7.5 nm. Then the $H_{SW}$ decrease to 1250 Oe at the thickness of 5 nm. The increase of the $H_{SW}$ with decreasing the thickness of magnetic dot relate to long range interaction from magnetostatic interaction when the thickness of the films reduce to few nanometer order. So that the magnetization reversal realize a single-domain configuration with incoherent rotation along to external field direction. The decrease of the $H_{SW}$ for the dot thickness of 5 nm should attribute from coherent rotation of single domain configuration in later case [8]. Interestingly result obtain for the magnetic dot thickness of 8 nm i.e. the magnetic field require for reversal $H_{SW}$ decrease to equal 1850 Oe. In order to understand more detail about the lowering magnetic field, the TAMR perform individual of initial randomly magnetized state as depicted Figure 2.

![Figure 2.](image)

Figure 2. Evaluation of the $H_{SW}$ calculate for 20 randomly magnetized state with the thickness dot magnetif of 8 nm in TAMR scheme.

As seen clearly at the Figure 2 that the magnetic field require for TAMR range from the $H_{SW}$ of 145 until 1850 Oe. It mean that the individual randomly magnetic state owing typical efficiency of stochastic effect for reducing the field require $H_{SW}$ for reversal. In high efficiency case, the $H_{SW}$ of 145 Oe is enough to realize reversal in TAMR scheme. Contrary for low efficiency case, it should exceed of 1850 Oe for thermally assited magnetization reversal realization. Observation of the micromagnetic steps indicate that typical the TAMR have a similar mechanisms. The reduced magnetic field mechanism seem to be temporary antiferromagnetic configuration before domain wall nucleation following domain wall propagation realize single domain configuration in alinging along to field direction. Moreover, the similar mechanism also observe for all succefully TAMR despite a different magnetic field required for TAMR. From the view point of application, it is interesting although the reducing mechanism of TAMR is still not clear. Figure 3 show a typical steps micromagnetic graph in TAMR procedure evaluated for the thickness magnetic dot of 8 nm under
magnetic field $H$ of 145 Oe. The uniform initial magnetization was set anti-parallel to magnetic field direction. The sufficient stochastic effect of heating observed after $t = 200$ ps. Randomly pattern of micro-magnetic graphs appear at a time interval of $t = 200$ ps dan $400$ ps. Then the orientation magnetized state of nano dot particles tend to field direction which indicate domain wall nucleation following domain wall propagation and realize single domain configuration.

![Micromagnetic configuration in the TAMR scheme:](image)

**Figure 3.** Micromagnetic configuration in the TAMR scheme: (a) initial configuration, (b) randomly magnetized state, (c) domain wall nucleation, (d) domain wall propagation and (e) single domain configuration.

4. **Conclusion**

The process of the reduced magnetic field required for thermally magnetization reversal discussed in this paper. Study of thermally assisted magnetization reversal conduct by using micromagnetic simulation. The results show that the reduced magnetic field mechanism seem to be temporary antiferromagnetic configuration before single domain configuration in alinging along to field direction. The same mechanisms observed for modify of thickness dot particles. The require magnetic field of 145 Oe in thermally assisted magnetization reversal open a possibility for MRAM application.

5. **References**

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