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MAGNETIZATION OF $Pb_{1-x}Cr_xTe$ SEMIMAGNETIC SEMICONDUCTOR

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We present experimental studies of magnetization of $Pb_{1-x}Cr_xTe$ ($x \leq 0.01$) crystals. The reasonable description of the data is obtained for a composition of $x \leq 0.001$ using Cr^{+++} model (Brillouin type paramagnetism $S = 3/2$).

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Recently synthesized semimagnetic semiconductors (SMSC) with chromium attracted considerable attention due to their interesting optical and magnetic properties [1]. It was found that magnetism of Cr based II–VI SMSC is substantially different from that observed for II–VI SMSC with Mn, Co or Fe, which is a consequence of a particular energy level structure of tetrahedrally coordinated Cr^{++} centers. On the other hand in IV–VI material a substitutional Cr^{++} (d^4) ion is octahedrally coordinated and therefore its energy structure should be analogous to that of tetrahedrally coordinated Fe^{++} (d^6) [2]. Eventually one should expect a typical Van Vleck-type behavior of the Cr^{++} center [3]. However, some of Cr^{++} ions autoionize to Cr^{+++} (d^3) centers, which should reveal a Brillouin type paramagnetism characterized by the spin $S = 3/2$.

In view of that we studied magnetization of PbCrTe in some detail. The crystals of $Pb_{1-x}Cr_xTe$ were synthesized by the Bridgman technique. A chromium concentration, checked by X-ray fluorescent analysis, was smaller than 1.5×10^{20} cm^{-3} ($x \leq 0.01$). The samples with a chromium composition of $x \geq 0.0015$ were n-type with a free carrier concentration 1.3×10^{19} cm^{-3}. Typically undoped PbTe samples grown by the Bridgman technique are p-type with a carrier concentration 3×10^{18} cm^{-3} originating mostly from Pb vacancies [4, 5]. Assuming a similar number of electrically active centers in our PbCrTe samples we expect up to 1.6×10^{19} cm^{-3} ionized Cr centers (in Cr^{+++} state). The existence of Cr^{+++} centers in these samples was confirmed by previous ESR studies [4]. We note that there were ferromagnetic precipitations in most of the samples. We used only the samples in which the amount of precipitations was relatively small.

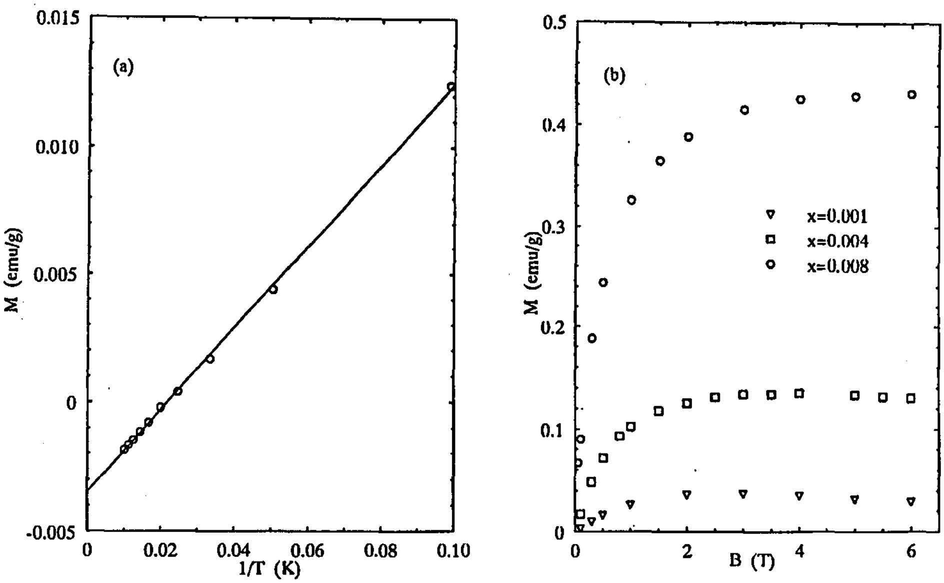

Fig. 1. Magnetization (for $B = 1T$) versus reversed temperature for $Pb_{1-x}Cr_xTe$ ($x = 0.001$), a solid line shows linear behaviour of the data; (b) raw magnetization data for $Pb_{1-x}Cr_xTe$ for three different chromium compositions.

