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Improving information storage by means of segmented magnetic nanowires

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ABSTRACT

A set of magnetic nanowires trapped in the membrane used to produce them can be employed to inscribe information in the form of sectors of wires with the same ferromagnetic orientation (Cisternas and Vogel, 2013 [1]). However, such a system relays on the shape anisotropy of each nanowire as the stabilizing mechanism avoiding magnetization reversal. Such stabilization mechanism weakens as the size of the nanowires decrease. In the present paper we introduce a way of using segmented nanowires to produce a self-stabilization mechanism based on the fact that interactions among segments of different layers can contribute with negative energies. Then, for some particular geometries it is possible to make this interaction the most important one producing a more stable system with respect to spontaneous magnetization reversal. Such inscribed ferromagnetic sector will then last longer than other ferromagnetic sectors formed by exclusively repelling elements. We make use of available algebraic expressions to calculate the energy contribution of noncoaxial segments. For the coaxial segments a similar expression is developed here and it is applied to real systems. The total interaction energy for all segments in the system is calculated for different geometrical possibilities. Application to two particular symbols (letters T and O) is fully discussed bringing out general aspects that could be applied to other symbols. Projections of this work are finally mentioned.

1. Introduction

Magnetic nanowires trapped in the porous membrane used to produce them [2,3] can be used to store information in the form of ferromagnetic patterns inscribed over such set of nanopillars [1]. However, magnetic orientation of single magnets is subject to reversal effects [4,5], which is more noticeable in small systems. This aging phenomenon could gradually fade away the stored information. In a recent paper it was proposed that an opposite magnetic band (OMB) inscribed within the original ferromagnetic pattern can stabilize the system with respect to spontaneous reversals [6]. In the present paper we propose an entirely different way to achieve the same purpose in a much simpler and effective way. It is based on geometrical considerations for the system of magnetic nanowires: under appropriate conditions the system can be self-stable without the need of inscribing an OMB, thus making the information easily recognizable. The idea is to naturally stabilize the ferromagnetic patterns increasing their duration. In this way the information stored as symbols, bar codes, security codes, firmware at the nanoscale can last for large periods of time.

Preparation techniques allow us to produce wires alternating magnetic and non-magnetic materials along the axes of the wires [7–10]; these are called segmented nanowires or barcode nanowires. An illustration of this kind of wires is given by Fig. 3 of Ref. [7]. The most direct way to achieve this task is by means of a chamber which allows us to alternate the deposition of metals in a controlled way. Thus, for some time magnetic atoms (Ni, say) are allowed to flow and fill in the pori of the membrane; then the corresponding valve is closed. Then, a flow of non-magnetic atoms (Gold, say) is allowed to deposit on the same pori for a short time which can be varied at will; this valve is closed now. Finally, the flow of magnetic atoms is allowed again to finish the process. As a result all pori will be filled with a segment of magnetic atoms, a spacer of a given length and another magnetic segment similar to the first one.

Here we show that the inscription of information within arrays of segmented nanowires can be very stable with respect to possible magnetization reversals. For the present purposes it is enough to consider each wire as formed by two magnetic segments (Co parameters will be used below), one at each end of the wire, separated by a nonmagnetic spacer.

When a Co nanowire is grown two anisotropy orientations compete: the shape anisotropy along the axis of the cylinder and the crystalline anisotropy which does not necessarily coincides

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with previous one [11]. In any case magnetic nanowires interact with their neighbors trying to minimize energy, closing the field lines locally. This effect produces a global nil magnetization in the membrane as a whole. Actually, the orientation of individual magnetizations look at random when inspected by a magnetic force microscope (MFM) [12].

The idea is to use this system to store information upon inscribing meaningful ferromagnetic patterns on the random original configuration. This can be achieved by a powerful enough magnetic tip as it has indeed been done [13] or by means of finer tips as it been recently proposed [14]. This technique will create sectors of magnetic nanowires with parallel magnetization creating a local field which will contrast with the nil magnetic field of the background. From this point of view the only positive repulsive energy might come from the oriented sectors which is what will be calculated below, ignoring the random background.

The prevalence of the stored information in the form of parallel magnetization of patterns within the systems will be improved upon minimizing the repulsive energy among the magnets within the ferromagnetic sectors. This is achieved by controlling the geometrical parameters that define the membrane, which can be done during the fabrication of the segmented nanowires.

Next section comprises three subsections the first of which defines the way calculations will be done; the second one analyzes a case in which competing interactions are defined in order to appreciate the role of the different contributions to the energy; the last subsection is devoted to calculate the total magnetostatic energy for actual symbols, namely two capital letters, showing that they can be made stable. Finally we reach the last section where conclusions are drawn.

