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MAGNETIC PROPERTIES OF $\text{Sm}_{1-x}\text{Gd}_x\text{Mn}_2\text{Ge}_2$

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Abstract. — Magnetic phase diagram of $\text{Sm}_{1-x}\text{Gd}_x\text{Mn}_2\text{Ge}_2$ have been studied by susceptibility and magnetization measurements. The $p-T$ diagram was also determined. The results indicate that the transition from antiferro- to ferromagnetic phase is strongly coupled with interatomic distances.

Ternary $\text{RMn}_2\text{Ge}_2$ compounds (R is a rare earth element) crystallize in the body-centered tetragonal structure of $\text{ThCr}_2\text{Si}_2$ type which consists of R, Mn and Ge atom layers piled up along the c-axis (with the sequence R-Ge-Mn-Ge-R). The compounds exhibit interesting magnetic properties [1]. In $\text{SmMn}_2\text{Ge}_2$ three different magnetic ordering types were determined: ferromagnetism for $153 < T < 341$ K, antiferromagnetism for $106.5 < T < 153$ K and reentrant ferromagnetism below 106.5 K [2, 3]. $\text{GdMn}_2\text{Ge}_2$ is an antiferromagnet for $95 < T < 365$ K and a ferrimagnet below 95 K [4, 5].

The present paper reports the results of magnetometric measurements carried out on the $\text{Sm}_{1-x}\text{Gd}_x\text{Mn}_2\text{Ge}_2$ ($x = 0, 0.1, 0.15, 0.25, 0.3, 0.6, 0.7, 0.8, 1.0$) compounds. The pressure dependence of magnetic phase transition temperature is also reported.

The powder samples were prepared by a combination of arc melting and solid state diffusion techniques. The purity was $3N$ for Sm and Gd, $4N$ for Mn and $5N$ for Ge. The samples were melted and annealed for 100 h at 800 °C and then cooled down to room temperature.

X-ray diffraction studies were carried out using the DRON-3 diffractometer with CoKα radiation. At room temperature, the X-ray diffraction patterns of all samples consist of peaks characteristic for the $\text{ThCr}_2\text{Si}_2$-type structure only. Calculated on their bases lattice parameters indicate that with increasing Gd contents the lattice parameter $a$ decreases while the parameter $c$ is constant.

Magnetometric measurements were carried out in the temperature range 78-400 K by means of a modified Faraday method with a maximal external field of 10 kOe. Basing on the temperature dependence of magnetization the magnetic phase diagram was determined (Fig. 1).

At high temperatures all samples are paramagnetic while at low temperatures behaviour of the samples with $x < 0.6$ is different than the ones with $x > 0.6$. In case of $x < 0.6$ the samples are ferromagnetic at low temperatures, then they are antiferromagnetic and a further increase in the temperature leads to a new ferromagnetic ordering. The samples with $x > 0.6$ are ferrimagnetic at low temperatures and become antiferromagnetic while the temperature increases.

Pressure enhanced changes of temperature of magnetic phase transition were determined on the basis of magnetic susceptibility measurements which were carried out at pressures up to 1.5 GPa. The UNIPRESS compressor of IF-012 type was used and gaseous helium was the pressure transmitting medium. The signal from the magnetometer was measured by a selective nanovoltmeter. The whole experiment was performed under constant pressure. The samples were heated and cooled with the speed of 30 K/h.

Figure 2 shows the $(p, T)$ magnetic phase diagram for samples with $x = 0, 0.15$ and 0.6. For all the samples the $(p, T)$ diagrams are similar: the Curie temperature decreases slowly with pressure while the temperature of the F-AF transition increases with pressure almost linearly. With an increase of Gd concentration the region of antiferromagnetic order decreases. The value of the critical point decreases from $T_c = 341$ K...
Because at room temperature the $R_{\text{Mn-Mn}}$ distance exceeds slightly the critical value of 0.285 nm, so the Mn sublattice orders ferromagnetically. As the $R_{\text{Mn-Mn}}$ distance decreases with decreasing temperature it seems to be possible that below 153 K it becomes smaller than 0.285 nm and the coupling of Mn moments changes from ferro- to antiferromagnetic. In case of Sm$_{1-x}$Gd$_x$Mn$_2$Ge$_2$ the substitution of Gd for Sm leads to an increase in the lattice parameter $a$ and the region of antiferromagnetic ordering increases.

The results obtained in course of our study support the suggestion that in RMn$_2$Ge$_2$ family of compounds the antiferro- to ferromagnet transition is strongly coupled with the interatomic distances.

330 K and $p_c=1.0$ GPa for $x = 0$ to $T_c=310$ K and $p_c=0.39$ GPa for $x = 0.6$.

Magnetic properties of RMn$_2$Ge$_2$ compounds are very sensitive to the Mn-Mn interlayer distance. The Curie (or Néel) temperature of RMn$_2$X$_2$ compounds as a function of interatomic Mn-Mn distance (see Fig. 4 in Ref. [6] and Fig. 4 in Ref. [7]) is a universal curve when plotted versus $R_{\text{Mn-Mn}}^{\text{a}}$ but not versus $R_{\text{Mn-Mn}}^{\text{b}}$. There is a critical value of $R_{\text{Mn-Mn}}^{\text{a}} = 0.285$ nm it means that the coupling between the interlayer Mn moments is antiferromagnetic for $R_{\text{Mn-Mn}}^{\text{a}} < 0.285$ nm and becomes ferromagnetic for $R_{\text{Mn-Mn}}^{\text{a}} > 0.285$ nm.

Fig. 2. – The pressure-temperature diagram of Sm$_{1-x}$Gd$_x$Mn$_2$Ge$_2$ ($x = 0, 0.15, 0.6$) showing the paramagnetic, ferromagnetic and antiferromagnetic regions.