Office for Technology Commercialization

March 16, 2009

Exchange Assisted Spin Transfer Torque Switching

Background:

Magnetoresistive Random Access Memory (MRAM) is a nonvolatile memory device using the magnetization to store information. It is a relatively new technology, proposed in early 1990s, compared to other forms of memory, such as dynamic random access memory (DRAM), electrically erasable programmable read-only memory (EEPROM), flash memory etc. The chief advantage of the MRAM over its competitors mentioned above is its ability to combine various appealing attributes into one single memory solution. The potential for MRAM to replace existing technologies leads to intensive research on the topic. In order to write information, a way to switch the magnetization is needed. In the current generation of MRAM, magnetic bits are written with the magnetic field produced by an electrical current. The spatial extended Orsted field seriously limits the recording density and the power consumption. An alternative method to manipulate the magnetization is to use a spin polarized current through the spin transfer torque (STT) effect. The effect originates from the exchange interaction between the itinerant electron and local magnetic moments. Magnetization switching has been realized in experiment. The main difficulty for wide application of the current induced switching is the high critical current density (of the order 10^7A/cm^2) required to reverse the magnetization. The high switching current increases the power assumption. More significantly, it prevents the minimization of the device when transistors providing large currents are needed.

Summary of the Invention:

It is an object of the present invention to lower the switching current. Instead of using a single magnetic hard layer as the recording layer, a composite structure combining exchange coupled assisting layer and recording layer is used. The recording layer is made of material with high uniaxial anisotropy. The assisting layer consists of at least one magnetic layer with lower anisotropy as well as lower damping constant. In general, lower switching current can be achieved by including multi-layers with gradient anisotropy in the assisting layer. Adjacent layers are exchange coupled.

An important advantage of the invention is significantly decreasing the switching current with no loss of thermal stability. This is achieved by optimizing the strength of exchange coupling, the damping constants and anisotropies in the soft layers. For example, when the assisting layer consists of 4 exchange coupled layers with gradually increasing anisotropy, the switching current can be lowered by a factor of 50. Therefore, the invention is expected to increase the recording density and lower the power assumption in RAM.

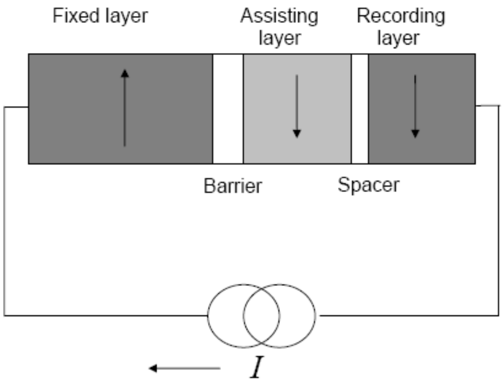

Figure 1

Detailed Description of the Invention:

Fig. 1 shows the STT switching device considered here. The device includes a DC current generator, magnetically fixed layer, tunnel barrier, assisting layer and a magnetically hard recording layer. The magnetization in the fixed layer is fixed by an exchange bias effect. The tunnel barrier is typically made metal oxide such as Al_2O_3, MgO. The recording layer is made of ferromagnetic materials with high anisotropy to assure thermal stability as the device shrinks in size. The assisting layer consists of material with lower anisotropy and damping constant. More details of the assisting layer will be discussed hereafter. It will be understood that the assisting layer can contain multiple layers even though only one is shown in Fig. 1. The exchange coupling strength between the assisting layer and the recording layer can be tuned by adjusting the thickness of the spacer separating the two layers.

To predict the dynamic behavior of the device, we employ the Landau-Liftshitz-Gilbert (LLG) with an additional spin transfer torque, which takes the form:

$$T\Big|_{STT} = \gamma M_s H_{STT} \hat{m} \times (\hat{p} \times \hat{m})$$

where $\hat{p}$ is the current polarization direction, H_{STT} is the effective field induced by a spin current. In particular $H_{STT} = jPeM / eMsd$, wherein: j is the current density, P is the polarization factor, d is the layer thickness. The direct switching current with no assisting layer takes the form,

$$j_{c0} = \frac{\alpha_H ed}{P\text{h}} K_H$$

wherein: K_H is the anisotropy of the hard layer, α_H is the damping constant. Hereafter, we shall assume the hard recording layer is characterized by the parameters

