First-order Magnetic Phase Transition in FeRh–Pt Thin Films

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The first-order anti-ferromagnetic (AFM)-ferromagnetic (FM) phase transition in ordered FeRh alloy with CsCl structure is known to take place at about 100°C.1 This transition is accompanied by a unit cell volume expansion of 1%–2%, a reduction in resistivity, and a large entropy change.2 The transition temperature is sensitive to composition, thus can be tuned by doping additives such as Pt or Ir to above 200°C.3 However, the physical mechanism of the transition mechanism is not well understood.

FeRh$_{100-x}$Pt$_x$ thin films ($0 \leq x \leq 15$) were deposited onto (100)MgO substrate by an e-beam technique using Fe, Rh, and Pt targets at substrate temperature around 450 °C. The film thickness was around 50 nm. The as-deposited films were annealed in vacuum at 800 °C for 2 h to obtain chemically ordered CsCl structure.

The XRD and the φ scan patterns of FeRh$_{100-x}$Pt$_x$ thin films confirm they are of single crystalline of the ordered CsCl structure. The temperature dependent magnetization curves for FeRh$_{100-x}$Pt$_x$ thin films with $x$ are shown in Fig. 1. The transition temperature shifts to high temperature while the width of thermal hysteresis decreases, and there is little thermal hysteresis when $x=15$. The magnetization curves under different applied magnetic fields $H$ during heating and cooling processes are shown in Figs. 2(a) and (b) for Fe$_{50}$Rh$_{50}$ and (Fe$_{50}$Rh$_{50}$)$_{55}$Pt$_5$ thin films, respectively. As $H$ increases, the transition temperatures during heating and cooling processes all decreased linearly. With $x$, $(dT/dH)$ reduces from -8.6 to -3.3 K/T. This means that the effect of magnetic field is to stabilize the FM phase and consequently decrease the transition temperature. However, the effect of $H$ on the AFM/FM phase transition is restrained by the addition of Pt. The result of this applied magnetic field dependence on transition temperature in FeRh$_{100-x}$Pt$_x$ thin films is similar to the behavior observed in FeRh nanoparticles, FeRh$_{100-x}$Pt$_x$ thin films, bulk FeRh alloys, and Ru-doped CeFe$_2$ alloys.3-5

According to the magnetic Clausius–Clapeyron equation,3 the total entropy change ($\Delta S_{\text{total}}$ associated with the magnetic phase transition was calculated, which is shown in Figure 3. The entropy change ($\Delta S_{\text{latt}}$ contributed by the lattice distortion is also plotted using the equation $(\Delta S_{\text{latt}})=3\alpha(V/V_0)\kappa D$, where $\alpha$ is the thermal expansion coefficient, $(V/V_0)$ is a relative volume change, $\kappa$ volume compressibility, and $D$ density. It is seen that $\Delta S$ is much larger than $(\Delta S_{\text{latt}}$. This result suggests that the lattice entropy change is not a determining factor for the first-order AFM-FM phase transition in FeRh-based alloys, but the entropy change originates from a change in the magnetic moments on Rh atoms between the AFM and FM states at the phase transition.

Fig.1 Temperature dependence of magnetization for heating and cooling processes of FeRh$_{100-x}$Pt$_x$ thin films ($0 \leq x \leq 15$).

Fig.2 Magnetization curves in the presence of various applied fields in FeRh$_{100-x}$Pt$_x$ thin films.

Fig.3 Compositional dependence of total and lattice entropy in FeRh$_{100-x}$Pt$_x$ thin films.

References: