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Demagnetization in photomagnetic films

Daniel M. Pajerowski [a,*], Scott J. Hallock [a,b]

[a] NIST Center for Neutron Research, Gaithersburg, Maryland 20899, USA
[b] Winston Churchill High School, Potomac, Maryland 20854, USA

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ABSTRACT

We present a model for demagnetization in photomagnetic films, and investigate different regimes for the magnetizing process using finite element analysis. It is found that the demagnetizing factor may depend strongly upon the high-spin fraction of the film, and the specifics of the dependence are dictated by the microscopic morphology of the photomagnetic domains. This picture allows for facile interpretation of existing data on photomagnetic films, and can even explain an observed photoinduced decrease in low-field magnetization concurrent with increase in high-spin fraction. As a whole, these results reiterate the need to consider demagnetizing effects in photomagnetic films.

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1. Introduction

Demagnetizing effects are important to consider for magnetic materials with shape anisotropy, and are particularly relevant for films with photoinduced magnetic order. It will be important to understand how demagnetization may alter the response of photomagnetic films as scientists look forward to potential device applications. While a wide variety of photomagnetic materials have been reported, the calculations herein were motivated by long-lived photoinduced magnetism in coordination polymers [1,2]. In such materials, the application of light may give rise to large changes in the bulk magnetization, caused by transitioning ions from diamagnetic to paramagnetic states. Furthermore, technologically relevant film morphologies of photomagnetic coordination polymers have been reported in the literature. These films have shown similar changes in magnetization with light as the bulk when the film planes are oriented parallel to applied magnetic field, but a reduction in the magnetic response when the film planes are oriented perpendicular to applied magnetic fields [3–5]. Moreover, certain preparation methods and experimental conditions can show a decrease in the bulk magnetization during photoirradiation, even while the total number of magnetic electrons is increasing [3,4]. Thin film studies of magnetic anisotropy in structural analogs to photomagnets that do not have a photoeffect have shown demagnetization to play a dominant role in the orientation dependence of the magnetic susceptibility [6,7]. These studies have provided motivation to explain magnetic anisotropy in photomagnetic films with the same underlying physical phenomenon of demagnetization.

In the present work, we seek to use the transparent formalism of demagnetization along with finite element analysis to explain the reported anisotropic response in photomagnetic thin films, emphasizing the importance of film microstructure. Specifically, we show how demagnetization can actually decrease the effective magnetic susceptibility while the amount of magnetic material increases. The results are presented in a general way so as to be applicable to more than just the case studies chosen.

2. Material and methods

All finite element calculations were performed on a standard desktop computer with free, open-source software using Python 2.6.5 with NumPy 1.6.1 and SciPy 0.7.2 libraries for use with the existing finite element package FiPy 2.1.1 [8]. Three dimensional square meshes with appropriate periodic boundary conditions were chosen for their stability, and results were checked to ensure no dependence upon grid density for the reported data. The magnetic potential formalism was used for its computational simplicity [9]. Demagnetizing factors were calculated by taking the average of the normalized internal magnetic field for a given magnetization distribution.

3. Theory/calculation

The internal field of a magnet can cause a decrease in the effective measuring field, as shown by

$$H_{eff} = H_{lab} - NM_{actual}, \quad (1)$$

* Corresponding author.
E-mail address: daniel@pajerowski.com (D.M. Pajerowski).

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where N is the geometrical demagnetizing factor, M_{actual} is the measured magnetization per unit volume, H_{lab} is the applied field in free space within the magnet coils, and H_{eff} is the effective field inside the material taking into account demagnetization. The bare magnetic susceptibility, χ_{bare}, is defined as the relationship between magnetization and effective magnetic field, namely

$$M_{actual} = \chi_{bare} H_{eff}, \tag{2}$$

while the effective magnetic susceptibility, χ_{eff}, is defined as the relationship between the magnetization and the lab magnetic field,

$$M_{actual} = \chi_{eff} H_{lab}. \tag{3}$$

Based upon these equations, a simple formula for the effective magnetic susceptibility is

$$\chi_{eff} = \frac{\chi_{bare}}{1+\chi_{bare} N}. \tag{4}$$

For the photomagnetic systems in question, the volume susceptibility is directly proportional to the amount of material in the magnetic or high-spin state, n_{HS}, such that

