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Journal of Magnetism and Magnetic Materials 226–230 (2001) 548–549

Journal of magnetism and magnetic materials

www.elsevier.com/locate/jmmm

Monte Carlo simulation of a two-dimensional magnetic foam

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Abstract

A two-dimensional Ising-like model with spin 1 and long-range interactions is studied numerically through a Monte Carlo simulation. The goal of the simulation is to describe pattern formations and critical temperature of two-dimensional magnetic structures. Three sets of parameters are considered, that give rise to stripes, labyrinths or cellular domain structures. We determine for each configuration the transition ordering temperatures, the relaxation of the energy, the hysteresis cycle, and the average size of the domains.

Keywords: Magnetic froth; Pattern formation; Monte Carlo simulation

Magnetic foams [1] are thin films (a few μm thick) of monocrystalline ferrimagnetic garnet, with a large value of the anisotropy perpendicular to the film, so that the magnetization remains along this axis except within the Bloch walls separating domains of opposite direction. Different types of domain structure are possible in such materials [2,3,6], depending on transient magnetic fields applied and on the thermo-magnetic history of the sample. The most common structures are parallel stripes, labyrinths and cells [3]. In some cases, the cellular structures look like soap froth, so they are called magnetic foams, and they can be generated by cooling a sample with initial temperature greater than the critical ones, in a weak magnetic field perpendicular to the sample plane.

Some properties of these systems have been described by Weaire et al. [5], who presented a model including surface and compressibility energy terms, so considering the system as a cellular one. On the other hand, Sampaio et al. [4] treated explicitly a $\frac{1}{2}$ spin model including long-range dipolar interaction and obtained a right angle labyrinth structure that reproduces some features of the experimental one. Here we propose a spin 1 Ising-like model with competing interactions up to the seventh neighbor, including anisotropy energy and the interaction with the magnetic field. The zero value of the spin is included in order to have a better description of the Bloch walls. The Hamiltonian is

$$H = -\sum_{i,j} \frac{J_{ij}}{2} S_i S_j - A \sum_i S_i^2, \tag{1}$$

where the J_{ij}'s constants characterize the interactions between neighbors, and A is the anisotropy energy. The $J_{ij}(r)$ values are considered as competing interactions, being a ferromagnetic one between nearest neighbors. With the aim of making these interactions depend on a unique parameter we adopt an RKKY-type relation: $J_{ij}(r) \approx \cos(kr)/(kr)^3$. Starting with the sample, a 200×200 square lattice, at a high temperature (all spins randomly aligned), we decrease the temperature step by step up to the desired temperature, by means of a single-spin-flip Monte Carlo dynamics. The model tends to polarize spins, generating magnetic structures with interconnected domains. We choose the following values of $k = 1.2$, $A = -0.8$ (labyrinth); $k = 4.2$, $A = -0.5$ (stripes); $k = 0.8$, $A = -0.1$ (cells), and the resulting structures are shown in Fig. 1:

There are experimental [3,4] evidences that garnet films at temperatures below the critical one, T_c, show

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0304-8853/01/$ - see front matter
PII: S0304-8853(00)00918-5

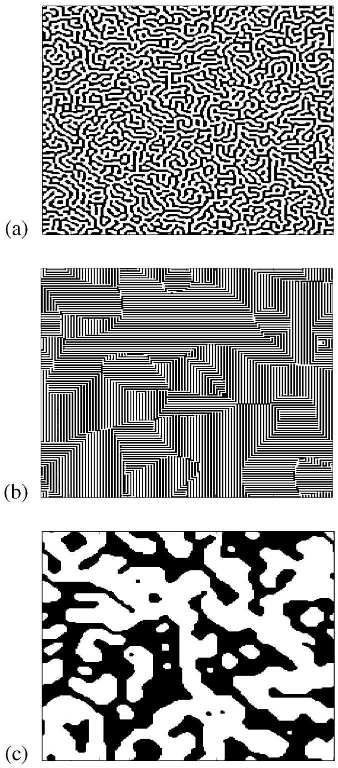

Fig. 1. Snapshot after quenching, showing the three characteristic domain pattern configurations: (a) $k = 1.2$, $A = -0.8$ (labyrinth); (b) $k = 4.2$, $A = -0.5$ (stripes); (c) $k = 0.8$, $A = -0.1$ (cells).

memory effects; in order to study them it is necessary to slowly vary the sample temperature to detect macroscopic evidences of such T_c. The relevant physical quantities are cellular size and specific heat per site; the latter being calculated as $\beta^2(\langle E^2 \rangle - \langle E \rangle^2)$. Fig. 2 shows the results for the specific heat and allows us to detect the critical temperature for stripes, labyrinth and cellular formation.

In conclusion, we have modeled the magnetic relaxation and the formation of magnetic domains in ultra thin films with anisotropy perpendicular to the film plane using Monte Carlo simulation. We used a two-dimensional spin 1 Ising Hamiltonian on a square lattice including anisotropy. Different structures are obtained just by changing k, the modulation of the magnetic interactions, and the anisotropy A. The stripe phase seems to be

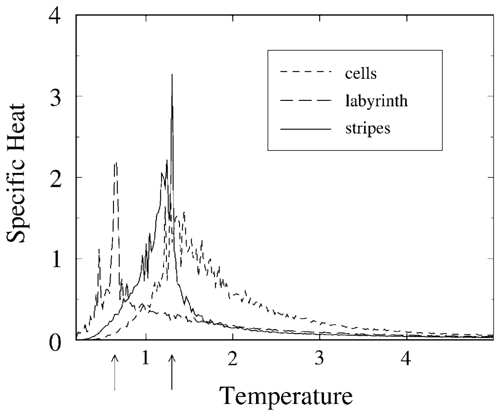

Fig. 2. Specific heat (arbitrary units) as function of temperature (in units of $J_1 = 1$) for the three configuration obtained by a Monte Carlo process.

the most likely one to present memory effect because its hysteresis cycle shows a "hard" phase, even if the domains are antiferromagnetic ones. Probably, in order to obtain truly cell structures we should still play with the magnetic field (as in experiments) and also consider defects (pinned sites).

Acknowledgements

We acknowledge the support from CNPq (Brazil) and the Fundación Andes (Chile), Antorchas (Argentina) and Vitae (Brazil). One of us (O.A.N.) acknowledges support from CLAF.

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