The magnetization measurements were performed with SQUID magnetometer providing a magnetic field up to 6 T and a temperature range from 2 to 300 K. In Fig. 1a the magnetization as a function of reversed temperature is presented for $Pb_{1-x}Cr_xTe$ ($x = 0.001$). A linear dependence of the data obeys the Curie law. An extrapolation of the data to 0, in $1/T$ scale, provides a diamagnetic susceptibility of the host lattice $\chi_d = 3.5 \times 10^{-7}$ emu/g. Figure 1b shows a field dependence of raw magnetization in the temperature of 2 K for three samples with different chromium concentrations.

For $x < 0.001$ a reasonable description of the data is obtained assuming that all the Cr centers are ionized, as exemplified in Fig. 2a. The data were corrected for diamagnetism of the lattice ($\chi_d = 3.5 \times 10^{-7}$ emu/g) and ferromagnetic precipitations. In order to subtract the magnetization contribution resulting from the ferromagnetic precipitations we assumed that this contribution saturates in a very low field (smaller than 0.1 T). We assumed also that the remaining magnetization should be linear for $B < 0.2T$ and we subtracted a constant value from the measured signal to obtain such a linear behavior.

For higher x the data cannot be described by Cr^{+++} solely, which reflects the fact that only 1.5×10^{19} cm^{-3} Cr centers are in 3^+ state. In order to obtain the magnetization originating from not ionized centers, the Cr^{+++} (1.5×10^{19} cm^{-3}) contribution was subtracted from the data (corrected for lattice diamagnetism and precipitations). Both the raw magnetization data and data after subtraction for a sample with a higher ($x = 0.008$) Cr concentration is presented in Fig. 2b. Assuming that the remaining Cr centers are Cr^{++} it should be possible to describe

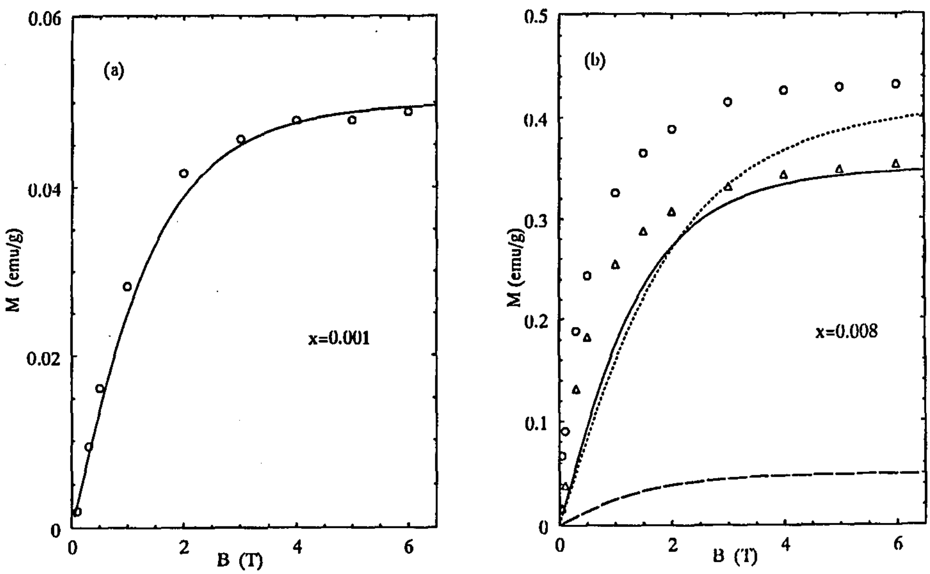

Fig. 2. Magnetization of $Pb_{1-x}Cr_xTe$ ($x = 0.001$, corrected for diamagnetism of host lattice and ferromagnetic precipitations) at $T = 2$ K. A solid line represents a Brillouin function for $S = 3/2$ (Cr^{+++}) and $x = 0.001$; (b) circles — magnetization of $Pb_{1-x}Cr_xTe$ ($x = 0.008$) as a function of magnetic field at $T = 2$ K, triangles — the data after subtraction of host lattice diamagnetism, ferromagnetic precipitations and Cr^{+++} contribution ($S = 3/2$, $x = 0.001$ — dashed line); a solid line represents a Brillouin function for $S = 3/2$, a dotted line — a crystal field model for an octahedrally coordinated Cr^{++} ion ($Dq = 300$ cm^{-1}, $\lambda = -50$ cm^{-1}).

the magnetization by the model similar to iron in II–VI compounds [3]. However there is no way to do that using any reasonable crystal field and spin–orbit interaction parameters. Magnetization saturates much faster than it is expected for any iron-like ion. Such fast saturation is appropriate for a very high spin value ($S = 4$ or more). We refrained from performing a detailed fit since no independent information about pair formation (chemical clustering, which could lead to such high spin values) is provided.

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