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Journal of Magnetism and Magnetic Materials 309 (2007) 326–332

Journal of magnetism and magnetic materials

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Effects of induced anisotropy on the bit stability and switching field in magnetic random access memory

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Received 4 November 2005
Available online 7 August 2006

Abstract

One of the features of the new spin-flop switching method with its wide writing window is to use a trilayer synthetic antiferromagnet (SyAF) with circular geometry as the free layer structure. For circular cells with zero in-plane shape anisotropy, the bi-stability of bits is achieved through the formation of induced anisotropy. Both the bi-stability and spin alignment become poor at a small induced anisotropy. On the other hand, a large induced anisotropy has an adverse effect of increasing the switching field. The switching field increase is more pronounced at higher antiferromagnetic exchange coupling of the trilayer SyAF. Our systematic investigations show that the suitable magnitude of induced anisotropy field is in the range 15–20 Oe.

PACS: 85.70.Ay; 85.70.Li; 73.40.Gk; 75.30.Gw

Keywords: Magnetic random access memory; Induced anisotropy; Bit stability; Switching field; Spin-flop switching

1. Introduction

Magnetic random access memory (MRAM) based on magnetic tunnel junctions (MTJs) is expected to possess excellent *intrinsic* properties, some of which include high density (comparable to dynamic random access memory) and speed (comparable to static random access memory), and unlimited read/write operation [1]. For the last several years, much work has been done to develop MRAM with all the excellent intrinsic properties realized. In spite of great efforts, however, there are still many problems to be solved for the development of commercially viable MRAM. With the recent breakthrough on giant tunneling magnetoresistance (TMR) [2,3], most of the problems related with the reading process are expected to be solved in the near future. However, many problems concerning writing still remain unsolved. Two main issues may be identified. One is a high switching field and the other is a small writing window. One typical example of solving the former problem (high switching field) is the use of a soft magnetic keeper layer, which is coated onto the word and bit lines. A significant increase of the magnetic field was observed with the inclusion of the soft magnetic keeper layer [4,5]. Although the improvement is still not satisfactory, this method appears very promising in solving the problems related with high switching field. The other writing-related problem, a small writing window, is one of most serious issues. Conventionally, the magnetization switching is done by applying pulsed currents *simultaneously* in both word and bit lines. In this case, the window for bit-writing is determined from the asteroid curve. This conventional method often suffers from a small margin of writing window. Great efforts have been made to solve this problem, one notable example being the design of a novel cell shape [6]. However, there has been limited success so far until recently when a new switching method was proposed by Savtchenko et al. [7]. Some features of the new switching method are the use of a trilayer synthetic antiferromagnet (SyAF) and the magnetization reversal

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doi:10.1016/j.jmmm.2006.07.014

through spin-flop under a timed pulse sequence in the word and bit lines. Another notable feature is the use of circular cell geometry, instead of usual rectangular one. With the absence of in-plane shape anisotropy, this is obviously a great advantage in maintaining the switching field at a low level even in the submicron cell range. However, the use of circular cells raises a serious concern of the bi-stability of bits, an essential feature of non-volatile memory. In the new scheme, the bi-stability is solely achieved via induced anisotropy which is formed at 45° with respect to both word and bit lines. In the viewpoint of bi-stability, large induced anisotropy is desirable, but this has an adverse effect of increasing the switching field. This indicates that there should be a suitable magnitude of induced anisotropy. It is noted that the new scheme [7] has the advantage of a wide write window, but one of the main drawbacks is a high switching field. In the present work, micromagnetic computer simulation based on the Landau–Lifshitz–Gilbert equation is carried out to examine the effects of induced anisotropy on the bi-stability and switching field.

