Optimization of domain-wall switching using energy landscape methods

P. B. Visscher, Zhihong Lu, and W. H. Butler

MINT Center and Department of Physics and Astronomy
The University of Alabama

This project was funded by NSF-DMR 0213985.

E vs m plot: K(z)~z^2 example

In a system with domain-wall switching, a thin-wall approximation [assuming the anisotropy remains nearly constant within the domain wall, which is far from the boundaries so that its energy is given by the exact result (AK)^2] Sus et al (2006) have shown that the pinning field should remain constant if we choose K(z)~z^2. In our E(mz) formulation, this means the slope should be nearly constant. This turns out to be true numerically, except near the hard end.

E vs m plot; Stoner-Wohlfarth example

We conclude that everything we need to know about the system (the coercivity and energy barrier) is contained in the function E(mz), the minimum energy at fixed magnetic moment mz and zero field. This result is very general. Although we motivated it above by considering domain-wall switching, it describes Stoner-Wohlfarth (S-W) switching as well. This is the limit in which K, A, and Ms are uniform and A is large so M(z) is uniform. The S-W energy (per area, of a grain of length L) is just E = Ksat sinθ = KL(1-mz^2/2)

Constrained minimum energy

It would appear that to find the quasistatic switching trajectory, in which H varies with time, we would need to minimize a function E(θ1, θ2, N, H) of a large number of variables θ1, θ2, ..., θN, for each value of H independently. However, there is a way around this. We can choose some coordinate in the space of θ’s (we choose the longitudinal component of the magnetic moment, mz, for reasons apparent below) and first minimize E(mz, H) for fixed mz, obtaining a function (the constrained minimum energy) E(mz, H). Then we can minimize E(mz, H) with respect to mz, obtaining the same relative minimum E(mz, H) we would have obtained by unconstrained minimization. (Note that there may be more than one relative minimum, so we should call this Ej(H) where j indexes the minima, but we will omit this index for simplicity.) The advantage of this apparently-circuous method of finding the minimum is that the configuration minimizing E(mz, H) is actually independent of H! This is apparent from Eq. (1) above, since the only dependence on H is the Zeeman term -mzH which is a constant when mz is held fixed.

Background

Several ideas have been suggested to lower the coercivity of thin-film granular media:
• Exchange spring media (Victoria 2005) – each grain has a soft and a hard layer (each internally uniform)
• Multilayer media – varying from soft to hard (low to high anisotropy)
• Continuously variable anisotropy (Suess 2006)

Employing this method of finding the minimum is that the configuration minimizing E(mz, H) is actually independent of H! This is apparent from Eq. (1) above, since the only dependence on H is the Zeeman term -mzH which is a constant when mz is held fixed.

Idealized model

We consider a one-dimensional model, in which the magnetization is a function only of one variable z (independent of x and y): M(z)

We will allow the anisotropy K(z), exchange constant A(z), and saturation magnetization Ms(z) to vary arbitrarily with z. Since we will do computations with a discrete approximation to the continuum model (which approaches the continuum model as the cell size → 0), we will draw a diagram of the discrete system. It has cells labeled by i, with magnetization vectors Mi. In the quasistatic energy minima we will consider, these vectors will lie in a plane, so they can be described by giving the angle θi of the magnetization relative to the long axis of the grain (the z axis):

\[ M_i = M_s \cos \theta_i \]

The energy (per unit area in the xy plane) E of our system is then given in terms of the values of K and M at each cell (and A between each neighboring pair of cells) by

\[ E = \sum_{i=1}^{N} a_i K \sin^2 \theta_i + \sum_{i=1}^{N} a_i A \cos(\theta_{i-1} - \theta_i) - \sum_{i=1}^{N} a_i \mu_i M_i H \cos \theta_i \]

where ai is the length of cell i, aiH is the distance between cells i and j, and H is the external field (assumed along z).

The University of Alabama

Center for Materials for Information Technology
an NSF Materials Research Science and Engineering Center