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Thermal reversal of magnetic nanoparticles with the quartic anisotropy

Ying Li*

Institute of Physics, Beijing National Laboratory for Condensed Matter Physics, Chinese Academy of Sciences, Beijing 100080, China

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Abstract

The effect of the quartic anisotropy on energy barriers and thermal reversal modes is studied in a system of two interacting single-domain particles. It is assumed that the two particles possess identical volumes and uniaxial anisotropies. The lowest energy barriers to be overcome for magnetization reversal are determined by saddle points of the energy surface. The presence of the quartic anisotropy results in a change in the locations of the saddle points, and then the reversal modes under thermal excitation, which is illustrated by the energy surface and corresponding contour plots of the two single-domain particles. In the presence of the quartic anisotropy, the energy barriers are calculated analytically for the coherent rotation and the symmetric fanning rotation modes.

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Keywords: Thermal reversal; Energy barriers; Single-domain particles; Quartic anisotropy

1. Introduction

With the continual reduction of the grain size in magnetic recording media to satisfy the need of miniaturization for devices, thermal stability becomes essential to the magnetic performance. Since the thermal stability of the recorded information depends mainly on the magnetic grain size and the uniaxial anisotropy, a decrease of the grain size requires an increase in magnetic anisotropy in order to maintain thermal stability of the recorded information. Single-domain particles, due to their small size and high anisotropy, have potential applications in magnetic recording media such as magnetic disks and tapes. Hence, considerable interest is aroused in understanding the magnetic properties of single-domain particles [1–5].

In the case of the zero magnetic field or the magnetic field below the coercive field, at a finite temperature the magnetization reversal of a magnetic system can occur by following an minimum energy path over the lowest energy barriers, which are determined by the saddle points of energy surface [1]. Thermal reversal is defined as the magnetization reversal assisted by thermal excitation by overcoming the lowest energy barriers at finite temperatures. For the system of single-domain particles, the energy barriers are affected by interparticle interactions, the uniaxial anisotropy energy, and the Zeeman energy. In many theoretical studies of system of single-domain particles, the contributions of the quartic anisotropy to energy barriers for thermal reversal were disregarded for computational simplicity [1,2,6,7]. However, for certain situations the quartic anisotropy is not negligible, and plays an important role in determining the magnetic properties of the system [8–14].

The present work investigates the effect of the quartic anisotropy on the energy barriers and the thermal reversal modes in a system of two interacting single-domain particles. The results show that the quartic anisotropy changes the positions of the saddle points, i.e., changes the paths leading to the lowest energy barriers, and then thermal reversal modes. This work can provide a useful guide for studying magnetic properties of many-particle problems, such as an assembly of single-domain particles.

*Tel.: +861062553698; fax: +861062553698.
E-mail address: yli@aphy.iphy.ac.cn.

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2. The energy surface of a two-particle system

Consider a simple magnetic system containing two single-domain ferromagnetic particles [2]. It is assumed that the two particles with saturation magnetization (M_s) have identical volumes (V), quadratic uniaxial anisotropy constant (K_1), and quartic uniaxial anisotropy constant (K_2). The bond connecting two particles makes an angle β with the easy axes, and the bond distance is denoted by R. The angles θ_1 and θ_2 describe the magnetization direction relative to the easy axes for two particles, respectively. Here we confine the magnetic moments of two particles to the plane defined by bond vector and the common anisotropy axes, and the angles θ_1 and θ_2 vary between $-\pi$ and π. We assume that an external magnetic field is applied only in the above plane, i.e., the common plane possessed by the bond vector, the anisotropy axes, and the magnetization. The reverse applied field is misoriented to the easy axes by an angle θ_h. In Fig. 1 a sketch of the magnetization, bond vector, the anisotropy axes, and the applied field directions is plotted. Then the total energy, normalized by the quadratic anisotropy energy K_1V, consists of quadratic anisotropy energy, quartic anisotropy energy, dipole–dipole interaction, and Zeeman energy

