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Threshold Current Density for Current-Induced Domain Wall Depinning

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The current-induced DW motion (CIDWM) has attracted a considerable interest because of its rich physics and potential for the application of storage [1] and logic devices [2]. Despite lots of studies on the CIDWM, its mechanism is still unsolved especially for the adiabatic and nonadiabatic spin torques. From the viewpoint of application, DW displacement should be controllable. A mechanical notch has been proposed as a method of controlling the position of DW on the nanowire precisely.

In our previous work [3], we have studied threshold current densities (Jc) for straight nanowires without a notch. Here, we investigate the current-induced DW depinning from a notch by means of micromagnetic simulation. The modified Landau-Lifshitz-Gilbert equation in the presence of the spin torque terms is used

$$\frac{\partial \mathbf{M}}{\partial t} = -\gamma \mathbf{M}\times\mathbf{H}_{eff} + \frac{\alpha}{M_s}\mathbf{M}\times\frac{\partial \mathbf{M}}{\partial t} - \frac{b_J}{M_s^2}\mathbf{M}\times(\mathbf{M}\times\nabla\mathbf{M}) - \frac{c_J}{M_s}(\mathbf{M}\times\nabla\mathbf{M}),$$

where Heff is the effective magnetic field consisting of the anisotropy, exchange, magnetostatic, and current induced Oersted fields, α is 0.02, the exchange constant (A_{ex}) is 1.3 × 10^{-6} erg/cm, M_S is 800 emu/cm^3, b_J and c_J (= $\beta \cdot b_J$) are the magnitude of the adiabatic and nonadiabatic spin torque, respectively. We assume zero crystalline anisotropy. The geometry of the nanowire is 1000 × 75 × 10 (length × width × thickness) nm^3 divided into 2.5 × 2.5 × 10 nm^3 cells. The shape of notch is a triangle and the length of the constriction is $w/3$ (width).

We classify the initial equilibrium state as static (Fig. 1. (a), (b)) and dynamic (Fig. 1. (c), (d)) cases according to the initial position of DW. We also classify clockwise transverse wall (CW-TW) (Fig. 1. (a), (c)) and anti-clockwise TW (ACW-TW) (Fig. 1. (b), (d)) according to the chirality of DW. The depinning Jc decreases with increasing β term (Fig. 2 (a), (b)). In both types of DWs, the dynamic Jc is higher (lower) than the static Jc when the β term is larger (smaller) than the damping constant α. Reminding the present debate over the magnitude of β term, our result indicates that it is possible to determine the nonadiabatic contribution, at least if $\beta > \alpha$ or $\beta < \alpha$, by comparing the static and dynamic Jc from a notch. When $\beta > 2\alpha$ (4a), the static Jc of ACW-TW (CW-TW) is larger than the dynamic Jc by factor of 1.5 (Fig. 2(c) and (d)). In these range of the β term, therefore, it is difficult to stop a DW at the next notch which is depinned from a prior notch, which can be a serious problem for the application of CIDWM in the mass storage device.

The depinning Jc is determined by pinning potential due to a notch. From the theoretical analysis by using the collective coordinate approach including DW position and the polarization angle [4, 5], we could explain the difference between the static and dynamic Jc in terms of the *β* term and *a*. We will explain the detail demonstration of the potential distribution and depinning Jc.

