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THE EFFECT OF MAGNETIC DOMAINS ON MEASUREMENTS OF THE MAGNETOCALORIC EFFECT

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ABSTRACT — We discuss how magnetic domains influence the magnetic entropy change calculated from magnetisation data. In a simple qualitative model we show that the effect is to change the shape of the apparent isothermal entropy change curve compared to the true curve determined by the entropy. We further show that failure to correct for the magnetostatic demagnetisation will augment the apparent effect of domains.

1. INTRODUCTION

Magnetic domains are present in all soft magnetic materials at low fields: In zero applied field the total macroscopic magnetisation will be zero due to the formation of magnetic domains within the sample, even though the intrinsic equilibrium magnetisation is still non-zero. This difference between the measured bulk magnetisation of samples and the actual intrinsic one may give rise to a concern about the validity of the measured and reported isothermal entropy change, as this is usually calculated by integrating magnetisation data using Maxwell's relation. Indeed, the influence of magnetic domains on the calculated isothermal entropy change has previously been addressed [1, 2]. In both papers it is recommended that one should try to avoid domains and integrate only in the region of saturation, but also that actually defining this region was ambiguous and applying such a correction was probably not worth it. Here we show that for a soft low anisotropy magnetic material careful demagnetisation correction will reduce the effect of domains to a negligible level. This will be done using magnetisation data for a single sphere of commercial gadolinium with a mass of 1.96 mg, measured in a vibrating sample magnetometer (LakeShore 7407). Also, as finding the actual saturation magnetisation is notoriously difficult, we introduce a phenomenological method of introducing domain effects into the otherwise domain free Weiss mean field model.

2. RESULTS

Formation of domains at low applied fields is due to the magnetostatic energy advantage of reducing the magnetic field created outside the sample, seeking to contain the magnetic field within the sample. The removal of domains towards the saturation is initiated by the application of a magnetic field, moving the walls separating the domains in such a way as to increase the volume of those oriented along the field at the expense of the others. Finally the directions of magnetisation of the domains are rotated to be in line with the applied field in order to reach saturation. The elimination of the domains is limited by defects pinning the domain walls to hinder their movement as well as the magneto-crystalline anisotropy inhibiting the rotation of the magnetisation.

Fig. 1(a) shows the magnetisation data obtained from the Gd sphere in the temperature range of T = 250 – 320 K and applied field range of $\mu_0 H_{appl}$ = 0 – 1.5 T. In this field range, appropriate for applications, saturation, i.e. the removal of the influence of domains, is reached only at significant applied fields. Only a few geometries have a constant demagnetisation factor, the sphere being one of these with a factor of N = 1/3. Applying this correction to the data in Fig. 1(top) results in the data in Fig. 1(bottom), where it is clearly seen how the apparent effect of domains has been reduced, saturation being reached already below 0.1 T internal field.

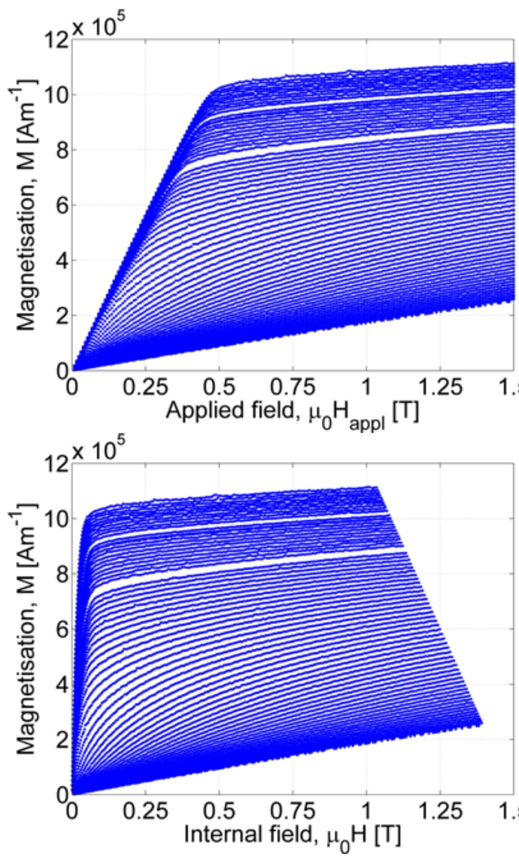

Fig 1. Top: Magnetisation of a single Gd sphere versus the applied field. Bottom: Same data corrected for demagnetisation.

