Electrical Properties of CdFeSe, CdMnTe Epitaxial Films

[1]MEHRABOVA M. A., [2]HASANOV N.H., [3]GULUZADE V.G., [4]SADIGOV R.M.
[1]Institute of Radiation Problems, Azerbaijan National Academy of Sciences,
1143, B.Vahabzade, 9, Baku, AZERBAIJAN
[2]Baku State University, 1148, Z.Khalilov, 23, Baku, AZERBAIJAN
[3]Azerbaijan Technical University, 1073, H. Javid ave. 25, Baku, AZERBAIJAN
[2]Institute of Physics, Azerbaijan National Academy of Sciences,
1143, H.Javid ave. 131, Baku, AZERBAIJAN

Abstract: - Optimal conditions of obtaining perfect $Cd_{1-x}Fe_xSe$ (x<0.08) and $Cd_{1-x}Mn_xTe$ (x=0.15) epitaxial films are defined. The electrical properties of $Cd_{1-x}Fe_xSe$ (x<0.08) and $Cd_{1-x}Mn_xTe$ (x=0.15) epitaxial films have been studied at room temperature. It was defined that $Cd_{1-x}Fe_xSe$ semimagnetic semiconductor epitaxial films are of *n*-type and $Cd_{1-x}Mn_xTe$ *p*-type. Electrical resistivity was defined 14.4 $\cdot 10^7$ Ohm·cm. The effect of γ-irradiation on VAC of $Cd_{1-x}Mn_xTe$ epitaxial films is studied at doses $D_\gamma \leq 1.5$ кGy.

Key-Words: - Semimagnetic semiconductors, molecular beam condensation, XRD, SEM, electrical, VAC

Received: April 18, 2021. Revised: April 12, 2022. Accepted: May 5, 2022. Published: June 6, 2022.

1 Introduction

Semimagnetic semiconductors (SMSC) are of II-VI and IV-VI group compounds in which a fraction of nonmagnetic cations has been substituted by magnetic transition metal ions. Most of the research performed so far on these materials has been devoted to Mn-based SMSC, which represents a rather simple magnetic case, since the Mn^{+2} ions possess only spin momentum (S = 5/2, L = 0) [1-4].

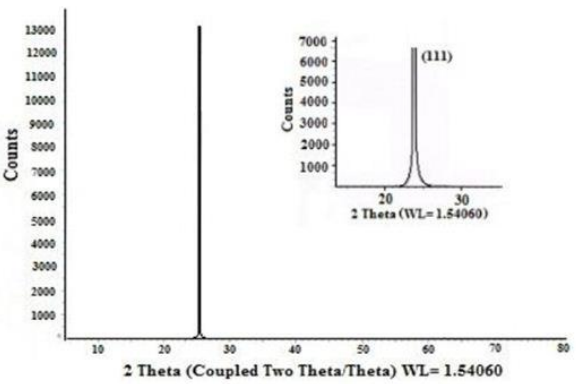
A natural development of SMSC is growing crystals with other transition metals, in particular, with Fe^{+2}. Materials based on Fe are not a simple extension of the SMSC family, since the physical situation, in this case, differs completely from that of Mn: substitutional Fe^{+2} possesses both spin and orbital momenta (S = 2, L = 2). The problem of the Fe^{+2} dopant in II-VI compounds has been studied for a long time. Unlike the well-known Mn-based DMS [5], the Fe-based II-VI compounds show a very low solubility of Fe, creating some difficulties in obtaining single - phase samples for studying the electronic properties. The $Cd_{1-x}Fe_xSe$ DMS are single-phase for x < 0.15. In $Cd_{1-x}Fe_xSe$ the transition metal Fe^{2+} ions replace randomly the Cd cations in the wurtzite structure of the host CdSe crystal [2]. Similarly to the Mn-based DMS's [6,7], there is a large exchange interaction between the Fe 3*d* electrons, which leads to the spin splitting of the Fe 3*d* states into two groups of sublevels (spin-up and spin-down).

In this work the conditions of obtaining perfect $Cd_{1-x}Fe_xSe$ (x < 0.08) and $Cd_{1-x}Mn_xTe$ (x = 0.15) epitaxial films and study of their electrical properties have been studied.

