INVESTIGATION OF $Cd_{1-x}Mn_xTe$ CRYSTALS ANNEALED IN A Cd MELT

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Abstract

$Cd_{1-x}Mn_xTe$ crystals are among the most efficient, from the practical point of view, semimagnetic semiconductors, which could be used in optoelectronic and magneto-optic devices [1, 2]. However, their using is limited by such factors as high concentration of inherited point-like defects and uncontrolled impurities, non-uniform distribution of the dissolved substance, presence of the inclusions of the second phase, mechanical stress, etc. The presence of these defects, first of all, is stipulated by the technological conditions of material fabrication [3, 4]. To decrease the number of defects, the annealing in the vapor or melt of components is carried out. In the given paper, the results of the investigation of the galvano-magnetic properties of $Cd_{1-x}Mn_xTe$ crystals annealed in a medium of cadmium are described.

1. Introduction

The parent $Cd_{1-x}Mn_xTe$ crystals were grown by Bridgeman method. Regardless the composition, all crystals have p-type conductivity [5], which indicates to the presence of inherited point-like defects, i.e., cadmium vacancies. The parent samples have a high resistance in the dark of $\sim 10^8$ Ohm, which under illumination decreases more than by an order of magnitude.

For the thermal annealing and also for the further measurements of galvanomagnetic properties, the crystals were prepared as follows. The samples of a rectangular form with dimensions of 0.2 x 0.2 x 1 cm^{-3} were polished using an M5 abrasive powder and then an ACM 3/2 diamond paste. The chemical etching was carried out in two stages: firstly, in a more concentrated 90% HBr + 10% Br_2 solution for 30 s and then in more diluted HBr + Br_2 (95% and 5%, respectively), which allows diminishing the crystal surface oxidation in contact with the air.

The annealing of the $Cd_{0.5}Mn_{0.5}Te$ samples was carried out under isothermal conditions at two different temperatures: 600^oC and 650^oC for 7 days. Pieces of the cadmium and $Cd_{0.5}Mn_{0.5}Te$ samples were placed in an ampoule. The samples were fixed in an especial holder placed at one of the ampoule edges. The cadmium amount was chosen so that, during annealing, samples were completely covered by the melt. At the termination of the annealing, the furnace was turned off, the melt flew to the ampoule bottom, and the sample remained in the holder. The sample surface after annealing was rather clean, the cadmium residues were removed by etching in HCl, and then the samples were subjected to a repeated mechanical and chemical treatment as it was shown above.

If the "parent" crystals exhibited p-type conductivity, then the change of conductivity type from p-type to n-type occurs in the cadmium melt as a result of the annealing. In addition, the resistivity of the samples decreases by 3-4 orders of magnitude.

2. Discussion

The Hall coefficient temperature dependence for $Cd_{0.5}Mn_{0.5}Te$ crystals annealed at 600°C (sample 1) and 650°C (samples 2 and 3) is given in Fig. 1. One should note that, for the samples annealed at 650°C, the electron concentration at 80 K is an order of magnitude higher than for the samples annealed at 600°C, and it is $(1…2) \cdot 10^{15}$ cm^{-3} and $3 \cdot 10^{14}$ cm^{-3} , respectively. All samples are characterized by the presence of a wide range of temperatures where the Hall coefficient and, accordingly, charge carrier concentration are constant. So, for sample 1, this range is up to 170 K; then Hall coefficient decreases almost by 2 orders of magnitude. In addition, the electron concentration increases up to $2 \cdot 10^{16}$ cm^{-3} at room temperature.