$$K_H = 10^7 \, erg / cm^3 , d = 2nm , \alpha_H = 0.1$$

while the polarization factor $P = 0.5$. Therefore, the direct switching current density is:

$$j_{c0} \approx 9 \times 10^6 A/cm^2$$

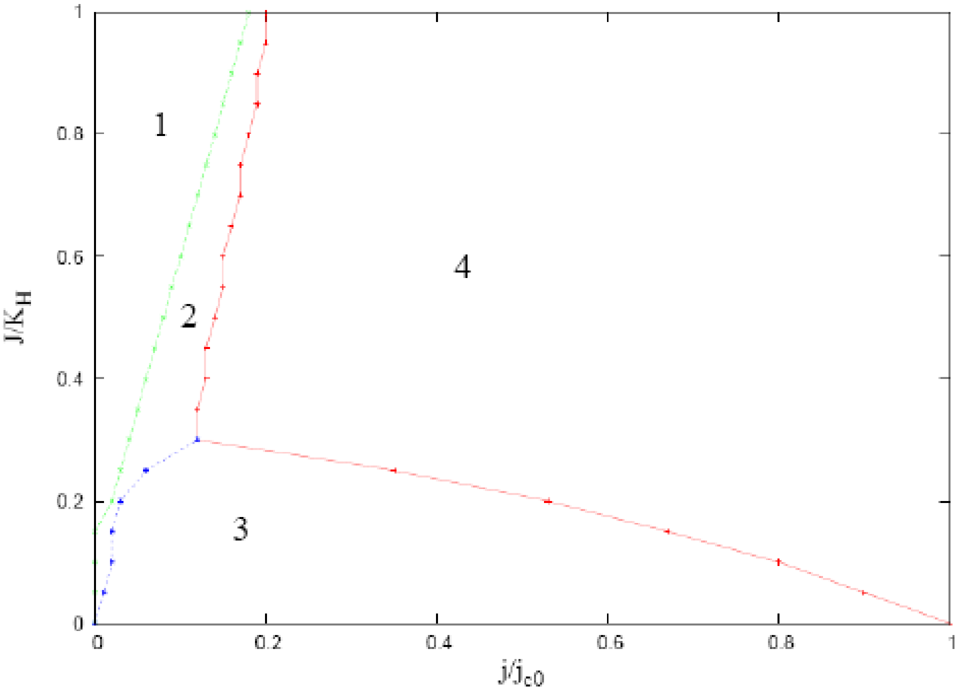

Figure 2

Fig. 2 shows the dynamic phase diagram of a bilayer structure made of a hard recording layer and a soft assisting layer with anisotropy $K_1 = K_H/10$ and damping constant $\alpha = 0.005$. In Fig. 2 the exchange coupling J and current density j is normalized by anisotropy of the hard layer and the direct switching current j_0 respectively. The system exhibit 4 distinct behaviors. In region 1, neither the assisting layer nor the recording layer is switched. In region 2, both layers are found in a steady precession state. In region 3, the assisting layer is switched while the recording layer is not, which exists only when exchange coupling is weak. In region 4, both the assisting and recording layer are switched. As clear from Fig. 2, the switching current j_c density can be reduced compared to j_{c0} and there exists an optimal exchange coupling J that minimizes j_c.

