

Dielectric Permittivity and Conductivity in $Cd_{1-x}Fe_xTe$ Semimagnetic Semiconductors

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Abstract—This paper presents results of dielectric permittivity and conductivity measurements performed at alternating current for semimagnetic semiconductors $Cd_{1-x}Fe_xTe$ ($x = 0.08$) within the frequency range of $1\text{kHz} \leq f \leq 1\text{MHz}$ and in the temperature area $T = 110\div 465\text{K}$. It was defined that conductivity and dielectric permittivity increase with an increase in the Fe concentration. An anomaly is observed in the temperature dependence of the dielectric permittivity and relaxation in the frequency dependence. Taking into account the nature of the dependences, the possibility of ionic conductivity in the crystal is assumed.

Keywords—Semimagnetic semiconductor, dielectric permittivity, conductivity, frequency, temperature.

I. INTRODUCTION

Semimagnetic semiconductors (SMSC) - are ternary or quaternary semiconductors whose cations are partially replaced by a controlled amount of divalent transition-metal or rare-earth ions. $Cd_{1-x}Fe_xTe$ belonging to the least studied II-VI group alloys

In works [1-8] were carried out studies of the dielectric permittivity and conductivity of

$Cd_{1-x}Fe_xTe$ ($0.01 \leq x \leq 0.05$) within the frequency range of $25\text{Hz} \leq f \leq 1\text{MHz}$. From measurements of dielectric permittivity, conductivity and electron paramagnetic resonance three regions of concentrations were defined that differ in the number of Fe atoms in elementary tetrahedron $Cd_{1-x}Fe_xTe$. The first region, $x \leq 0.03$, is characterized by the temperature - frequency dependences of the conductivity and dielectric permittivity, which indicates hopping mechanism of charge transfer. Based the results of changes in the dependence of the activation energy dielectric permittivity on the concentration of Fe atoms, it is suggested that there are defects in this region, including 1 and 2 iron atoms. Further rearrangement of tetrahedra occurs in the $Cd_{1-x}Fe_xTe$ $0.03 \leq x \leq 0.045$ with the appearance of three Fe atoms in them. This is indicated by and a change in the nature of conductivity on a variable current is the transition from hopping to band conductivity, and also the disappearance of additional polarization of materials.

Increasing x to 0.05 results in a line EPR with a width of $\sim 2500\text{G}$. This line is associated with the appearance of clusters with a high iron concentration [1-3]. In work [4] the Fe-doped $Cd_{1-x}Fe_xTe$ samples show significant local structural variations upon $x=0.08$ Fe concentration that is mainly attributed to the redistribution of Cd atoms from their original locations.

In our previous works we studied dielectric properties of $Cd_{1-x}Fe_xTe$ SMSC at Fe concentration $0 \leq x \leq 0.03$ and effect of γ -irradiation on them [5-9]. This work presents results of experimental studies of the dielectric properties of $Cd_{1-x}Fe_xTe$ SMSC at $x=0.08$ concentration. It have been investigated temperature-frequency dependences of dielectric permittivity and conductivity of $Cd_{1-x}Fe_xTe$ ($x = 0.08$) at the measuring field frequencies $f = 1\text{kHz} - 1\text{MHz}$ in the temperature range $T = 110\div 465\text{K}$.

II. EXPERIMENTAL

The $Cd_{1-x}Fe_xTe$ ($x = 0.08$) SMSC were synthesized by alloying primary components (purity no less than 99.99) in evacuated quartz cells. The tetragonal axis c of the freshly cleaved rectangular crystal samples prepared for study was oriented in the cleavage plane. Crystal structure has been studied by X-ray diffraction method on the Bruker D8 Advance X-ray diffractometer. The capacitance, resistance, dielectric permittivity and conductivity were studied using an E7-20 LCR meter in the temperature range $T = 110\div 465\text{K}$. The measuring field amplitude did not exceed 1V/cm . The sample sizes were 0.35mm , 0.5mm , 0.2mm . To measure the temperature dependences of the $Cd_{1-x}Fe_xTe$ crystal conductivity and impedance, capacitors with insulating plates made of the materials under study were fabricated. Conductive layers were obtained by applying a silver paste onto the plate surface.

