11th International Workshop on Computational Electronics
TU Wien, 25-27 May 2006

Simulation of Magnetization Reversal and Domain-Wall Trapping in Submicron NiFe Wires with Different Wire Geometries

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INTRODUCTION

In recent years, there has been a surge of interest in current-induced magnetic domain-wall motion (CIDWM) and domain-wall trapping in submicron NiFe (permalloy) wires [1-3]. In these experiments, the domain wall is generated by an external magnetic field that induces magnetization reversal of the wire, and the location of domain-wall generation can be controlled by the wire geometry. The reversal process starts from the extended wire pads which inject domain walls into the wire [4-5]. These propagating domain walls then can be trapped in the wire, and they can be dragged by an applied electrical current due to spin-momentum transfer, i.e. CIDWM. This method is considered for novel memory devices [6]. In this work, we investigate the effect of different wire-pad geometries on magnetization reversal and domain-wall injection, and we report results for threshold magnetic field values required in these experiments. We also present a novel method of trapping domain wall in the magnetic wire without pinning. This method can be used in the above mentioned CIDWM studies, and in addition, it is a promising candidate as read-out structure for magnetic quantum-dot cellular automata (MQCA) [7].

DISCUSSION

We performed micromagnetic simulations [8] in order to determine the switching-field values, i.e. the field thresholds for field-induced magnetization reversal, as a function of wire-pad geometry. Figure 1 shows a comparison of threshold fields for various pad shapes, such as square, triangular, diamond, circular, and others. We find that the magnetic properties of these wire-pad structures strongly depend upon geometry, and we find switching-field variations of more than a factor of two. Our results have implications for magnetic-field-assisted CIDWM since these auxiliary fields need to be chosen below the switching field of the wire in order to avoid injection of additional domains and field-induced magnetization reversal. We also study wire structures with differently-shaped contact pads on either end, which can be used to preferentially nucleate domain walls on one end of the wire, or the other. The wire geometry between the pads can be further used to manipulate CIDWM. The effect of geometrical constrictions in wires was carefully studied by several groups [9-15], who demonstrated successful trapping of domain walls by pinning at the constrictions. Here we present a novel method to trap domain wall by placing two nanomagnets near the permalloy wire. We investigate this structure both theoretically and experimentally. The fabrication is done by electron-beam lithography and lift-off process. Figure 2.a shows one of our test patterns with a circular disk at one end and a pointed shape at the other end of the wire. The additional nanomagnets are placed in the close vicinity, in this case, about 40 nm away from the wire. These nanomagnets consist of only one domain, and their stray field penetrates the wire. The process of trapping a domain wall begins with applying a relatively large magnetic field parallel to the axis of the wire, such that the nanomagnets and the wire have a uniform magnetization pointing from the pointed end to the circular end. By applying a small, 210 Gauss magnetic field in the opposite direction, the magnetization of the wire starts to reverse from the circular end, and a domain wall propagates toward the pointed end. When it reaches the region between the two nanomagnets, where a local magnetic field is generated, it is stopped, and thus a head to head domain wall is trapped (Figure 2.b).

SUMMARY

The magnetization reversal of submicron NiFe wires is largely dominated by the physical geometry. Domain walls that are nucleated at the end of the wires can be controlled by choosing appropriate pad-shape design. Using the stray field of additional nanomagnets the domain walls can be trapped as they propagate along the wire. This provides a novel method for CIDWM studies, since the critical value of required current density, that is capable of moving the domain wall, is expected to be different from those corresponding to experiments where the domain wall is pinned by geometrical constriction of the wire. This kind of domain wall trapping can be employed to serve as a signal detector and an interface to electronic circuits for MQCA.

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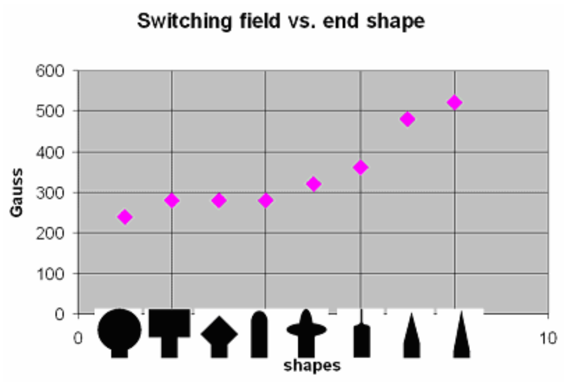

Fig. 1. Simulation results of switching-field dependence on different wire pad shapes (end shapes). All of the wires shown here were designed to be 4 µm long, 180 nm wide, 10 nm thick and made of NiFe.

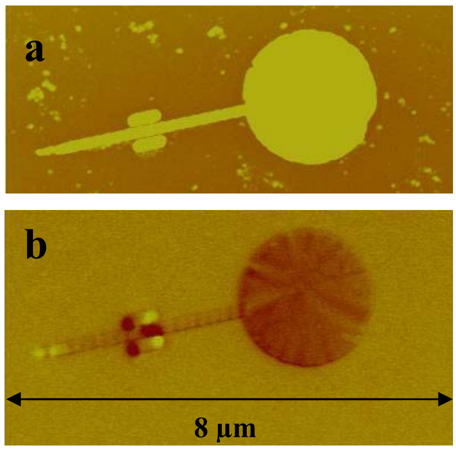

Fig. 2. Domain wall trapped in a permalloy wire by means of stray field of two nearby nanomagnets. a, Atomic force microscopy image of a test sample shows topographic information. b, Magnetic force microscopy image reveals the internal magnetization of the test sample.