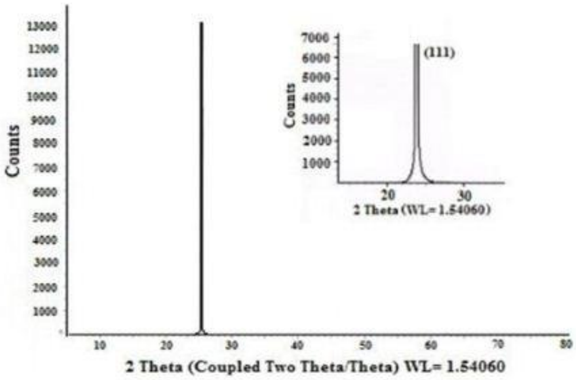
2 Experimental

Thin films of $Cd_{1-x}Fe_xSe$ (x < 0.08) and $Cd_{1-x}Mn_xTe$ (x=0.15) epitaxial films were obtained by the Molecular Beam Condensation method in a vacuum of (1÷2)10^{-4} Pa on glass substrates. It is determined the optimal conditions to obtain epitaxial films with perfect structure and a clean, smooth surface. The substrate temperature was T_{sub}=640 ÷ 670K and source temperature was T_{sub} = 1100 ÷1200K. Epitaxial films were growing in the (111) plane of a face-centered cubic lattice.

Crystal structure of investigated epitaxial films was studied by X-ray diffraction (XRD) method on Bruker, Germany D8 ADVANGE X-ray diffractometer. XRD studies show that thin films grown on glass substrates at temperature T_{sub} = 640 ÷670 K have a monocrystalline (fig.1,a) and polycrystalline (fig.1,b) structures. To characterize a film quality, the full width at half maximum (FWHM) of diffraction peak is used. The FWHM of diffraction peak for $Cd_{1-x}Fe_xSe$ (x = 0.04) is $W_{1/2}$ = 1000-1100” (fig.1,a, insertion) and for $Cd_{1-x}Mn_xTe$ (x = 0.15) is $W_{1/2}$ = 1000-1100” (fig.1,b, insertion).



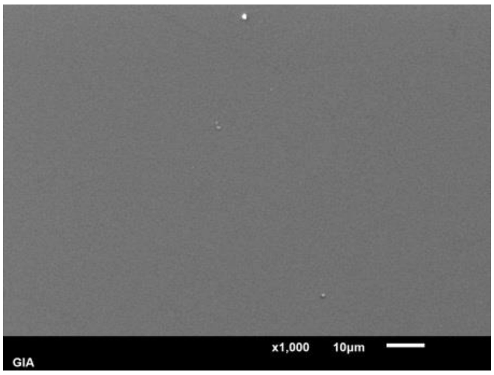
a)



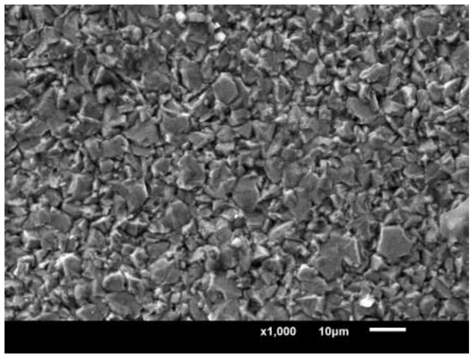
b)

Fig. 1. X-ray diffraction pattern of a) $Cd_{1-x}Fe_xSe$ (x = 0.04), b) $Cd_{1-x}Mn_xTe$ (x = 0.15)

The surface morphology of investigated epitaxial films was studied by Scanning Electron Microscope (SEM) method on JEOL JSM-7600F Field Emission SEM (fig. 2). SEM image shows that the obtained $Cd_{1-x}Fe_xSe$ epitaxial films were smooth and glossy (fig.2,a), but surface of $Cd_{1-x}Mn_xTe$ epitaxial films were roughness with a grain size of up to 10 microns (fig. 2,b).



a)



b)

Fig. 2. SEM image of the a) $Cd_{1-x}Fe_xSe$ (x = 0.04) b) $Cd_{1-x}Mn_xTe$ (x = 0.15) epitaxial films obtained on the glass substrate

3 Results and Discussion

The dark electrical resistivity of $Cd_{1-x}Fe_xSe$, $x < 0.08$ epitaxial films was measured at T = 300 K temperature. To measure electrical resistivity silver paste was applied to make Ohmic contacts to $Cd_{1-x}Fe_xSe$, $x < 0.08$ epitaxial films. The nature of contact was checked up to 50 V. The VAC of $Cd_{1-x}Fe_xSe$, $x < 0.08$ epitaxial films are shown in fig. 3. The VAC has linear nature which confirms that silver produces Ohmic contact with $Cd_{1-x}Fe_xSe$. The measurement of thermo–emf across $Cd_{1-x}Fe_xSe$ SMSC epitaxial films confirms that films are of n–type.