III. RESULTS AND DISCUSSION

Crystal structure of $Cd_{1-x}Fe_xTe$ ($x=0.08$) solid solutions, studied by X-ray diffraction method is shown in fig. 1. It was defined, that the $Cd_{1-x}Fe_xTe$ ($x=0.08$) solid solutions have a cubic crystal structure with a lattice parameter $a = 6.47\text{Å}$.

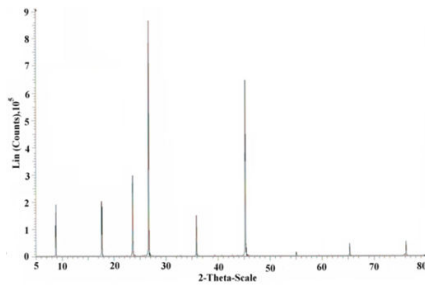


Fig.1. XRD spectra of Cd_{1-x}Fe_xTe (x = 0.08) solid solutions

The temperature-frequency dependences of dielectric permittivity of Cd_{1-x}Fe_xTe (x = 0.08) were studied at the measuring field frequencies 1 kHz–1 MHz in the temperature range T = 110÷465 K (fig. 2). As seen in fig. 2, the dielectric permittivity remains constant over the entire measured frequency range at low temperatures T = 110÷250 K. A further increase in the temperature T > 250K leads to an increase in the permittivity ε'. The higher the measuring field frequency, the later the growth begins. The slope of the curves obtained at low frequencies up to a frequency of about f < 200 kHz remains constant, at frequencies above f > 200 kHz, an increase appears with a tendency towards saturation. There are two maximums at the temperatures 413 and 461 K at the frequencies 1 kHz and frequencies 10 kHz, however for Cd_{1-x}Fe_xTe (0 ≤ x ≤ 0.03) there is only one maximum at the temperature 500 K. With increase of the measured frequency the features on curves ε'(T) shifted to lower temperatures, and the corresponding values fall.

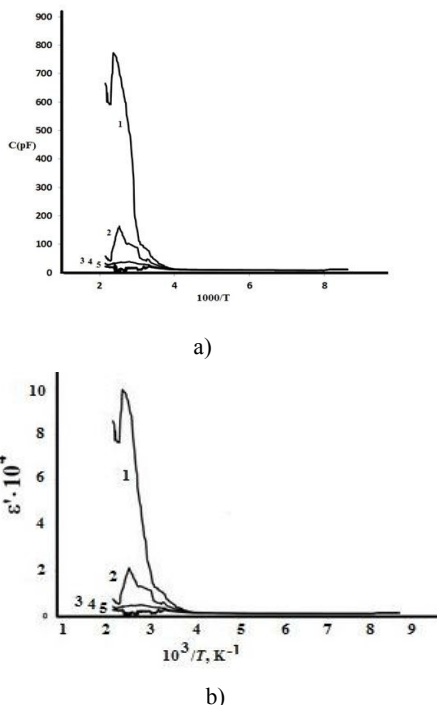


Fig.2 Temperature-frequency dependences of capacitance (a) and dielectric permittivity (b) of Cd_{1-x}Fe_xTe (x=0.08) solid solutions: 1- 1 kHz, 2-10 kHz, 3 -200 kHz, 4 -500 kHz, 5 -1MHz

Comparison of obtained results with temperature-frequency dependences of dielectric permittivity of Cd_{1-x}Fe_xTe (0 ≤ x ≤

0.03) [9], show that dielectric permittivity increase with an increase in the Fe concentration to x=0.08 and maximum of curves in the temperature-frequency dependences of the dielectric permittivity shifts to lower temperatures (table 1).

Table 1. Dielectric permittivity and conductivity of Cd_{1-x}Fe_xTe (0 ≤ x ≤ 0.08)

x	E _g , eV	T, K (ε' max)	ε'	σ, Ω ⁻¹ cm ⁻¹
0	1.53	500	2000	0.0006
0.03	1.56	500	17000	0.025
0.08	1.63	413 and 461	20000	0.25

Fig.3 shows the dependences of ln(ε') on 1000/T. We can see that the experimental points are well fitted by a straight line according to the equation:

$$\varepsilon(T) = \varepsilon_0 \exp(-\Delta E_a / kT), \quad (1)$$

where ΔE_a is the activation energy, k is the Boltzmann constant. Activation energy is found by the equation (1) E_a = 0.38 eV. It is observed an anomaly in fig.3.

