MICROMAGNETIC SIMULATIONS AND APPLICATIONS

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1 Introduction

The development of advanced magnetic materials requires a precise understanding of the magnetic behavior. A prominent example are magnetic recording systems with an areal density exceeding 100 Gbit/in², where both recording medium and recording heads have to meet certain characteristics [1]. Novel recording concepts like discrete media rely on narrow distribution of the switching field of individual magnetic island [2]. As the size of the magnetic components approach the nanometer regime, detailed predictions of the magnetic properties becomes possible using micromagnetic simulations. The theory of micromagnetism combines Maxwell's equations for the magnetic field with an equation of motion describing the time evolution of the magnetization. The local arrangement of the magnetic moments follows from the complex interaction between intrinsic magnetic properties such as the magnetocrystalline anisotropy and the physical/ chemical microstructure of the material. The finite element method is a highly flexible tool to describe magnetization processes, since it is possible to incorporate the physical grain structure and intergranular phases and to adjust the finite element mesh according to the local magnetization [3]. The comparison of simulations and experiments can provide useful hints for artificial structuring of the material, in order to tailor the magnetic properties according to their specific applications [4].

2 Numerical Methods

Time dependent magnetization processes on the nanometer lenght scale can be simulated due to the numerical solution of the Gilbert equation of motion. This equation describes the movement of the magnetisation in the presence of an effective field, resulting from an external field, the demagnetising field, the exchange field and the anisotropy field. We use the preprocessing tool MCS/PATRAN to create the finite element mesh. The integration of the equation of motion is performed by a backward differentiation method. Therefore the software package VODPK is used. The calculation of the demagnetisation field requires the solution of the strayfield problem by a boundary element method. For the implementation we used subroutines of the program library DIFFPACK. Simulations (especially large models) were carried out partly on the following servers of the computational center of TU-Vienna (*ZID*): fe.zserv, cfd.zserv and fpr.zserv.

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3 Applications

3.1 Discrete media

Magnetic nanoelements may be the basic structural units of future magnetic storage media [5]. Discrete media stores each bit in an individual magnetic particle. With this technology the size of the bits, their location, and their magnetic moment are predefined, leading to high density and low signal to noise ratio. The particles are either magnetized in plane or perpendicular to the plane [2]. Here we analyze the switching behavior of elongated Co-nanoparticles which are magnetized in plane. In particular we investigate the influence of edge roughness and polycrystalline microstructure on the switching field and on the switching time. The elements are 400 nm long, 80 nm wide and 25 nm thick. We compare the magnetization reversal process in three different elements. Element (A) consists of a perfect microstructure. The surface is flat, no grains are assumed within the particle and the crystalline anisotropy is zero. Element (B) takes account of surface roughness. The notches are in average 8 nm. Element (C) consists of 500 columnar grains (diameter is 8 nm) with random distribution of the magnetocrystalline anisotropy directions. Figure 1 gives the

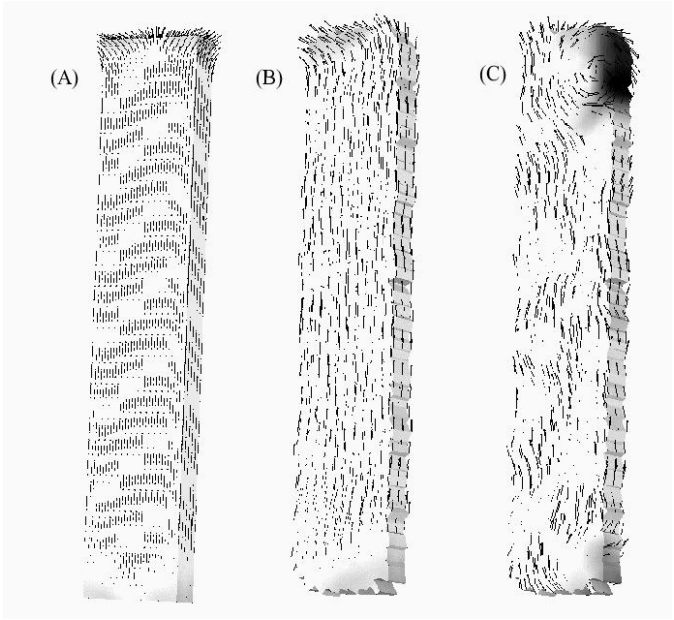

Figure 1. Co-Nanoparticles used to investigate the influence of surface roughness and grain structure on the switching field and the switching time. (A) flat surface, (B) surface roughness, (C) surface roughness and polycrystalline grains.

