Colossal Magnetocaloric Effect in Gd_2CrMnO_6 Oxide for Next-Generation Cooling

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Summary: Gd_2CrMnO_6, synthesized via the sol-gel technique, crystallizes in a single-phase orthorhombic (*Pbnm*) structure. Magnetic studies reveal multiple transitions AFM (95 K), spin reorientation (50 K), and Gd^{3+} ordering (11 K), with a second-order phase transition. Isothermal magnetization shows a high entropy change ΔS_m (~20.13 J/kg·K at 7 K) and the relative cooling power RCP (~390.7 J/kg at 70 kOe), making it promising for next-generation cooling.

Keywords: Magnetocaloric effect, Magnetic Refrigeration; Double Perovskite Oxide

1. Introduction

The global transition toward sustainable and energy-efficient cooling technologies has intensified interest in magnetocaloric materials as viable alternatives to conventional refrigeration systems. The magnetocaloric effect (MCE), wherein a material exhibits temperature variations under an applied magnetic field, offers an environmentally benign solution by eliminating reliance on harmful refrigerants. Among various magnetocaloric candidates, rare-earth-based double perovskites have emerged as promising materials due to their structural robustness, tunable electronic interactions, and superior thermal response, making them well-suited for cryogenic applications.

Gadolinium-based double perovskites, particularly Gd_2CrMnO_6, exhibit complex Gd^{3+}-Cr^{3+}-Mn^{3+} magnetic interactions, leading to multiple phase transitions and enhanced MCE behavior. Despite its potential, structural and magnetic properties remain underexplored. This study synthesizes and investigates Gd_2CrMnO_6, analyzing its structure, magnetic interactions, and phase transitions and evaluating its feasibility for advanced magnetocaloric applications and cryogenic refrigeration.

2. Results and discussion

The Rietveld refined XRD pattern of Gd_2CrMnO_6 (GDCMO) confirms its single-phase nature with an orthorhombic, *Pbnm* (62) space group. The refined lattice parameters a = 5.3165 Å, b = 5.5785 Å, c = 7.5730 Å and unit cell volume 224.601 Å³ align with the expected double perovskite structure. The Goldschmidt tolerance factor of 0.88 indicates octahedral distortion, ensuring structural stability. The average crystallite size, calculated via the Scherrer formula, is 57.43 nm, confirming the well-ordered microstructure.

The temperature-dependent magnetization M(T) of GDCMO, measured under a 100 Oe field in ZFC and FCC modes shown in Figure 1:(a), exhibits multiple magnetic transitions, indicating complex magnetic interactions. The ZFC-FCC divergence suggests magnetic frustration due to Cr^{3+}-Mn^{3+} mixed sublattices. The primary AFM transition at T_{N1}= 95 K is governed by Cr–O–Mn superexchange interactions. A spin reorientation transition (T_{SR} = 50 K) arises from competing anisotropies or structural distortions. At T_{N2} = 11 K, a secondary transition, likely due to Gd^{3+} ordering or a weak ferromagnetic (WFM) component, is observed. The dM/dT plot confirms these transitions illustrated in Figure 1: (a), establishing GDCMO as a potential magnetocaloric and spintronic material. The magnetocaloric (MC) properties of GDCMO were analyzed via isothermal magnetization curves from 3 K to 51 K under 0–70 kOe (Fig. a). The entropy change ($-\Delta S_m$), derived from Maxwell's relation, reaches a maximum value of 20.13 J/kg·K at 8 K, signifying a strong magnetocaloric response. Additionally, the relative cooling power (RCP), a measure of cooling efficiency, was found to be 390.7 J/kg, further reinforcing GDCMO's superior performance in cryogenic refrigeration applications.

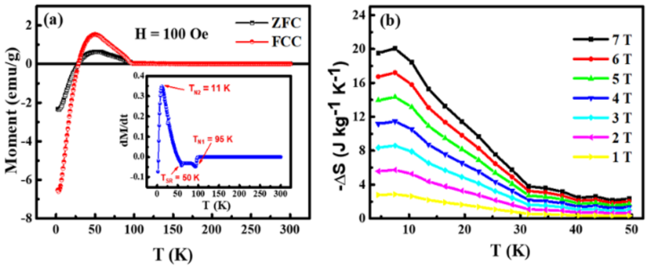

Figure 1: (a) M-T curves at 100 Oe both ZFC and FC, with inset showing dM/dT curve and (b) Magnetic entropy change ($-\Delta S_m$) vs. T under 0–7 T fields for Gd_2CrMnO_6 compound.

In conclusion, the Gd_2CrMnO_6 compound crystallizes in the orthorhombic *Pbnm* structure with high phase purity. Magnetization studies reveal AFM (95 K), spin reorientation (50 K), and Gd^{3+} ordering (11 K) due to Cr^{3+}-Mn^{3+} interactions. The MCE exhibits $-\Delta S_m$ ~20.13 J/kg·K (7 T) and RCP ~390.7 J/kg, making it a strong candidate for cryogenic magnetic refrigeration and spintronic applications.

References

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