Nano-device fabrication utilizing degree of freedom of multipoles of rare earth elements

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Magnetocaloric effect (MCE), displaying itself in production or absorption of heat by a magnetic material under the action of a magnetic field, has been extensively researched theoretically and experimentally in recent years, in order to find out promising materials exhibiting large MCE as magnetic refrigerants. Typically, investigation of MCE has been focused on ferromagnetic (FM) and antiferromagnetic (AFM) materials, because of the maximum value of isothermal magnetic entropy change (ΔS_M) in the vicinity of magnetic phase transition. For FM materials, the largest MCE is often obtained at the Curie temperature T_C.

In this project, the MCE of $TbMn_{1.8}Fe_{0.2}$ polycrystal and (Tm,Ho)Ga single crystals under modest magnetic fields have been investigated. Large ΔS_M and high relative cooling power (RCP) are both observed around T_C, with no thermal and magnetic hysteresis. Magnetization isotherms of $TbMn_{1.8}Fe_{0.2}$ are measured at various temperatures with increasing magnetic field from 0 to 7 T, and selected results are shown in Fig. 1. The behavior of the magnetization as a function of the magnetic field below $T_C \sim 80$ K is typical of a ferromagnet. Fig. 2 shows the calculated $-\Delta S_M(T)$ data from the M-H data in Fig. 1 with magnetic field changes ΔH = 1-7 T. Here the sign of ΔS_M is negative, indicating the FM nature of the compound. Around $T_C \sim 80$ K, the maximum values of magnetic entropy change ($-\Delta S_M^{max}$) and RCP go up with increasing field. The evaluated RCP for ΔH = 2, 5, 7 T are 235, 607 and 869 J kg^{-1}, respectively, as shown in the inset of Fig. 2. The correlative parameters of MCE in (Tm,Ho)Ga single crystals at ΔH = 5 T are listed in Table 1. It should be noted that, $-\Delta S_M^{max}$ = 26 J/(Kg K) for TmGa at T_C = 12 K and RCP = 1005 J/Kg for HoGa at T_C = 65 K. The obtained adiabatic temperature changes ΔT for these three samples are also quite large. These values make them ideal candidates for the active magnetic refrigerants working near the liquid nitrogen and hydrogen temperatures.

Table 1 The easy axis, transition temperature T_C, and the maximum values of magnetocaloric parameters ($-\Delta S_M^{max}$, RCP and ΔT^{max}) at 5 T for (Tm,Ho)Ga single crystals.

	Easy axis	T_C (K)	ΔS^{max} (J Kg^{-1} K^{-1})	ΔT^{max} (K)	RCP (J/Kg)
TmGa	a	12	26	12.9	468
HoGa	c	65	14.9	6.48	1005

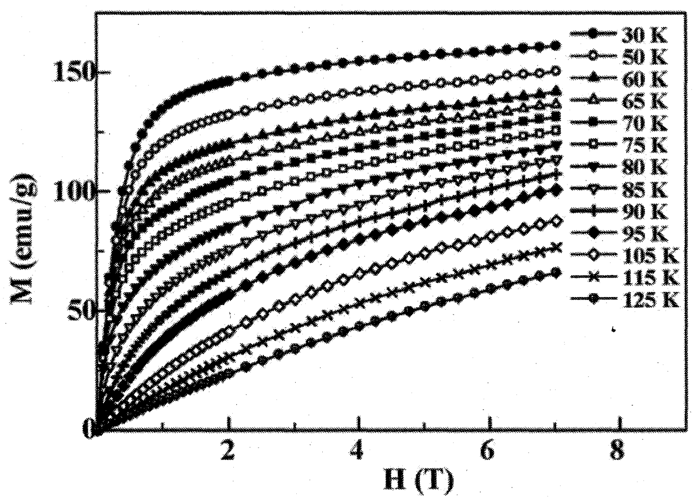

Fig. 1 Initial magnetization as a function of magnetic field at the temperatures indicated

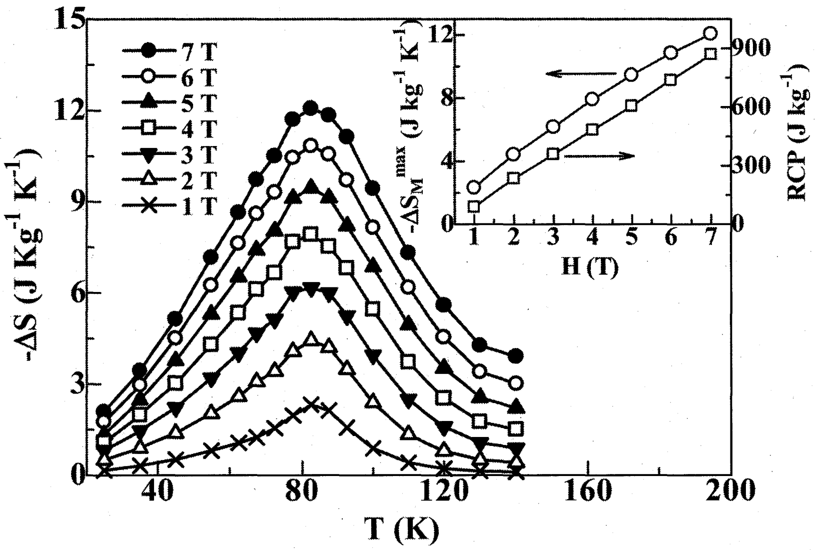

Fig. 2 Isothermal magnetic entropy change ($-\Delta S_M$) of polycrystalline $TbMn_{1.8}Fe_{0.2}$ as a function of temperature for magnetic field changes up to 7 T calculated from the magnetization isotherms. The maximum value of $-\Delta S_M$ and RCP around T_C as a function of magnetic field for $TbMn_{1.8}Fe_{0.2}$ are also shown in the inset.

Publications: 1) Reentrant spin-glass behavior induced by the frustration of Fe-Fe interactions in Laves phase $Nb_{1-x}Hf_xFe_2$ alloys: T. Gao et at., J. Appl. Phys. 111, (2012) 013913. 2) Large magnetocaloric effect in Laves phase $TbMn_{1.8}Fe_{0.2}$ compound over a wide temperature range: T. Gao et al., (submitted to J. Alloys Compd.). 3) Magnetic properties and magnetocaloric effect of HoGa and TmGa single crystals (submitted to Solid State Comm.)