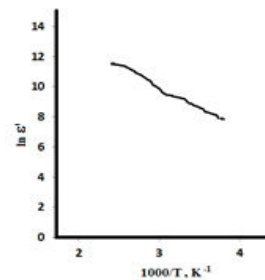


Fig.3 The dependences of ln(ε') on 1000/T of Cd_{1-x}Fe_xTe (x=0.08) solid solutions, f= 1kHz

Fig.4 shows frequency dependence of the dielectric permittivity for Cd_{1-x}Fe_xTe (x = 0.08) at T = 166 K. As seen in fig.4, the dispersion of the dielectric permittivity has a relaxation character.

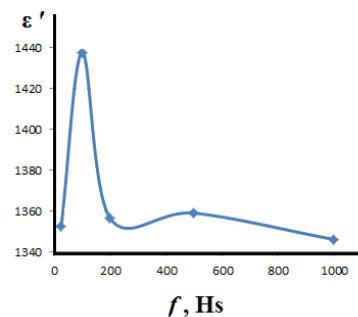


Fig.4 Frequency dependence of dielectric permittivity for Cd_{1-x}Fe_xTe (x = 0.08) at T = 166 K

The conductivity of the $\text{Cd}_{1-x}\text{Fe}_x\text{Te}$ ($x=0.08$) solid solutions were studied in the temperature range $T = 110\div 465$ K and at the measuring field frequencies 1 kHz–1 MHz. Fig. 4 shows the temperature dependences of conductivity for the $\text{Cd}_{1-x}\text{Fe}_x\text{Te}$ ($x=0.08$) solid solutions. It was defined that up to a frequency $f < 500$ kHz, σ increases, and at a temperature $T = 250$ K, a sharp increase in the curves occurs. The slope of the curves obtained at different measuring field frequencies remains constant. At frequencies $f > 500$ kHz, a further increase appears with a tendency towards saturation. The dependences of $\ln(\sigma)$ on $1000/T$ show that the experimental points are well fitted by a straight line (fig. 5).

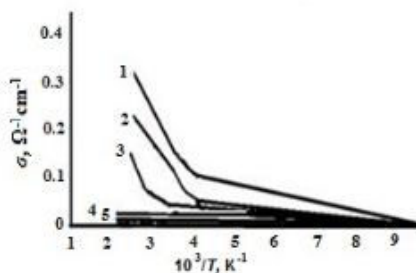


Fig.5 Temperature dependences of conductivity σ of $\text{Cd}_{1-x}\text{Fe}_x\text{Te}$ ($x=0.08$) solid solutions: 1-1kHz, 2-10 kHz, 3 -200 kHz, 4 -500 kHz, 5 -1MHz

Results of conductivity of the $\text{Cd}_{1-x}\text{Fe}_x\text{Te}$ ($0 \leq x \leq 0.08$) show that the conductivity increase with an increase in the Fe concentration to $x=0.08$ and maximum of curves in the temperature-frequency dependences of the conductivity shifts to lower temperatures (table 1).

IV. CONCLUSION

The temperature-frequency dependences of the dielectric permittivity and conductivity of $\text{Cd}_{1-x}\text{Fe}_x\text{Te}$ ($x=0.08$) SMSC have been studied. Along with the temperature growth the segment of dielectric permittivity and conductivity increase gets shifted to the area of higher frequencies. It was defined that conductivity and dielectric permittivity increase with an increase in the Fe concentration of $\text{Cd}_{1-x}\text{Fe}_x\text{Te}$ SMSC and maximum of curves in the temperature-frequency dependences of the dielectric permittivity and conductivity shifts to lower temperatures (about room temperature). An anomaly is observed in the temperature dependence of the dielectric permittivity and relaxation in the frequency dependence. Taking into account the nature of the dependences, the possibility of ionic conductivity in the crystal is assumed.

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