

Matrix-induced strain effects on the magnetostructural response of Cu-embedded FeRh nanostructures

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Introduction

Materials systems which exhibit coupled magnetic and structural phase changes - magnetostructural transitions - are capable of providing large functional effects (such as giant magnetoresistance, giant magnetocaloric and giant volume magnetostriction effects) in response to perturbations in magnetic field, temperature and strain. Thus, magnetostructural materials may have significant potential for technological impact as they can be incorporated into a wide array of magnetic devices ranging from actuators to sensors. Based on theoretical predictions [1,2], it is hypothesized that nanostructuring may provide an alternative route for engineering magnetostructural phase transitions in functional materials systems due to enhancement of the surface to volume ratio. In this study, the near-equiatomic phase of FeRh serves as a test bed to explore the effects of nanostructuring on the magnetostructural response.

In its bulk form, $\text{Fe}_{1-x}\text{Rh}_x$ ($0.47 \leq x \leq 0.53$) has a cubic B2 ((CsCl)-type) crystal structure ($a=2.987 \text{ \AA}$) that exhibits an abrupt antiferromagnetic (AFM) to ferromagnetic (FM) transition at $T \sim 350 \text{ K}$ [2], accompanied by a unit cell volume increase of 1 % [3]. Comparison of the structural and magnetic properties of bulk and nanostructured forms of FeRh is anticipated to provide insight into the mechanism of magnetostructural phase transitions at the fundamental atomic level. Although extensive research has been carried out in the nanostructural scale on thin film forms of FeRh, very little work has been performed on FeRh nanoparticle systems.

Experimental Results & Discussion

In the current work, nanoprecipitates of FeRh ($\sim 10\text{-}15 \text{ nm}$) embedded in a Cu ribbon matrix were synthesized via heat treatment of a rapidly solidified alloy of composition $(\text{FeRh})_5\text{Cu}_{95}$. Characterization of the nanocomposite system using structural and magnetic probes indicates that the crystallographic and magnetic properties of the FeRh precipitates may be altered at the nanostructural scale by changing the annealing conditions of the $(\text{FeRh})_5\text{Cu}_{95}$ system.

Upon isochronal annealing in the temperature range $373 \text{ K} < T_a < 1073 \text{ K}$, the crystal structure of the FeRh nanoprecipitates evolves from a metastable tetragonal $L1_0$ structure ($a=4.32 \text{ \AA}$, $c=4.20 \text{ \AA}$) to the anticipated equilibrium B2 crystal structure (Fig. 1). A hysteretic magnetothermal transition, remarkably similar to the magnetostructural transition reported in bulk FeRh at $\sim 350 \text{ K}$, is observed in the nanostructured $L1_0$ -ordered FeRh phase, at $T \sim 100 \text{ K}$. The net magnetization of the $L1_0$ -ordered FeRh nanostructures at this transition increases upon annealing to higher temperatures and additional broadening is observed in the B2-ordered FeRh nanostructures. It is hypothesized that the Cu matrix influences the structure and magnetic character of the FeRh-based nanoparticles through interfacial strain.

These results emphasize the sensitivity of the magnetostructural response of FeRh to changes in the nanostructural scale. Further, it is important to note that the formation of the metastable $L1_0$ -ordered structure in nanoscaled FeRh systems has not been reported before, until now. Overall, the experimental evidence obtained in this study suggests that nanostructuring may provide a potential route for controlling magnetostructural phase transitions in functional materials systems that are expected to play a key role in the development of future nanodevice technologies.

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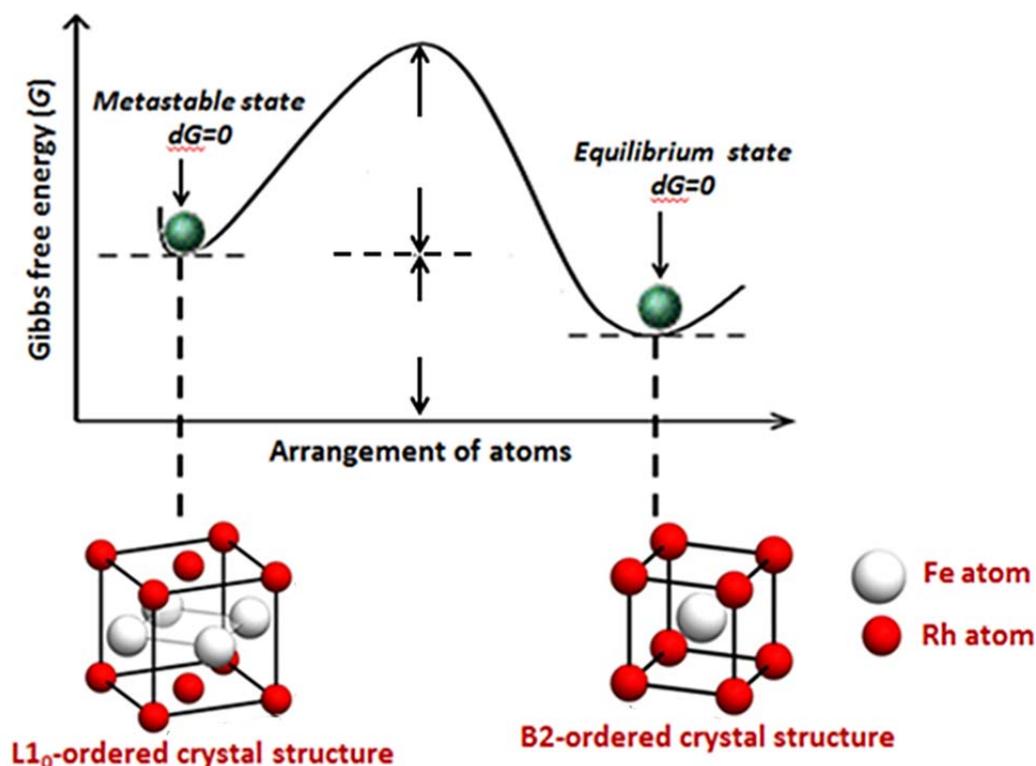


Figure 1. Schematic representation of variation of Gibbs free energy with the arrangement of atoms in the FeRh system. Upon annealing in the temperature range $373\text{ K} < T_a < 1073\text{ K}$, the crystal structure of the FeRh nanoprecipitates evolves from a metastable $L1_0$ structure to the anticipated equilibrium B2 crystal structure

References:

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