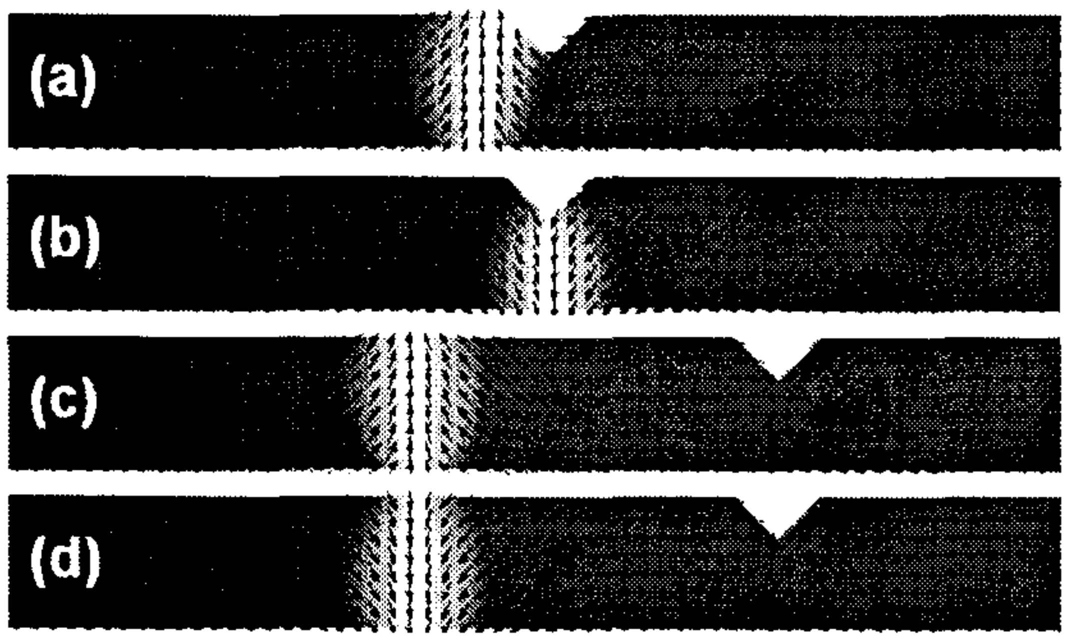

Fig. 1. Initial state of the DW.

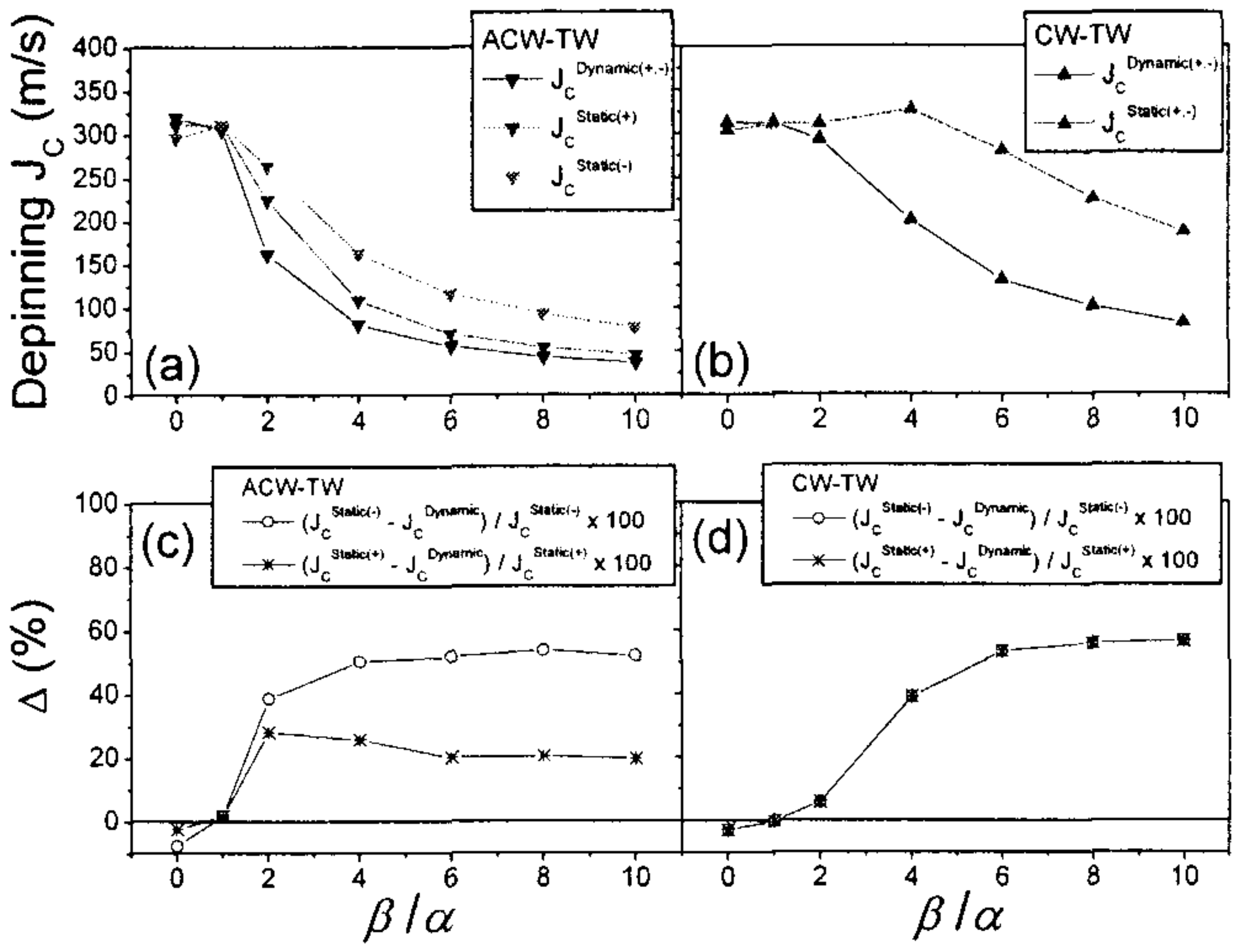

Fig. 2. Ratio of the Static and Dynamic depinning Jc vs *β/a*.

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