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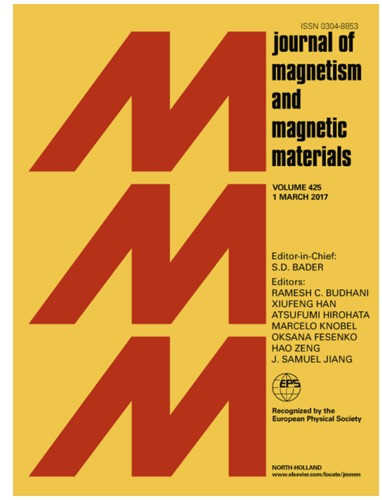

Research articles

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The magnetic state in the binary Dy_xGe_{1-x} ($x \leq 0.02$) alloy semiconductor

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Abstract

Diluted bulk magnetic alloy semiconductors Dy_xGe_{1-x} ($x \leq 0.02$) were prepared by a two-step fabrication procedure and studied experimentally by XRD, EDX and magnetic methods. The polycrystalline materials had the ccp (cubic closed-packed) structure of the host Germanium up to ≈ 2 at % of Dysprosium. They exhibited different low-temperature and high-temperature behavior. Low-field dc magnetic susceptibility data showed sharp peaks and irreversibility between zero-field cooled and field-cooled states for $x < 0.02$. A stable antiferromagnetic phase with temperature of the antiferromagnetic to paramagnetic transition T_N = 25 K was observed at x = 2 at % of Dysprosium. The solubility range of the binary Dy_xGe_{1-x} alloy system is limited to ~ 2 at % due to the large atomic radius of the solute. The low-temperature magnetic phase is characterized as spin-glass below 2 at %. The magnetic relaxation and non-linear susceptibility χ_{nl} of $Dy_{0.01}Ge_{0.99}$ were analyzed, and the spin-glass phase was defined with the critical exponents of the phase transition $\beta = 0.52 \pm 0.10$, $\gamma = 2.85 \pm 0.10$ and $\delta = 6.49 \pm 0.02$. From the Curie-Weiss behavior of the susceptibility at high temperatures, we determined an average effective Dy-Dy exchange constant J_1 = – 6. 90 K and effective magnetic moment per Dy ion $\mu_{eff} = 10.08\ \mu_B$. The rare-earth Dy atoms behave as isolated in Ge matrix at high-temperatures.

Keywords: dilute magnetic semiconductors; Germanium semiconductor; spin-glass transition; critical exponents; static scaling analysis

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1. Introduction

The nature and stability of the magnetic phase in diluted magnetic semiconductors (DMS) has been studied theoretically [1 - 5] to validate the room temperature (RT) ferromagnetism (FM) in semiconductors (SCs), and experimentally [6 - 10] to utilize additionally the spin of the SC carriers in combined, magnetic-memory and logic devices.

The FM phase is fragile and dependent on the ratio (n_c/n_i) in magnetically doped SCs; n_c and n_i are the carrier and dopant concentrations, respectively [1, 2]. The carrier concentration and the Fermi wave number (k_F) are related, $k_F \propto n_c^{1/3}$, and the dopant concentration determines the mean spacing (l_x) between the magnetic ions, $l_x \equiv n_i^{-1/3}$. For a FM ordering, l_x should be << $1/k_F$, thus $\frac{n_c}{n_i} < 1$; then the indirect, carrier mediated Ruderman-Kittel-Kasuya-Yosida interaction (RKKY) is not disrupted by the direct antiferromagnetic (AFM) coupling [2, 5]. The magnetic interaction may become random and the magnetic behavior spin-glass-like when short-range AFM coupled magnetic ions set in the RKKY wave upon increasing of the n_i [2, 5]. This becomes especially relevant in degenerate, magnetically-doped SCs for which k_F increases and l_x becomes commensurate with $1/k_F$.