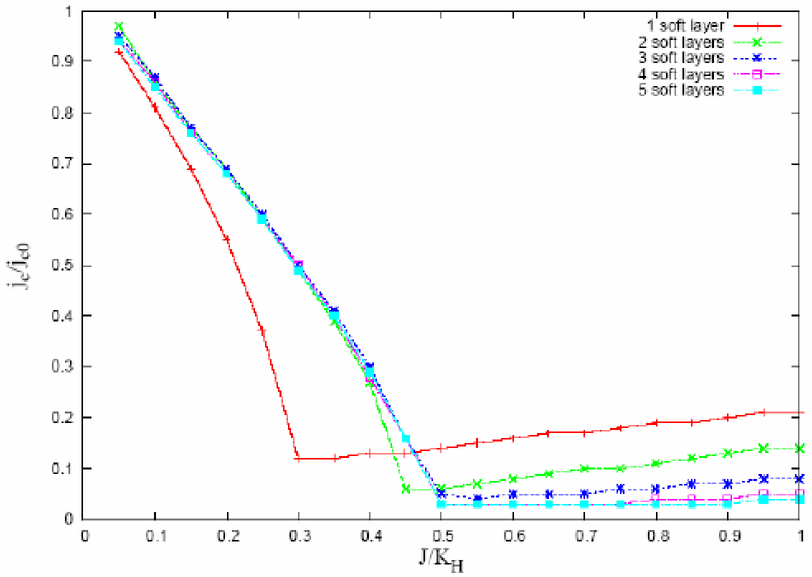

Figure 3

The assisting layer can be made of multiple layers with gradually increasing anisotropy. Fig. 3 shows the switching current as a function of exchange coupling when the number of soft layer ranges from 1 to 5. The damping constant in all soft layers is taken to be 0.005. In each case, the optimal exchange coupling appears around $J = K_H/2$. When more than one soft layer is included, the anisotropies are taken to gradually increase from layer to layer as shown in Table 1. Theses anisotropies are chosen so that the switching current is minimized. As shown in Fig. 3, the current density can be reduced significantly, up to a factor of 30.

Number of soft layers	$\frac{K_1}{K_H}$	$\frac{K_2}{K_H}$	$\frac{K_3}{K_H}$	$\frac{K_4}{K_H}$	$\frac{K_5}{K_H}$
1	1				
2	2	6			
3	2	5	6		
4	1	3	5	6	
5	1	2	4	5	6

In Fig. 4 the switching current are plotted against damping constant α in the soft layers, when the number of layer ranges from 1 to 5. In each case, the switching current increases linearly with α.

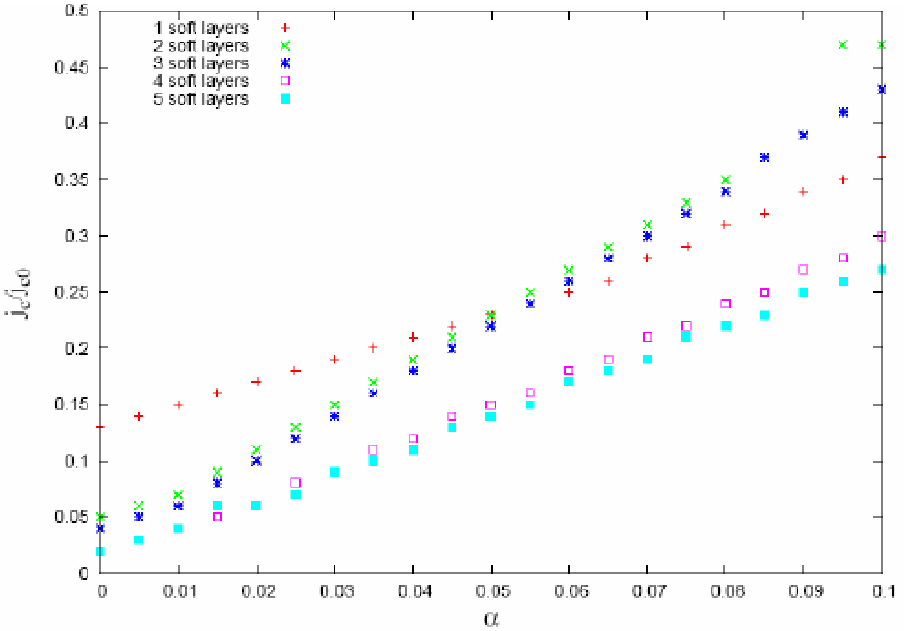

Figure 4

Professor Victora:

B.S., 1980, Physics, Massachusetts Institute of Technology
B.S., 1980, Mathematics, Massachusetts Institute of Technology
Ph.D., 1985, Physics, University of California, Berkeley

Professor Victora's research involves the theory and modeling of magnetic materials, primarily for information storage. His focus is on predicting the macroscopic properties, such as hysteresis loops and magnetic recording noise, from atomic and microscopic information. Two primary tools are micromagnetic simulation and electronic structure theory based on the local density approximation. Other techniques include diffraction theory and molecular dynamics. Professor Victora's research is chosen based on personally experienced industrial problems in the areas of magnetic and optical recording. Typical projects involve extensive collaboration with experimentalists.

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