2. Model and computation

Magnetization reversal behavior was investigated by using a commercial program code of advanced recording model (Euxine Technologies, USA) based on the Landau–Lifschitz–Gilbert equation. A two-dimensional array of honeycomb-shaped and completely packed hexagons was used to simulate the free layer structure, the geometry of which is shown in Fig. 1, together with the pinned layer structure and the tunneling barrier. The word line was located on top of the free layer structure and was directed, say, in the x-axis, while the bit line was placed in the bottom (below the pinned layer structure) and was directed, say, in the y-axis. The present geometry is identical to that used by Savtchenko et al. [7]. One of the two free magnetic layers nearest to the tunneling barrier, denoted by F_1, was always thicker than the other free layer (F_2) on top of the spacer layer (which was fixed at 7 Å); namely $t_1 > t_2$. The shape of the free layer structure was circular, as was used previously [7], in order to avoid the in-plane shape anisotropy. The diameter of the circle was 380 nm. Since the cell size is in the submicron range, a slight deviation from the circular geometry will cause a large shape anisotropy. This shape anisotropy should be avoided since this will bring about additional "induced" anisotropy. Great efforts were made to avoid the shape anisotropy in the construction of the cell. The constructed circular cell is shown in Fig. 1(b). After the simulation, it will be useful to examine the magnetization configuration of the cell by looking at the magnetization direction of each hexagon. However, it was not easy to see the magnetization direction of each hexagon clearly because of too many hexagons used in the simulation. So, a part (approximately 25%) of the hexagons and their magnetization directions are displayed as in Fig. 1(c), and also in magnetization configurations to be shown later. The grain size, more specifically the distance between the two parallel sides of the hexagon, was 10 nm. The height of the hexagon corresponds to the thickness of F_1 and F_2. In most cases, the total thickness ($t_1 + t_2$) was fixed at 50 Å. The interlayer exchange coupling of the trilayer SyAF (J) was varied from 0 to $-3.0\,\mathrm{erg/cm^2}$ (the negative sign indicates antiferromagnetic interaction). The condition $J = 0$ means no interlayer exchange coupling between the two ferromagnetic layers. Even in this case, the two magnetic layers sandwiching the very thin spacer can be aligned antiparallel due to strong magnetostatic interactions for cell dimensions of current interest, and hence they are subjected to spin-flop under an applied magnetic field. The magnetic parameters used for the F_1 and F_2 layers were those corresponding to a mixture of a permalloy and an Fe–Co alloy: specifically, a magnetocrystalline anisotropy constant (K) of $1000\,\mathrm{erg/cm^3}$, a saturation magnetization (M_s) of $1200\,\mathrm{emu/cm^3}$ and an exchange constant (A) of $1 \times 10^{-6}\,\mathrm{erg/cm}$. The Gilbert damping constant (α) was assumed to be 1.0 (critical damping) in order to reduce the computational time. Although this value is considered to be much higher than the experimentally measured values for similar materials, this does not affect the final calculated results of the present *static* condition. A uniaxial induced anisotropy (K_u) was formed at a 45° angle to the word and bit lines (Figs. 1(b) and (c)). So, the magnetic moment vectors, M_1 and M_2, were oriented to the anisotropy direction in the absence of applied field (no currents in the word and bit lines). The actual parameter used in the calculation to represent the induced anisotropy was the anisotropy field (H_u).

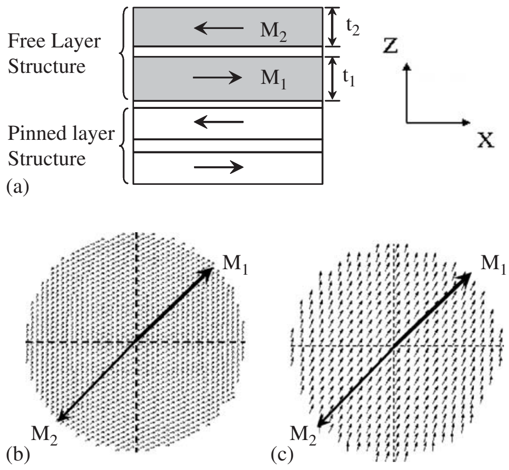

Fig. 1. (a) The cross-sectional and (b) top view of the magnetic tunnel junction used in this work. In order to display the magnetization direction of each hexagon more clearly, a part (approximately 25%) of hexagons and their magnetization directions are shown in (c). Both the free and pinned layer structures are composed of a trilayer SyAF structure and they are separated by a very thin tunneling barrier. In the free layer structure, the thickness of F_1 (which is next to the insulating barrier) is assumed to be always thicker than F_2, namely $t_1 > t_2$. The definition of the axes is also indicated in (a).