2. The system

2.1. Calculations

We will consider a set of $N \approx 5000$ nanowires, all alike, parallel among themselves, perpendicular to the plane of the holding membrane and spanning a triangular lattice, whose lattice constant is d which is usually of the order of a few hundreds nm. Each nanowire of total length $2L$ and diameter $2b$ is composed of two equal magnetic segments of length $2l$ each and a spacer in between of length t, as illustrated in Fig. 1 ($2L = 4l + t$). Such bundle of cylinders is trapped by the fabrication membrane which we suppose circular with radius R (we assume that a circular shape for simplicity but calculations can be done for any geometry). We will consider all interactions, so the distance between the axes of any particular pair of non-coaxial interacting wires is D ($d \le D \le 2R$).

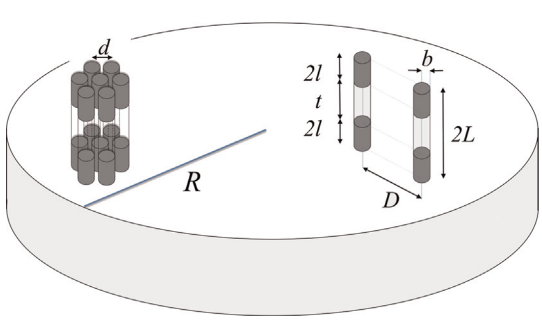

Fig. 1. Schematic representation of a circular membrane of radius R and height $2L$ having inside a huge amount of parallel segmented nanowires (for clarity reasons only a few of them are represented). The length of each magnetic segment is $2l$, the spacing of the non magnetic sector is t ($2L = 4l + t$). The triangular lattice constant is d. The separation between the axes of any two wires is D. Notice that the set looks like two layers of segments.

Through this paper we shall use $d = 700$ nm, a typical separation distance [2,3].

Such system can be understood as three layers of parallel segments: one layer of magnetic segments at the bottom, the other magnetic one on top and a third layer of non-magnetic segments in between. Let us define by s the displacement of one segment with respect to any other one measured perpendicularly to the membrane. Then, $s = 0$ for segments belonging to the same layer and $s = 2l + t$ for segments belonging to different layers. We can define three different kinds of interactions: (a) intralayer interactions ($s = 0$; $D \ge d$); (b) interlayer interactions ($s = 2l + t$; $D \ge d$); (c) coaxial interactions ($s = 2l + t$; $D = 0$).

We will consider the contributions to the magnetostatic energy coming from these three sources each one calculated separately. The starting point is always a pair of magnetic nanowires with parallel magnetization in any of the previous configurations. Later on we shall add them all up for a ferromagnetic pattern within the random background.

(a) The intralayer contribution to the magnetostatic energy is equivalent to the calculation of a similar array of homogeneous magnetic nanowires and it has been reported elsewhere [1,15]. We will directly applied the expression available in the literature to calculate this contribution to the energy. This interaction is always repulsive, namely positive, as it corresponds to any couple of magnets facing each other with parallel magnetization. This will be appreciated when discussing Fig. 3.

(b) Expressions for the interaction of a pair of interlayer nanowires (parallel cylinders displaced one with respect to the other) have been proposed in the literature [6,16]. For any given D value the interlayer magnetostatic interaction can be either positive (small s) or negative (large s), fading away for both large s and large D values as it will be discussed below regarding Fig. 2.

(c) Algebraic expressions similar to previous ones are not available for the case of coaxial wires so we proceed to obtain such expressions and report them in the present paper. In doing so we use the same framework of the intralayer interactions to produce algebraic expansions following the procedure explained in the literature [6,15]. The starting point is exact integral expressions [16,17] which are then expanded into power series truncating them to algebraic polynomials of the desired accuracy. The magnetostatic energy between two coaxial segments ($D = 0$) can be put in the following way:

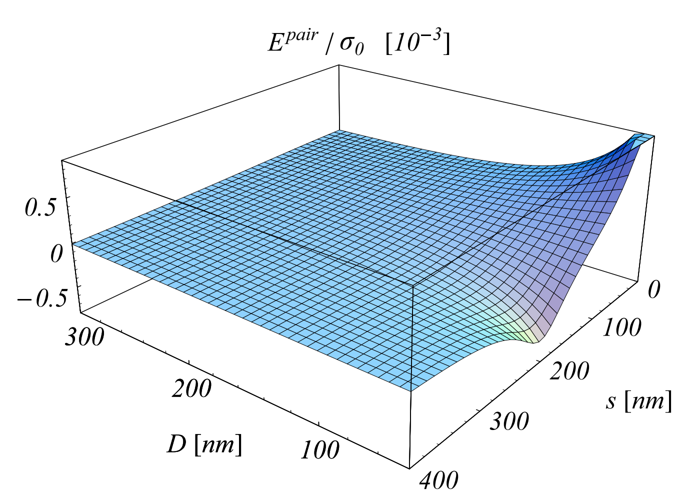

Fig. 2. Interaction energy for a pair of parallel magnetic segments as a function of axis separation D and longitudinal displacement s along the axial direction.