Computer simulation of word line design and magnetization reversal in MRAM

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Introduction

In a practical density level of magnetic random access memory (MRAM) utilizing magnetic tunnel junctions, the cell dimensions are expected to be in the submicron range where the switching of a magnetic layer is dominated by magnetostatic interactions, causing a significant increase of the switching field. It is therefore highly desirable to devise a method of generating a large switching field from a word line at a low applied current. An effort is made in this work by introducing a soft magnetic keeper layer to a word line [1] and optimizing the shape of the word line. The effects of non- uniform field distribution generating from the word line on the magnetization reversal process was also examined.

Model and Calculation

The cross-sectional area of the word line was fixed at 1 μm^2as shown in Fig.1. With an applied current of 10 mA, the current density was 1 MA/cm^2. The distance between the word line and a magnetic layer (which is to be switched during MRAM operation, usually the free layer) was fixed at 0.13 μm, which is relevant to a typical MRAM. The soft magnetic keeper layer was disposed in the bottom and the two vertical sides of the word line. The thickness of the keeper layer was fixed at 0.03 μm. The word line shape was indicated by the aspect ratio (r), which was varied widely from 0.25 to 16. The switching field from the word line containing the keeper layer was calculated with an FEM computer program package which involves solving the Maxwell equations.

The micromagneric simulation was carried out for a magnetic thin film with the dinemsions of 0.93 μm × 0.4 μm × 0.008 μm . Some important magnetic parameters used were: the exchange constant (A) of 1.0×10^{-6} erg/cc, anisotropy constant (K) of 1000 erg/cc, and saturation magnetization (M_s) of 800 emu/cc. Three different types of applied field (Types I, II and III) were used, Type I is uniform field, and Type II and III are non-uniform field.

Results and Discussion

The switching field profiles generated from the word line without and with the keeper layer are shown in Figs.3(a) and (b), respectively. The results were obtained at r= 1 which corresponds to the word line dimensions 1×1 μm^2. The switching field is significantly increased by the introduction of the keeper layer. The switching field in the length direction (B_y), being the most important field component, is 28 Oe at the center of the free layer in the absence of the keeper layer, but it is increased to 72 Oe with the introduction of the keeper layer. Considering a very thin keeper layer (0.03 μm), this increase (approximately 240%) is really significant. In addition to the large increase of the magnitude of B_y, a large difference also exists in the field distribution. In the case of no keeper layer, the maximum in B_y occurs at the center (y=0) and then B_y decreases slowly as y deviates from the center. With the introduction of the keeper layer, however, the B_y

profile is similar to a step-function; the magnitude of B_y is nearly uniform in the range $-0.3\ \mu m < y < +0.3\ \mu m$ but outside this range B_y decays very quickly, reaching zero at $y = \pm 0.65\ \mu m$. It is noted that, at this y value, B_y is still high (54 % of the maximum value) in the case of no keeper layer. The step function like field distribution obtained for the word line with the keeper layer plays an important role of reducing the cross-talk effect which is an important factor to high-density MRAM.

The difference in magnetization reversal mechanism was observed by the applied field distribution. This can clearly be seen from the results for the magnetization configuration at various magnetization reversal steps during a field cycle and these results are shown in Figs.3(a) and (b) for the type I and III field profiles, respectively. In the figures, m denotes the normalized magnetization ($m = m_x/m_s$). The magnetization is initially "saturated" to the $+x$ direction.

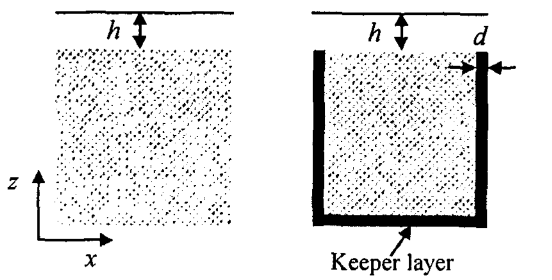

Fig.1. The geometry of the word line without and with a keeper layer. The distance between the word line and the free layer (h) and the keeper layer thickness (d) were fixed at 0.13 μm and 0.03 μm, respectively.

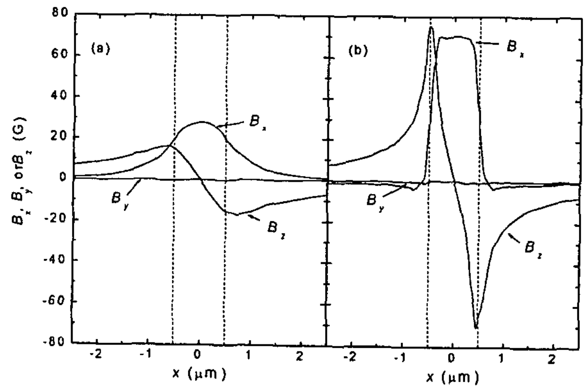

Fig. 2. The switching field profiles (B_x, B_y and B_z) generated from the word line. (a) Without the keeper layer. (b) With the keeper layer.

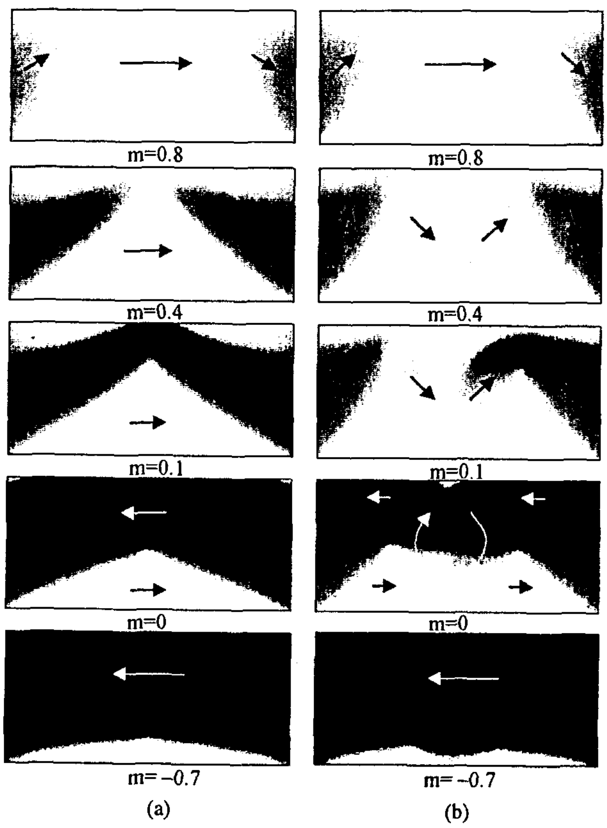

Fig.3. The magnetization configuration at several steps of magnetization reversal. (a) Type I and (b) Type III.

References

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