magnetization distribution of the three different elements for zero applied field. We calculated the demagnetisation curves. The external field is decreased in steps of 4.2 kA/m, in order to calculate the demagnetization curve quasistatically. For each field value the Gilbert equation is integrated until equilibrium is reached. The granular element (C) has the largest coercive field, Hc = 72 kA/m. The coercive field decreases by less than 10% for the perfect Co-element without crystalline anisotropy. Surface roughness leads to a reduction of the coercive field of about 20%. We also studied the switching. The field is applied instantaneously to the remanent state of the particles (figure 1). The field strength is 100 kA/m. Magnetization reversal occurs by the formation of a

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vortex which breaks away from the end domains. This process is similar in the elements (A) and (B). However, surface roughness causes high local demagnetizing fields which favor the formation of the vortex. In element (C) vortices is already present for zero applied field. In addition, vortices nucleate at grain boundaries within the element. Thus the total reversal time is the smallest for element (C).

3.2 Magnetic nanowires

Magnetic nano-wires are of great practical and theoretical interest. Future magneto-electronic devices and magnetic sensors may be based on the magneto-resistance of domain walls moving in nano-wires [6]. Here we investigate the domain wall velocity of Co nanowires as a function of the wire diameter using an adaptive algorithm which adjusts the grid to the current wall position. The thickness of the wires is varied in the range from 10 nm to 40 nm. The length of the wires is 600 nm. Initially, a reversed domain is created in one end. For a diamater of 10 nm a so-called transverse wall forms. In the center of the wall the magnetization points normal to the long axis of the wire. However, this configuration causes magnetic surface charges which increase the magnetostatic energy. As the wire diameter is increased the magnetization may become arranged parallel to the surface, in order to reduce the magnetostatic energy. For a diameter of 40 nm the gain in stray field energy due to the formation of a vortex is bigger than the expense of exchange energy. Thus only vortex walls are formed. For an intermediated diameter of 20 nm both wall types occur. Figure 2 schematically shows the magnetization distribution in the transverse wall and in the vortex wall. Under the influence of an applied field the domain with the magnetization parallel to the field direction expands and the domain wall moves through the wire. The wall structure remains the same during the motion of the wall. The domain wall velocity depends on the wall structure. The vortex wall moves faster than the transverse wall. Figure 3 gives the domain wall velocity as a function of the applied field for a Gilbert damping constant $\alpha = 1$.

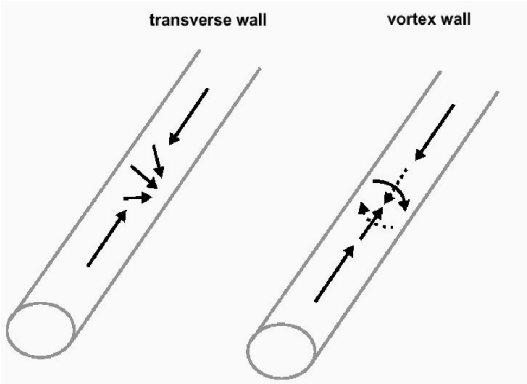

Figure 2. Schematics of the magnetisation distribution in the transverse wall and in the vortex wall.

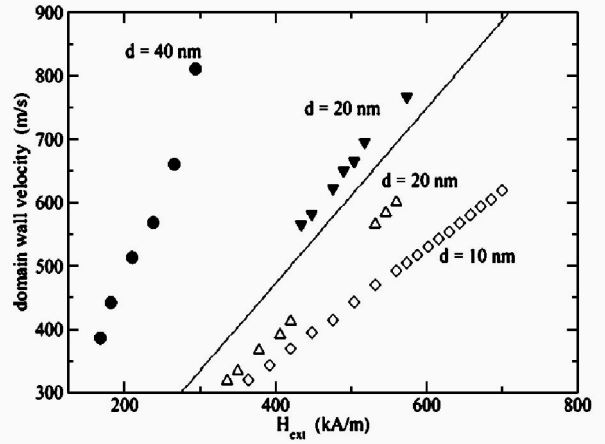

Figure 3. Domain wall velocity as a function of the applied field assuming a Gilbert damping constant $\alpha = 1$.

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