MAGNETIZATION OF Pb$_{1-x}$Cr$_x$Te SEMIMAGNETIC SEMICONDUCTOR

W. Mac$^a$, T. Story$^b$ and A. Twardowski$^a$

$^a$ Institute of Experimental Physics, Warsaw University
Hoża 69, 00-681 Warszawa, Poland
$^b$ Institute of Physics, Polish Academy of Sciences
Al. Lotników 32/46, 02-668 Warszawa, Poland

We present experimental studies of magnetization of Pb$_{1-x}$Cr$_x$Te ($x \leq 0.01$) 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$_x$Te were synthesized by the Bridgman technique. A chromium concentration, checked by X-ray fluorescent analysis, was smaller than $1.5 \times 10^{20}$ 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 $1.3 \times 10^{19}$ cm$^{-3}$. Typically undoped PbTe samples grown by the Bridgman technique are p-type with a carrier concentration $3 \times 10^{18}$ 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 $1.6 \times 10^{19}$ 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.
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_{x}Te (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 \( 1.5 \times 10^{19} \) cm\(^{-3}\) Cr centers are in 3\(^+\) state. In order to obtain the magnetization originating from not ionized centers, the Cr+++ (\( 1.5 \times 10^{19} \) 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...
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.

References


