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Magnetic irreversibility and spin dynamics in nanoparticles of iron-doped europium chromite

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Abstract

The magnetic properties of nanoparticles of $\text{Eu}_{1-x}\text{Fe}_x\text{CrO}_3$ ($0 \leq x \leq 1$) prepared by a combustion reaction technique were investigated. An irreversible behavior in the magnetization was observed for a sample with $x = 0.10$ below the Néel temperature (T_N) yielding a complex phase diagram. The irreversibility data was fitted to a de Almeida-Thouless line by using $\phi = 3.0$ for the critical exponent and a glassy temperature T_G of 174.4 K for $H \leq 40$ kOe. The dynamics of the spins was investigated by measuring the ac magnetic susceptibility (χ_{ac}) near T_N for frequencies (f) in the range $10 - 10^4$ Hz. The maximum in χ_{ac} was found to shift to higher values of T for increasing values of f , yielding $\simeq 0.003$ for the shift per decade of f parameter. The Vogel-Fulcher law and a power-law were used for analyzing χ_{ac} yielding $\tau_0 = 1.8 \times 10^{-9}$ s ($= 1.6 \times 10^{-15}$ s) for the characteristic relaxation time, $E_a/k_B = 39.23$ K for the activation energy and $T_G = 165.9$ K ($= 167.5$ K) for the Vogel-Fulcher (power-law) model. Moreover, the power-law yielded $z\nu = 5.62$ for the product of the dynamical critical exponent (ν) with the one associated to the correlation length (z). The dependence of T_N with the bonding angles $\text{Cr}^{3+}-\text{O}^{2-}-\text{Cr}^{3+}$ was investigated for as-prepared samples yielding a trend contrary to the expected. The overall results were accounted for by taking into consideration the microstrain introduced by the sample preparation technique and by the ionic doping.

1. Introduction

The rare-earth orthochromites $[\text{RE}]\text{CrO}_3$ are orthorhombic distorted perovskites that have been attracting considerable attention because of their potential in application such as multifunctional materials [1, 2]. These systems are isostructural with the rare-earth orthoferrites $[\text{RE}]\text{FeO}_3$ and they show physical and chemical properties that are strongly influenced by the rare-earth ion lying on the A-site of a perovskite structure [3, 4, 5]. $[\text{RE}]\text{CrO}_3$ presents a rich variety of magnetic spin interactions, namely $\text{Cr}^{3+} - \text{Cr}^{3+}$, $\text{Cr}^{3+} - [\text{RE}]^{3+}$ and $[\text{RE}]^{3+} - [\text{RE}]^{3+}$ that are highly temperature dependent [2, 6]. The easy-axis for the Cr^{3+} magnetic moments is along the c -axis direction of an orthorhombic cell while the magnetic structure is represented by the $\Gamma_4(G_x A_y F_z)$ configuration, with G_x , A_y , F_z being the components of the Cr^{3+} spins along the crystallographic directions a , b and c , respectively [5, 7, 8]. Magnetic data has indicated that the weak ferromagnetic moment of the Cr^{3+} spins below the Néel temperatures (T_N) arises from a Dzialoshinski-Moriya (D-M) type antisymmetric exchange interaction [1, 9]. Furthermore, the Néel temperature was found to be mainly determined by the $\text{Cr}^{3+} - \text{Cr}^{3+}$ antiferromagnetic coupling, increasing monotonically with the size of the ionic

radius in the lanthanide series. This behavior has been associated to the decreasing in the lattice distortions and to an increasing in the $\text{Cr}^{3+}-\text{O}^{2-}-\text{Cr}^{3+}$ distance which in turn varies the inter-cationic super-exchange interaction [6]. More recently, exchange-bias and spin-glass-like properties have also been reported in pure and in Ca-doped europium chromites [10, 11, 12].

Among the rare-earth orthochromites, the europium orthochromite (EuCrO_3) exhibits a weak spontaneous ferromagnetic moment below the Néel temperature that has been attributed to the ordering of the localized Cr^{3+} magnetic moments in a canted-antiferromagnetic (CAFM) phase [3, 7, 8]. It is also known that a net exchange interaction is produced in optically excited Eu^{3+} ions yielding a long-lived magnetically ordered state [13]. Thus EuCrO_3 have also been considered as an active medium for high-density optical storage and optical processing devices. Despite of its potential for applications, the magnetic properties of EuCrO_3 has not been fully investigated yet. For instance, it is believed that T_N is influenced by the bonding angle $\text{Cr}^{3+}-\text{O}^{2-}-\text{Cr}^{3+}$ (θ_B) but up to now there is no detailed investigation showing that this occurs indeed. Moreover, the nature of the spin-glass-like phase in these materials is not fully understood yet.

In this work, the magnetic properties of nanopowders of pure and Fe-doped europium chromite ($\text{Eu}_{1-x}\text{Fe}_x\text{CrO}_3$) samples prepared by a combustion reaction technique [14] are investigated. It is expected, for instance, that the dif-

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