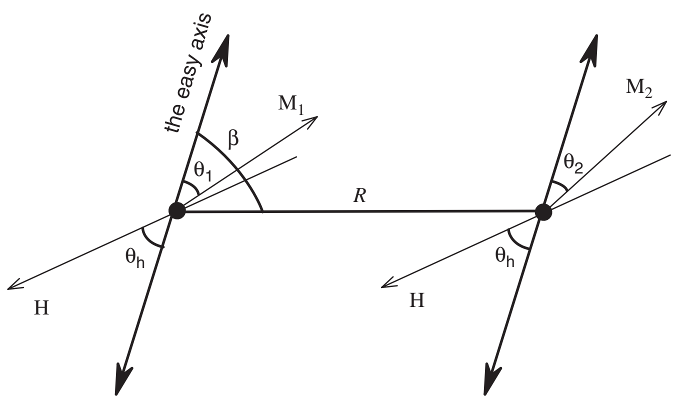

Fig. 1. A sketch of the magnetization, bond vector, the anisotropy axis, and the applied field direction for a two-particle system.

$$\frac{E}{(K_1V)} = \sin^2\theta_1 + \sin^2\theta_2 + k(\sin^4\theta_1 + \sin^4\theta_2) + h_{dip} \times\{\cos(\theta_1-\theta_2) - 3\cos(\beta-\theta_1)\cos(\beta-\theta_2)\} + h(\cos(\theta_h-\theta_1) + \cos(\theta_h-\theta_2)), \quad (1)$$

where the coefficient k represents the value of K_2/K_1, $h_{dip} = M_s^2V/(K_1R^3)$ represents the dipole–dipole interaction

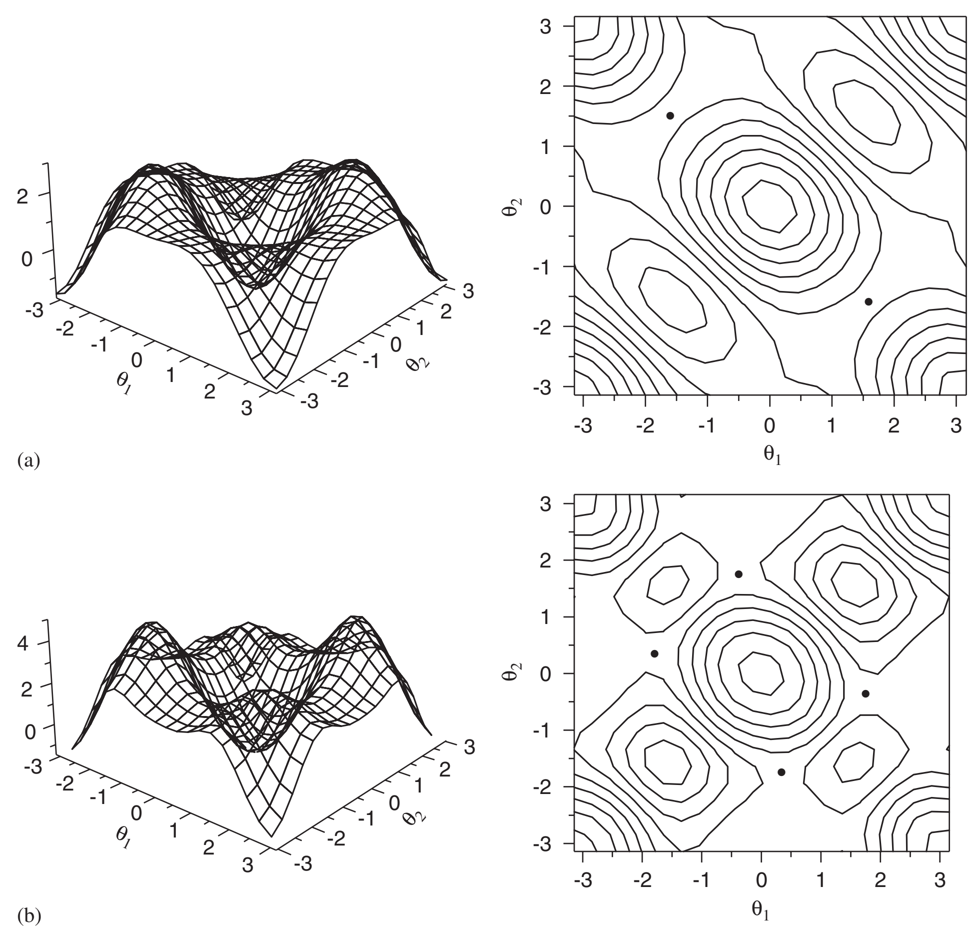

Fig. 2. The energy surfaces and corresponding contour plots of two particles for $\beta = 0$, $h_{dip} = 0.8$, $h = 0$: (a) $k = 0$; (b) $k = 1$. The equilibriums for the two cases are at $\theta_1 = \theta_2 = 0$. The lowest saddle points are marked by dark dots.