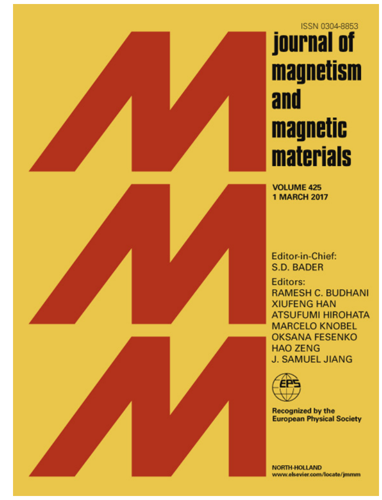

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PII: S0304-8853(18)30091-X
DOI: https://doi.org/10.1016/j.jmmm.2018.04.011
Reference: MAGMA 63857

To appear in: *Journal of Magnetism and Magnetic Materials*

Please cite this article as: B. Ravi Kumar, S.N. Kaul, Thickness as a control parameter for magnetocaloric effect in $Cr_{75-x}Fe_{25+x}$ (x = 0, 5) thin films, *Journal of Magnetism and Magnetic Materials* (2018), doi: https://doi.org/10.1016/j.jmmm.2018.04.011

Thickness as a control parameter for magnetocaloric effect in $Cr_{75-x}Fe_{25+x}$ (x = 0, 5) thin films

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Abstract

The results of a detailed investigation of the magnetocaloric effect (negative isothermal magnetic entropy change, -$\Delta S_M(T,H)$) in $Cr_{70}Fe_{30}$ and $Cr_{75}Fe_{25}$ thin films are presented. The generalized magnetic scaling equation of state in nonlinear scaling variables, which makes use of the previously reported critical exponents, not only reproduces the observed -$\Delta S_M(T)$ at constant magnetic fields (1 kOe $\leq H \leq$ 70 kOe) over a wide temperature range around the ferromagnetic-paramagnetic phase transition temperature, $T = T_c$, but also describes correctly the functional dependence of -ΔS_M on H at $T = T_c$. Reasonably large relative cooling power (RCP) and magnetic refrigerant capacity (RC), primarily due to the unusually large (130 K - 180 K) full-width at half-maximum (FWHM) of the -$\Delta S_M(T)|_H$ curve, is observed for the magnetic field change ranging between 20 kOe and 70 kOe. This work clearly bears out that the film thickness can be used as a control parameter to tune both the peak value of -ΔS_M as well as the FWHM, and hence RCP and RC. Another important result is the observation of giant isothermal magnetic entropy change at $T = 2$ K within the reentrant regime (where long-range ferromagnetic order coexists with cluster spin glass order) when the film thickness is reduced to $\simeq$ 20 nm.

Keywords: Magnetocaloric effect; Reetrant state; Relative cooling power; Magnetic refrigerant capacity; CrFe thin films.

1. Introduction

Ever-growing interest in the study of magnetocaloric effect (MCE) in magnetically-ordered materials basically stems from the realization that the MCE-based magnetic refrigeration is far superior to the conventional gas compression/expansion technology because it offers an ecofriendly (by completely avoiding the use of ozone-depleting, and hence environmentally harmful, gases), highly efficient, energy-saving and cost-effective technology. Historically, magnetic refrigeration came to be regarded as a viable alternative technology two decades ago when giant MCE was discovered [1] in the compound $Gd_5Si_2Ge_2$. Since then, MCE has been investigated in numerous magnetic alloys and compounds. The important findings are summarized in the review articles [2, 3, 4, 5, 6]. On the engineering front, prototype magnetic refrigerators have been built and tested [7, 8]. Such studies are mostly confined to bulk magnetic materials. Considering that the heat exchange between the MCE material of a refrigerator and the surroundings is a critical engineering requirement for the development of an efficient magnetic refrigerator, a high surface area-to-volume ratio, conducive for efficient heat transport, makes the MCE materials with reduced dimensions (e.g., thin films, ribbons and microwires) better suited for this technological application [9].

In this paper, we report novel aspects of magnetocaloric effect (MCE) in $Cr_{75-x}Fe_{25+x}$ (x = 0, 5) thin films. Following the customary practice, the isothermal magnetic entropy change -ΔS_M is calculated from the magnetization data taken as a function of the temperature at different but fixed magnetic fields, $M(T,H)$. These films exhibit two magnetic phase transitions: the ferromagnetic-paramagnetic phase transition at $T_c \simeq$ 160 K ($T_c \simeq$ 90 K) followed by the transition to the re-entrant state at $T_{RE} \simeq$ 10 K ($T_{RE} \simeq$ 20 K) in $Cr_{70}Fe_{30}$ ($Cr_{75}Fe_{25}$) thin films [10, 11]. At a given external magnetic field, H, -$\Delta S_M(T)$ goes through a peak at $T \simeq T_c$, as expected, but increases steeply as the temperature

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