$$\chi_{bare} \rightarrow n_{HS}\chi_{bare} \tag{5}$$

and

$$\chi_{eff} = \frac{n_{HS}\chi_{bare}}{1+n_{HS}\chi_{bare} N}. \tag{6}$$

From Eq. (6), the photomagnetic response of a film will depend upon the demagnetizing factor, with the largest response being observed for small demagnetizing factors. By differentiating Eq. (6) with respect to n_{HS}, with only the explicit dependence upon n_{HS} and $\chi_{eff} > 0$, $\chi_{bare} > 0$, n_{HS} between 0 and 1, and N between 0 and 1, it is clear that there is no way to decrease the χ_{eff} while increasing n_{HS}. However, if the demagnetizing factor is allowed to depend upon the amount of magnetic material, the effective susceptibility will decrease if

$$\chi_{bare} \frac{\partial N}{\partial n_{HS}} {n_{HS}}^2 > 1. \tag{7}$$

Therefore, it is important to know how demagnetizing factors of a given system change as a function of the amount of magnetic material, and in the next section, model calculations of experimentally motivated morphologies are presented.

The limit of film thickness being negligible compared to breadth is assumed for all calculations, and this motivates the use of periodic boundary conditions within the plane of the film. For coherent domain growth models, the film is parameterized with CG, the ratio between the height of the film and the separation between magnetic growth nucleation sites. For random growth, the film is parameterized with RG, the ratio between the height of the film and the length of the randomly excited region. Coherent growth with dense site nucleation, $CG > 1$, is modeled using regularly growing cubes with uniform magnetization that are stacked to give integral values of CG. Coherent growth with sparse site nucleation, $CG < 1$, is similarly modeled with uniformly magnetized sheets in cells of varying size. The random growth process only allows for dense, $RG > 1$, configuration.

4. Results

The magnetic fields due to the previously mentioned photomagnetic growth models were calculated, and epitomic field

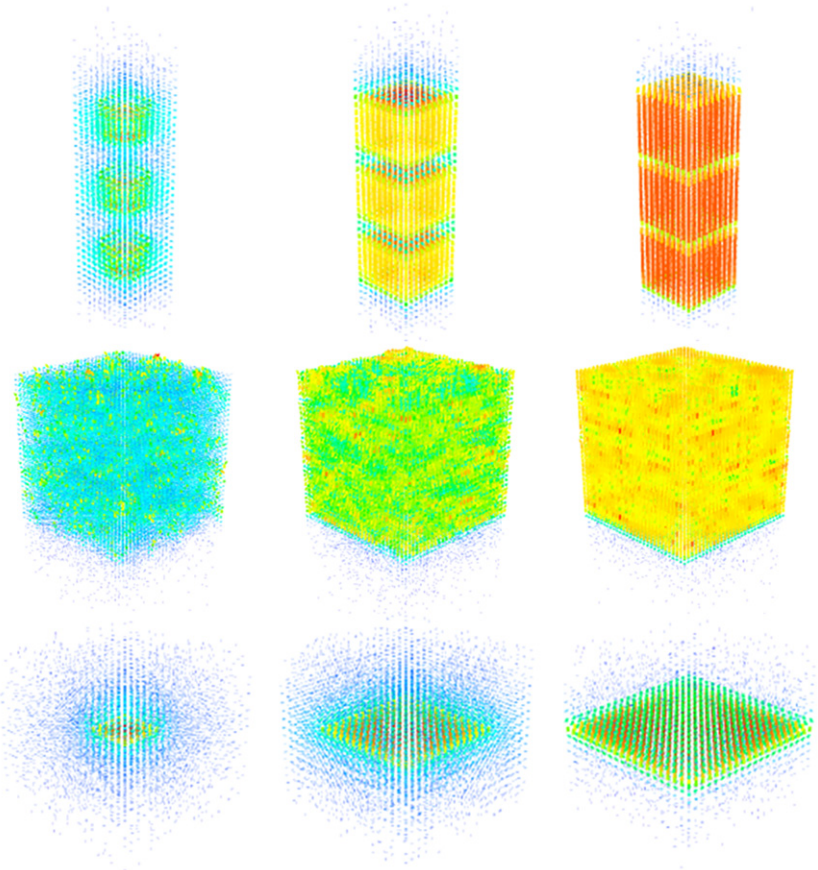

Fig. 1. Magnetic field distributions for photomagnetic growth processes. From left to right, n_{HS}=0.1, 0.5, and 0.9. (top row) Coherent growth with CG=3, (middle row) random growth with RG=50, and (bottom row) coherent growth with CG=0.05.