Effect of Size Reductions on the Magnetostructural Transition in FeRh Thin Films

Melissa Loving and Laura H. Lewis

Department of Chemical Engineering, Northeastern University, Boston, MA

Introduction

Materials with coupled magnetic and structural phase changes — magnetostructural materials — have the potential to exhibit a large functional response to physical inputs such as small deviations in temperature, pressure, or magnetic field, and are thus of both technological and basic scientific interest. Equiatomic FeRh (α′-FeRh) is a model magnetostructural material with the chemically-ordered CsCl crystal structure. In bulk form, FeRh undergoes a first-order magnetic phase transition, with increasing temperature, from antiferromagnetic (AF) to ferromagnetic (FM) order (at T~370 K) with a 10 K thermal hysteresis; this change in the magnetic order is accompanied by a 1% volume expansion in the unit cell.[1, 2] Numerous studies have shown that the onset and character of the FeRh magnetostructural transition may be modified with changes in the applied magnetic field[3], strain (pressure)[4], composition[5], or volume[6,7]. However, to date the effects of finite size reduction on the magnetostructural character of α′-FeRh have not been subjected to deeper study. It is hypothesized that changes to the surface-to-volume ratio in α′-FeRh may offer a means of tailoring the magnetostructural transition to defined parameters leading to further advances and insight in the application of FeRh for future media[8] and sensor[9] devices.

Results and Discussion

To explore the effects of size reductions on the FeRh magnetostructural behavior, films of varying thicknesses (10 → 50 nm) have been deposited onto (001)-MgO. Information obtained from volume-averaged magnetic studies reveals that a reduction of the FeRh film thickness modifies the magnetic properties, as signaled by a reduction in the onset of T_t, an increase in the magnetic background signal and a broadened thermal hysteresis, Figure 1. The remainder of the results are focused on understanding the anomalous behavior of the magnetostructural transition of the 10 nm FeRh film.

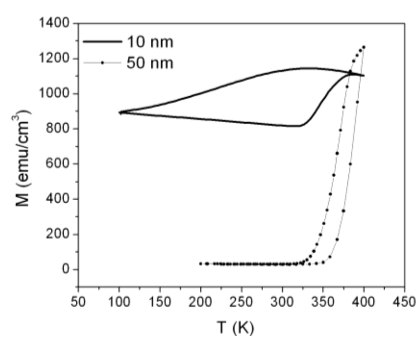

Figure 1: Magnetization vs. temperature measurements for representative 10 and 50 nm FeRh films in a 1 kOe applied magnetic field.

Structural studies confirm that the 10 nm FeRh film has a chemically-ordered CsCl-type α′-FeRh phase and a film-substrate orientation relationship of (001)-FeRh on (001)-MgO. Bragg reflections collected in the AF and FM states exhibit a shift to higher 2θ values when in the AF state, signaling the anticipated decrease in the FeRh unit cell volume, Figure 2(a). Interestingly, the AF FeRh Bragg reflections are asymmetric in nature as marked by a remnant tail suggesting the presence of an additional minor phase. This asymmetry is attributed to the presence of 1) the AF phase and 2) a remnant FM phase. Most interestingly, further structural analysis shows that the topography of the 10 nm FeRh forms a discontinuous, or island-like, architecture comprised of well-separated and non-uniform faceted particles, Figure 2(b). Overall, the anomalous behavior of the magnetostructural transition in the 10 nm FeRh film is attributed to a magnetic pinning mechanism induced by the enhancement of the FeRh surface morphology. Overall, these results are anticipated to contribute to future technological advances for sensor and media technologies.

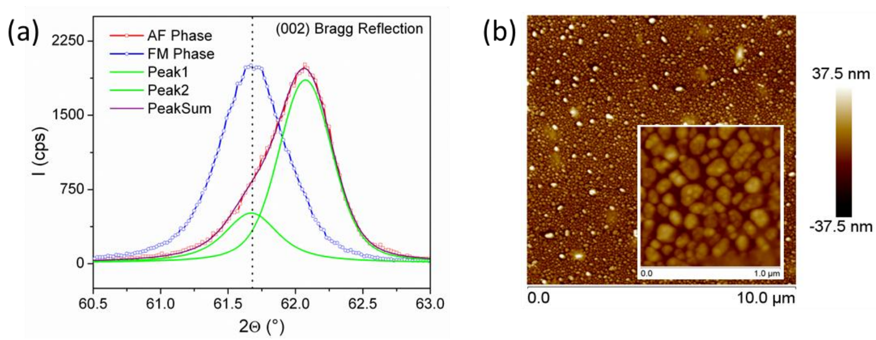

Figure 2: (a) (002) Bragg reflection obtained from the 10 nm FeRh in the AF and FM states (b) topography obtained with atomic force microscopy imaging which shows the formation of a discrete island-like archetecture

Acknowledgements: NSF - Grant No. DMR-0908767 and UK EPSRC - Grant No. EP/G065640/1.

References:

[1] M. Fallot, Ann. Phys. **10,** 291 (1938).
[2] A. I. Zakharov, A. M. Kadomtseva, R. Z. Levitin, and E. G. Ponyatovskii, J. Exp. Theor. Phys. **46,** 2003 (1964).
[3] S. Maat, J. U. Thiele, and E. E. Fullerton, Phys. Rev. B **72** (2005).
[4] Y. Ohtani and I. Hatakeyama, J Magn Magn Mater **131,** 339 (1994).
[5] J. V. Driel, R. Coehoorn, G. J. Strijkers, E. Brück, and F. R. d. Boer, J. App. Phys. **85** (1999).
[6] H. Y. Y. Ko, T. Suzuki, N. N. Phuoc, and J. Cao, J. Appl. Phys. **103,** 07D508 (2008).
[7] I. Suzuki, T. Koike, M. Itoh, T. Taniyama, and T. Sato, J Appl Phys **105** (2009).
[8] J. U. Thiele, S. Maat, and E. E. Fullerton, Appl Phys Lett **82,** 2859 (2003).
[9] J. U. Thiele, S. Maat, J. L. Robertson, and E. E. Fullerton, IEEE Trans. Magn. **40,** 2537 (2004).