East Asian Journal on Applied Mathematics
doi: 10.4208/eajam.181016.300517d

Vol. **7**, No. 4, pp. 837-851
November 2017

Pinning Effect on Current-Induced Domain Wall Motion in Nanostrip

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Received 18 October 2016; Accepted (in revised version) 30 May 2017.

Abstract. Pinning effect on current-induced magnetic transverse domain wall dynamics in nanostrip is studied for its potential application to new magnetic memory devices. In this study, we carry out a series of calculations by solving generalized Landau-Lifshitz equation involving a current spin transfer torque in one and two dimensional models. The critical current for the transverse wall depinning in nanostrip depends on the size of artificial rectangular defects on the edges of nanostrip. We show that there is intrinsic pinning potential for a defect such that the transverse wall oscillates damply around the pinning site with an intrinsic frequency if the applied current is below critical value. The amplification of the transverse wall oscillation for both displacement and maximum value of m_3 is significant by applying AC current and current pulses with appropriate frequency. We show that for given pinning potential, the oscillation amplitude as a function of the frequency of the AC current behaves like a Gaussian distribution in our numerical study, which is helpful to reduce strength of current to drive the transverse wall motion.

AMS subject classifications: 35R05, 58J35, 35Q60.

Key words: Spin current, domain wall motion, Landau-Lifshitz equation.

1. Introduction

Recent research activities in precise control and manipulation of magnetic domain structures have been focused on magnetization dynamics driven by current due to its possible application on the new digital data storage [13, 14]. From the application point of view, the current induced magnetization reversal opens a way to control and manipulate the magnetization dynamics, and it is much better to control the spatial region and individual magnetic elements compared with the conventional magnetic field induced reversal. For technological applications, the domain walls must be moved on much shorter timescales which is easier to be achieved by a current. High current densities used for the experiments yield the local higher temperature, which induces many magnons. Therefore, high velocity

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of domain wall motion and low current density are important issues to optimize magnetic device performance. To realize lower current density, further understanding of the driving mechanism as well as extrinsic effects, such as pinning, are necessary.

Magnetic domain wall dynamics induced by current in magnetic nanostrip has received great interest both experimentally and numerically [2,4,5,8,10,12,15,21,22,27] for applications in magnetoelctronic devices. In the perfect magnetic nanostrip without defects, the domain wall can move along the strip when an external magnetic field or polarized current is applied along the wire axis. In realistic nanostrips, domain walls are not completely free to move. There are various pinning sources such as kinds of defects and roughness. Pinning effect of defects on domain wall motion is important and interesting phenomena and has attracted much attention in recent years [6, 7, 24]. The control of domain wall is very important in the study of current induced domain wall motion. One of the most feasible domain wall control methods is to place defects on the magnetic nanowire [11, 19]. The dynamics of magnetization under the applied spin current is modeled by the generalized Landau-Lifshitz equation with a spin transfer torque term [26]. Numerical methods have been investigated to solve the generalized Landau-Lifshitz system [20, 23].

In this paper, we study the pinning effect on the transverse domain wall motion induced by current spin torque in one and two dimensional models numerically. In Section 3, we construct the nanostrip with rectangular defects of various size on the edges and initial steady transverse domain wall. The two dimensional numerical calculation is carried out for the full generalized Landau-Lifshitz equation with current spin transfer torque, and we provide insight on the pinning effect of the domain wall dynamics induced by current in the numerical results. In Section 4, a pinning potential term is involved to model defect in one dimensional system for more study on intrinsic pinning effect on the transverse wall motion by applying different kinds of current. We show the domain wall dynamics induced by DC current flows, nanosecond-long current pulses and AC current flows with different periods. By using current pulses and AC current, whose frequency is tuned to the precession one, the domain wall's oscillations can be amplified, which makes it possible to reduce the strength of current to drive the domain wall motion.

2. Model and Numerical Method

We consider domain wall propagation induced by current in a sufficiently long nanostrip. By assuming the current flow in the x direction along the long length of nanostrip, the spin transfer torque Γ_{st} [10, 27] is written as:

$$\Gamma_{st} = -\frac{b_J}{M_s^2}\mathbf{M} \times \left(\mathbf{M} \times \frac{\partial \mathbf{M}}{\partial x}\right) - \frac{c_J}{M_s}\mathbf{M} \times \frac{\partial \mathbf{M}}{\partial x}, \tag{2.1}$$

where $b_J = P j_e \mu_B / e M_s$ and $c_J = \xi b_J$, P is the spin polarization of the current, j_e is the current density in the x direction, μ_B is Bohr magneton, and ξ is a dimensionless constant which describes the degree of the nonadiabaticity between the spin of the nonequilibrium conduction electrons and local magnetization.