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Journal of Magnetism and Magnetic Materials 290–291 (2005) 700–702
Journal of magnetism and magnetic materials
www.elsevier.com/locate/jmmm

Thermodynamic model of the magnetocaloric effect near the first-order magnetic phase transitions

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Available online 15 December 2004

Abstract

Magnetocaloric effect (MCE) arising in the materials with the first-order magnetic phase transitions (such as heavy rare earth metals, FeRh and GdSiGe alloys, lanthanides) has been considered in the framework of thermodynamic approach. The exchange, magnetoelastic, anisotropic and magnetic energy contributions to the MCE and their temperature dependences were calculated in the vicinity of the first-order transition. It was shown that the model adequately describes the MCE and gives the values of the adiabatic temperature change and isothermal magnetic entropy change, which are in accord with direct experimental measurements. Possible mechanisms of the MCE near the first-order transitions are discussed.

PACS: 75.30.Sg

Keywords: Magnetocaloric effect; Phase transitions—first order; Magnetic order

In recent years an interest to magnetocaloric effect (MCE) has essentially grown. This is connected first of all with its possible practical application in magnetic refrigerators, which can be highly effective and energy saving and where a magnetic material is used as a working body. It was established that the highest values of the MCE is observed near the magnetic phase transitions, in particular, near the first-order transitions accompanied by structural phase transitions, where magnetization and other magnetic characteristics of the material can be changed drastically by changing the temperature or external magnetic field. High MCE values were observed, in particular, in $Gd_5(Si–Ge)_4$ compounds with the first-order transitions accompanied by structural changes [1,2] and in $MnFeP_{1-x}As_x$ compounds [3]. In this article the question about the contributions is considered on the basis of a thermodynamical approach applied to the rare earth metals Tb, Dy, Er, and alloys $Tb_{0.5}Dy_{0.5}$ ($T_C = 220.6$, 85, 20, 146 K, respectively), $Fe_{0.49}Rh_{0.51}$ ($T_N = 308$ K) (near magnetic phase order–order transitions), and $Gd_5Si_{1.7}Ge_{2.3}$ ($T_C = 240.2$ K) and compound $Sm_{0.55}Sr_{0.45}MnO_3$ ($T_C = 128$ K) (near the order–disorder transitions) where the first-order transitions of different nature are observed.

For calculations a thermodynamic model of the first-order magnetic phase transition was used. The model considers a magnetic material in which one magnetic phase can be transformed to another by the field-induced first-order magnetic phase transition occurring at the certain critical value of magnetic field. In this case the Gibbs energy in the corresponding magnetic state

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doi:10.1016/j.jmmm.2004.11.341