Physica E 83 (2016) 486–490

Contents lists available at ScienceDirect

Physica E

journal homepage: www.elsevier.com/locate/physe

Atomistic simulation of static magnetic properties of bit patterned media

O.D. Arbeláez-Echeverri [a,b,*], J.D. Agudelo-Giraldo [a,b], E. Restrepo-Parra [a,b]

[a] Departamento de fisica y quimica, Universidad Nacional de Colombia – Sede Manizales, A.A. 127 Manizales, Colombia
[b] PCM Computational Applications, Academic Research Group, Colombia

HIGHLIGHTS

- An atomistic model for bit patterned media is developed.
- Magnetic impurities between adjacent bits greatly affect the behavior of the material.
- A considerable amount of magnetic impurities can be tolerated in bit patterned media.
- A phase diagram of magnetic impurity concentration vs. temperature is presented.

ARTICLE INFO

Article history:
Received 29 October 2015
Received in revised form
8 December 2015
Accepted 14 December 2015
Available online 9 March 2016

Keywords:
Bit patterned media
Atomistic simulation
LLG equation
Bit patterned media

ABSTRACT

In this work we present a new design of Co based bit pattern media with out-of-plane uni-axial anisotropy induced by interface effects. Our model features the inclusion of magnetic impurities in the non-magnetic matrix. After the material model was refined during three iterations using Monte Carlo simulations, further simulations were performed using an atomistic integrator of Landau–Lifshitz–Gilbert equation with Langevin dynamics to study the behavior of the system paying special attention to the super-paramagnetic limit. Our model system exhibits three magnetic phase transitions, one due to the magnetically doped matrix material and the weak magnetic interaction between the nano-structures in the system. The different magnetic phases of the system as well as the features of its phase diagram are explained.

1. Introduction

Bit patterned media is a promising candidate for the next generation of two dimensional magnetic recording media of densities of 5 Tb/in.^{2} and beyond [1–3]. Bit patterned media consists of individual magnetic nano-islands that are, in the best case scenario, isolated in terms of exchange interaction. In order to achieve the required storage densities in this material, the island sizes should have a diameter of less than 10 nm and they should have less than 5 nm of interstitial separation. These media also require very low variability in size and separation. These requirements push the fabrication techniques down to their resolution limits.

Common fabrication techniques include directed block co-polymers and, more recently, lithography and patterning techniques [4]. Both of this processes struggle to keep the islands isolated at high densities. A poor island isolation can be interpreted as magnetic impurities in the interstitial region which produces a weak exchange interaction coupling between the nano-islands depending on the concentration of magnetic impurities in the interstitial region.

However, lowering the cost to benefit ratio of the fabrication down to an industry acceptable level, reducing written in-errors and several other obvious problems, such as head synchronization, spread switching field and anisotropy distribution, still suppose a challenge [2,5–7]. Due to manufacturing process imperfections, the pattern inherits imperfections, shifts in island sizes, spacing and location leading to errors in both the read and write processes [8]. By 2006 it was very well established that the performance of bit patterned media was limited by written in errors rather than signal to noise ratio [8,9]. Written in (or write synchronization errors) are not a concern of traditional recording techniques; in bit pattern recording the read/write head needs to be synchronized to align itself with the nano-metric domain containing the bit.

* Corresponding author.
E-mail addresses: odarbelaeze@unal.edu.co (O.D. Arbeláez-Echeverri), jdagudelog@unal.edu.co (J.D. Agudelo-Giraldo), erestrepopa@unal.edu.co (E. Restrepo-Parra).

http://dx.doi.org/10.1016/j.physe.2015.12.016
1386-9477/

Impactful models were developed to understand the repercussion of defects in the fabrication process in the read/write performance of bit patterned media [10,11]. Image processing techniques that allowed to characterize the bit patterned media imperfections from scanning electron microscopy (SEM) images were introduced; researchers concluded that the size and spacing fluctuations showed weak correlations extending just to neighboring islands while the fluctuations in location presented longer range correlations [12].

Besides, increasing the difficulty of head synchronization, variations in the size, shape and anisotropy of the islands may lead to variations in the switching field of each island, producing spread switching field distributions. Spread switching field distributions also lead to write errors; either if the writing field is not strong enough to switch the magnetization of some of the islands or if it is strong enough to switch the magnetization of islands nearby [2,7,13,14]. Targeting this issue, a micro-magnetic model that predicts switching fields for different island shapes was developed; researchers concluded that using an aspect ratio different from 1:1 may increase the probability of write errors in neighboring islands and consequently predicted that circular cylindrical islands are optimal [14]. Furthermore, an experimental method to compute the switching field distribution of thin film was created using non-equilibrium hysteresis recoil loops [13].