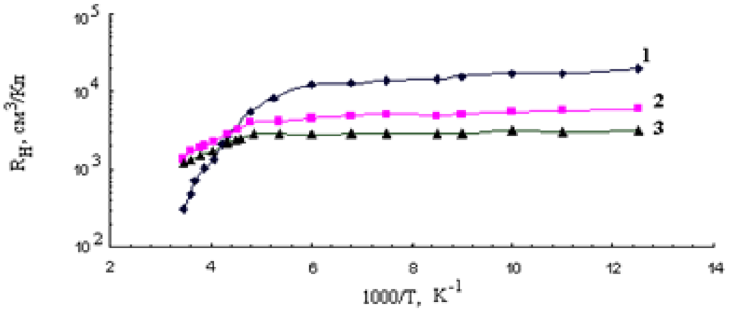

Fig. 1. Hall coefficient temperature dependence for $Cd_{0,5}Mn_{0,5}Te$ crystals annealed in Cd melt at 600ºC (1) and 650ºC (2,3)

The region of unchanged electron concentration for $Cd_{0.5}Mn_{0.5}Te$ crystals annealed at 650°C is wider. The Hall coefficient decrease is observed only at temperatures higher than 210 K, which is considerably less comparable than for sample 1, and electron concentration increases up to $(4…5) \cdot 10^{15}$ cm^{-3}. Taking into account that the studied temperature region corresponds to the impurity conductivity, for the determination of the activation energy, the lg $(n\cdot T^{-3/4}) = f(1000/T)$ dependences were plotted. The given dependences for the high temperature region where the concentration increase is more considerable are given in Fig. 2.

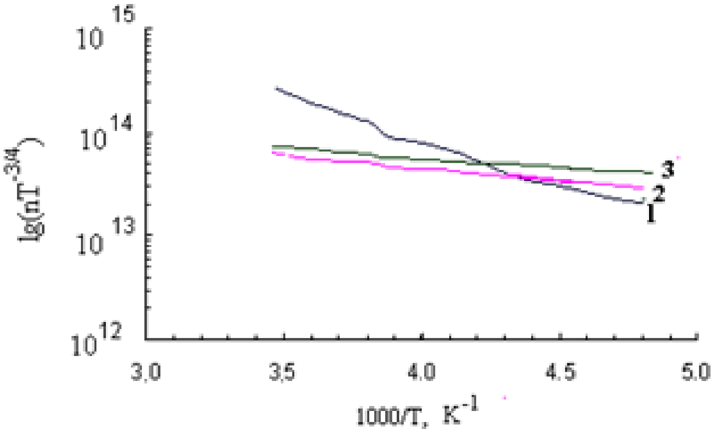

Fig. 2. Temperature dependence of charge carrier concentration for $Cd_{0,5}Mn_{0,5}Te$ crystals annealed in Cd melt at 600ºC (1) and 650ºC (2,3)

By using the relation

$$\Delta E = 2k \cdot \frac{\Delta \ln\left(n \cdot T^{-3/4}\right)}{\Delta\left(10^3/T\right)},$$

the impurity activation energy was estimated as ΔE = 0.37eV for the $Cd_{0.5}Mn_{0.5}Te$ crystals annealed at 600°C and ΔE = 0.37eV for the $Cd_{0.5}Mn_{0.5}Te$ crystals annealed at 650°C.

The electrical conductivity temperature dependences given in Fig. 3 at a considerable level are similar to charge carrier concentration temperature dependences. In the low temperature region (up to 170 K) for all samples the electrical conductivity increases insignificantly with increasing temperature. But at higher temperatures, a region of the activated conductivity is observed.

The mobility temperature dependences for the crystals annealed at 600^{o}C differ from μ (T) dependences for the crystals annealed at 650^{o}C (Fig. 4). So, in sample 1 with the lowest electron concentration, the charge carrier mobility decreases in the whole temperature region studied. In samples 2 and 3, which have electron concentration by an order of magnitude higher, in a temperature region of 80 to 200 K, the electron mobility increases and then remains practically constant with a further increase in temperature. Taking into account that, in many cases, the temperature dependence of charge carrier mobility is a power function of $\mu \sim T^{\nu}$ type, the power index ν was estimated to characterize the charge carrier dissipation mechanism. The following values for ν index were obtained: $\nu = -0.25$ for sample 1; $\nu = 0.62$ for sample 2, and $\nu = 1.5$ for sample 3. So, in the crystals with the higher electron concentration the dissipation on impurity ions is more considerable, but with the temperature increase, the part of dissipation on the lattice thermal oscillations becomes more considerable, which leads to a decrease in the charge carrier mobility with increasing temperature.

