Micromagnetic simulations of domain wall driven by spin polarized current pulses for a magnetic wire with pinning sites

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1. Introduction

Recently proposed future data storage technology of the race track memory is a solid state shift register type memory, where a nano scale domain wall (DW) is utilized as a bit information carrier and propagated along the magnetic wire with spin polarized currents. Artificial DW pinning along the magnetic wires and well controlled propagation between the neighboring pinning sites are fundamental memory operations. In the present study material modulation along the magnetic wire is proposed as a novel DW pinning site, and feasibility of bit density exceeding 10 $Gbit/cm^2$ is demonstrated by micromagnetic simulations.

2. Numerical model

A schematic of a magnetic wire with periodic pinning sites (PS) is shown in Fig. 1. The following structural parameters were assumed in the simulation: thickness d = 5 nm, width W = 40 nm. Pinning sites with lateral length (L_1) were numerically modeled by the gradual parabolic reduction of the saturation magnetization M_s and the related perpendicular anisotropy K_u ($\propto M_s^2$). The modulation coefficient $r = (M_s - M_{s,min})/M_s$ was defined as a measure of pinning intensity. Standard material parameters for a Co/Ni multilayer were adopted: M_s = 600 emu/cm^3, $H_k = 4.0\times10^6$ erg/cm^3, Gilbert damping constant α = 0.02, non-adiabatic coefficient β = 0.03. Magnetic wire was descretized into one dimensional dipole array with 4nm period, and the LLG equation was numerically integrated with a finite differential method. Controlled DW propagation was performed with successive application of pulsed spin polarized currents (width t_1 = 1 ns, interval t_2= 3 ns).

3. Results and discussions

Energy barrier height ΔE, evaluated from the energy landscape during the DW propagation, are plotted for wires with various r at a fixed value of W = 40 nm and L_1= 20 nm. The practical data stability requirement (ΔE > 60 k_BT) was satisfied with r = 0.3. Simulation results carried out for various values of r reveal that both of the ΔE and the threshold current J_{th} required for the DW propagation increase with the increase of r, as shown in Fig.2. A successful bit propagation and failures were demonstrated in Fig. 3 as a parameter of the current density. The current density amplitude margin for bit propagation increases with increase of r, as shown in Fig. 4. The value of r, thus, should be optimized considering the tradeoff between the data stability and the power consumption. For example, the optimum value of r is 0.3 for structural parameters of W = 40 nm and L_1 = 20 nm, where ΔE = 59.7 k_BT and $J_{th} = 5.8\times10^7$ A/cm^2. The DW was stabilized inside the PS after the pulse end, though the subtle positional fluctuation caused by the residual momentum dissipation was observed.

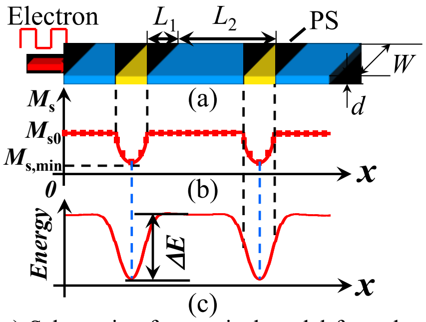

Fig. 1 (a) Schematic of numerical model for a domain wall propagation truck, (b) modulated saturation magnetization M_s and (c) magnetic energy of nanowire alone the magnetic wire.

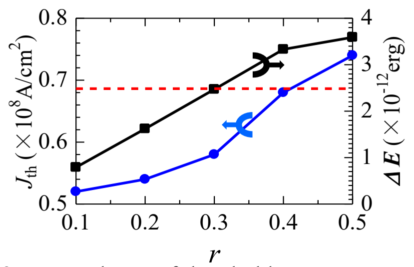

Fig. 2 Dependence of threshold current J_{th} required for DW depining and ΔE as a function of pinning coefficient r.

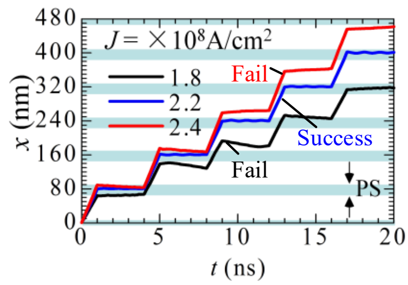

Fig. 3 Time evolution of the propagating DW position along the magnetic stripe.

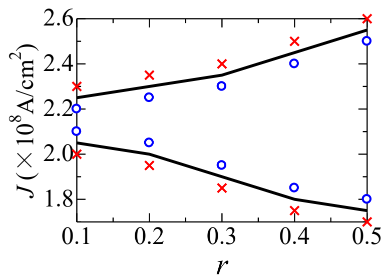

Fig. 4 Current density margin with different pinning coefficient r.