In the present work, we propose a new atomistic model for cobalt based bit patterned media. Using this model we, attempt to explain the behavior of bit patterned media when magnetic impurities are present in the interstitial area between nano-islands. We consider the media matrix and the nano-islands to be the same material, yet the matrix is considered to be an amorphous and lower density phase of the nano-island material. The rest of the work is organized as follows, the geometric model as well as the Hamiltonian and the integration methods are described in Section 2, results and discussion are presented in Section 3, finally a summary of the work, remarks and conclusions are presented in Section 4.

2. Model

2.1. Geometric model

All the geometric models studied in this work are composites of crystalline flat cylinders embedded in a disordered matrix, the first iteration of the model (Fig. 1a) considers a two dimensional composite where the crystals have a square lattice structure and the matrix is drawn from a Poisson distribution, and also, the matrix have the same density as the crystal structure.

A Poisson distribution leads to local clustering in atom positions. However, it does not affect the universality class of the system according to the work of Lima et al. [15–17]. Nonetheless, a Poison distribution models an amorphous material with large stress and far from geometrical stability; this stress is generated by the short separation between some atoms in the matrix.

In order to reduce the matrix stress, the second iteration of the model implements Euler disk sampling; this technique a forbidden radius r_0 is defined around each site (see Fig. 1b). In the final sample, the distance between two sites cannot be less than r_0, while keeping the randomness of the distribution. For a reference on the implementation of the Euler disk sampling algorithm see [18]. Despite the efforts in constructing a more realistic sample, by reducing the stress; Euler disk sampling combined with Delaunay triangulation for nearest neighbor calculations yields a material in which the amorphous matrix is "not less magnetic" than the magnetic nano-islands it surrounds. This is due to the fact that the average coordination number of such lattices ($\sim$6 for 2D Poisson or Euler disk distributions and $\sim$12 for 3D) is comparable with the most densely packed Bravais lattices.

The third iteration of the geometric model (see Fig. 1c), features a more densely packed Bravais lattice for the nano-island material (*hcp*), to resemble cobalt, one of the most used materials in bit-patterned media fabrication; furthermore it features random site depletion for the matrix (amorphous) material, i.e, we take and hcp lattice and attempt to remove each site with a probability $p=1-\rho$, ending up with a set of sites with relative density ρ. Random depleted crystals resemble very well an amorphous material, keeping the short range ordering and lowering the average coordination number per site at low matrix densities. The caveat is that the local ordering in the matrix preserves the orientation of the nano-island crystalline system, but that is not a big concern for Hamiltonians that do not include spatial dependent terms.

2.2. Hamiltonian and mathematical model

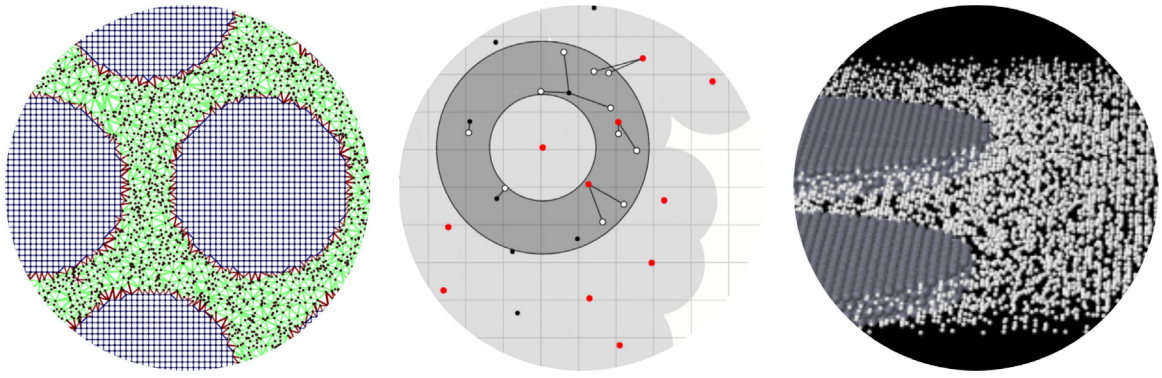
In this work we used a classical Heisenberg Hamiltonian, taking into account exchange interaction couplings between nearest neighbor pairs and uni-axial anisotropy.

$$\mathcal{H} = -J_0 \sum_{\langle ij \rangle} \vec{s}_i \cdot \vec{s}_j - \sum_i K_{eff,i} \left(s_i^{(z)}\right)^2 \tag{1}$$

In Eq. (1) the sum over $\langle ij \rangle$ means sum over nearest neighbor pairs; the exchange interaction constant is computed, according to [19,20], from

$$J_0 = \frac{3k_B T_c}{\in z} \tag{2}$$

for cobalt, with a critical temperature of 1388 K and with



(a) Poisson distribution. (b) Euler disk sampling. (c) Random site depletion.

Fig. 1. Model evolution through three iterations.