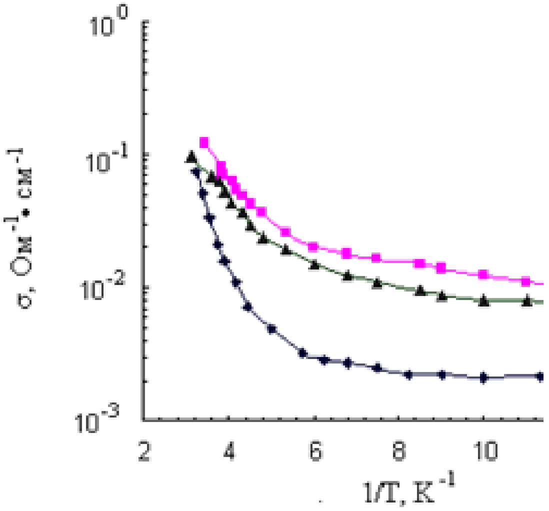

Fig. 3. Temperature dependence of electrical conductivity for $Cd_{0,5}Mn_{0,5}Te$ crystal annealed in Cd melt at 600ºC (1) and 650ºC (2,3)

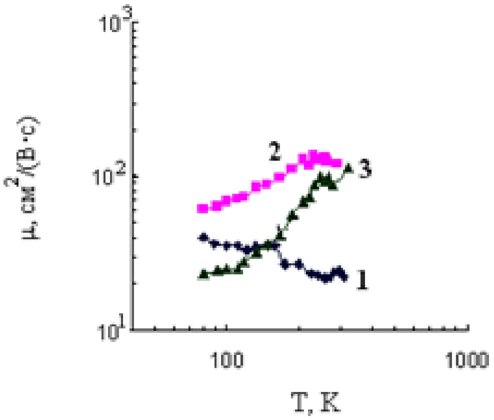

Fig. 4. Temperature dependence of charge carrier mobility for $Cd_{0,5}Mn_{0,5}Te$ crystal annealed in Cd melt at 600ºC (1) and 650ºC (2,3)

From the electrical conductivity temperature dependence, taking into account values of ν index, the $\ln \sigma \cdot T^{-(3/4+\nu)} = f(1/T)$ were plotted in the temperature region, which corresponds to the region of impurity activation, and the activation energy was estimated. The values of $\Delta E = 0.15$ eV were obtained for the sample annealed in Cd melt 650^{o}C and $\Delta E = 0.39$ eV for the sample annealed in the Cd melt at 600^{o}C, which correlates with the results obtained from the temperature dependence of charge carrier concentration.

Based on the experimental results, the following conclusions were made.

It is well-known that p-type conductivity of the undoped $Cd_{1-x}Mn_xTe$ crystals is stipulated by cadmium vacancies. During the thermal annealing, the diffusion of the Cd atoms occurs; they occupy the metal vacancies; this, in turn, leads to the “liberation” of the uncontrolled impurity.

Based on the obtained results, we suppose that, after annealing at 600^{o}C, the concentration of Cd vacancies nevertheless remains considerable and the shallow impurities compensate them. Thus, from this shallow donor levels the electron activation in the conduction band does not occur with increasing temperature. The electron activation occurs from the deeper levels, stipulated also by the uncontrolled donor impurity which is placed ~0.37 eV lower to the bottom of the conductivity band. The annealing at 650°C leads to the introduction of the high amount of Cd atoms in $Cd_{0.5}Mn_{0.5}Te$ crystals. The shallow donors do not participate in the compensation of cadmium vacancies, and a slope corresponding to the energetic position of the shallow impurity position of ~0.15 eV occurs on the concentration temperature dependence.

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