Brown showed [3] how for an ideal ellipsoid, with negligible anisotropy, saturation is reached at an applied field of $-NM_{sat}$, equal to the demagnetising field. Thus, correcting for demagnetisation will remove the observed effects of domains. In real materials with shapes different from ellipsoids, impurities and anisotropy will impede saturation and distributions of N will complicate the demagnetisation correction. Focussing on gadolinium it has been shown how very pure Gd will saturate at very low fields [4, 5] due to the lack of defects and the very low crystalline anisotropy of Gd metal. Conversely, samples where a high crystalline anisotropy has been introduced by mechanical working will only saturate at very high applied fields [6].

The mean field model can be used to model the temperature and field dependence of the magnetisation [7], generally in good correspondence with measured data. Lacking spatial resolution and anisotropy the model is free of domains. In order to study how the changes in shape of the magnetisation curves affect the calculated entropy change we introduce a phenomenological correction to the mean field model magnetisation data

$$M_d(T,H) = M(T,H)\tanh\left(\frac{AM_{sat}}{M(T,0)}\mathrm{H}\right) \tag{1}$$

where saturation magnetisation, M_{sat}, is taken as the zero field magnetisation at the lowest temperature, H is the internal field and A is a constant related to the difficulty of removing the domains. Applying this correction to mean field model data, with A = 30, we can make it resemble that of the experimental data in Fig. 1. Also, Fig. 2 shows the corrected data added with the demagnetisation field from N = 1/3.

Using the mean field and two modified sets of magnetisation data from Fig. 2 we can now calculate the entropy changes using the Maxwell equation as shown in Fig. 3. It is seen that including domains only has a very minor effect on the calculated entropy change, far less than the effect of not correcting for demagnetisation. The FWHM in 1.0 T is reduced by 4%, due to the narrowing on the low temperature side. In the modelled magnetisation data resembling the experimental data on a single Gd sphere the constant A in (1) was set to 30. Decreasing A to 10 significantly increases the field at which the domains are fully removed to about 0.3 T, still the reduction in FWHM is only 16% in 1.0 T compared to the case without domains. At lower fields the relative importance of the domains in the field integral to find the entropy change will increase, further decreasing the FWHM.

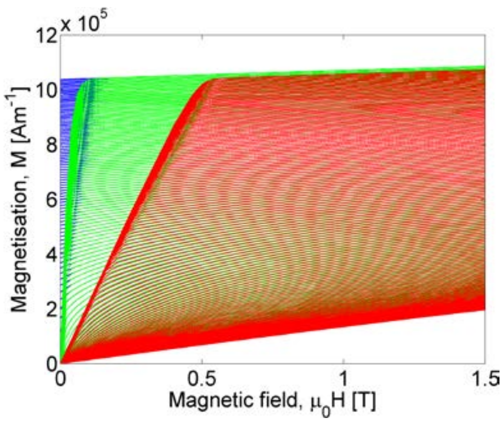

Fig. 2. Magnetisation data from the mean field model (blue), corrected to include domains using Eq. (1) (green) and corrected to include demagnetisation with N = 1/3.

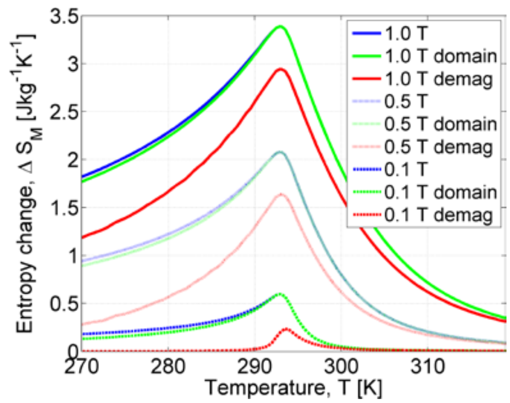

Fig. 3. Entropy change calculated from the data in Fig. 2 from an initial field of zero to the fields indicated in the legend.

3. Conclusion

In conclusion, for soft low anisotropy magnetocaloric materials, as are common in magnetocalorics, carefully correcting for demagnetisation will almost remove all effects of domains. Adequate correction requires an ellipsoidal sample with a constant demagnetisation factor, N. The presented phenomenological correction to mean field modelling is a useful way to explore the effect of domains.

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