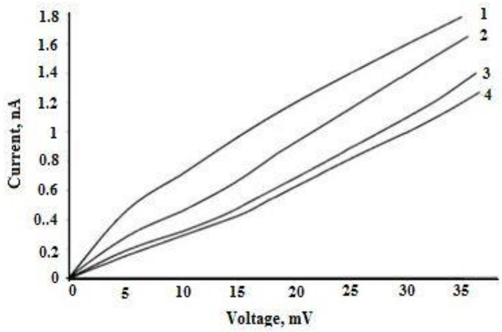


Fig. 3. VAC of $Cd_{1-x}Fe_xSe$ epitaxial films: 1- CdSe, 2- $Cd_{0.6}Fe_{0.4}Se$, 3- $Cd_{0.2}Fe_{0.8}Se$, 4-FeSe

VAC of $Cd_{1-x}Mn_xTe$ (x = 0.15) epitaxial films has been studied at room temperature. There is observed a linear part $J \sim U$ corresponding to Ohm's law and quadratic part $J \sim U^2$ in VAC (fig. 4). $Cd_{1-x}Mn_xTe$ epitaxial films had p-type conductivity with a resistivity of ρ=14.4 $\cdot 10^7$ Ohm·cm.

The effect of γ-irradiation on VAC of $Cd_{1-x}Mn_xTe$ epitaxial films is studied at T=300K at doses $D_\gamma \leq 1.5$ кGy. After irradiation of samples with γ- quanta at a dose of D_γ < 100 Gy, a parallel shift of the curve occurs towards the current decrease in the entire investigated voltage range (figure 4). The nature of dependence does not change, Ohmic and quadratic parts are observed, the Ohmic part lengthens. The observed character shows that at irradiation of $Cd_{1-x}Mn_xTe$ thin films with small doses, deep levels are formed in the band gap and are captured by electrons, that leads to a decrease in the conductivity. According to [8], when the sample contains traps with the concentration exceeding the concentration of majority carriers, the carriers injected first are captured by the traps, and the carrier concentration in the conduction band is almost unchanged [9]. At irradiation of samples at D_γ = 500 Gy dose Ohmic part in VAC decreases, quadratic part lengthens, the conductivity increases. Such a behavior of VAC can likely be due to the thermal-field ionization of the traps [10] whose concentration is dependent on the irradiation doze. Further irradiation at doses $D_\gamma \geq 1.5$ kGy leads to increasing of Ohmic part and decreasing of quadratic part, so conductivity decreases. Significant decreasing of conductivity is explained by increasing of defects concentration and so destruction of the crystal structure. Obtained results satisfy to the results of our previous works [9].

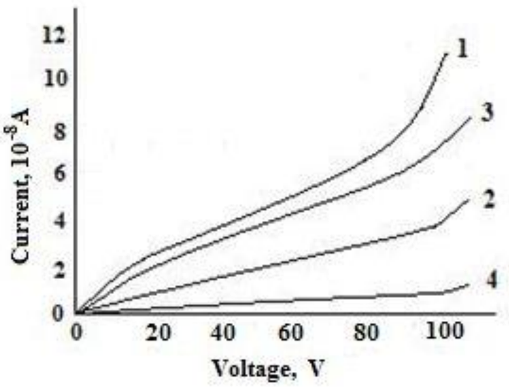


Fig. 4. VAC of irradiated $Cd_{1-x}Mn_xTe$ (x = 0.15) epitaxial films: 1) Dγ = 0, 2) Dγ = 100 Gy, 3)Dγ = 500 Gy, 4)Dγ=1.5 кGy

4 Conclusion

Optimal conditions of obtaining perfect $Cd_{1-x}Fe_xSe$ (x < 0.08) and $Cd_{1-x}Mn_xTe$ (x = 0.15) epitaxial films are defined. Crystal structure and surface morphology have been investigated by XRD and SEM methods. XRD studies show that thin films grown on glass substrates at temperature T_{sub} = 640 ÷670 K have a monocrystalline and polycrystalline structures. SEM image shows that the obtained $Cd_{1-x}Fe_xSe$ epitaxial films were smooth and glossy, but surface of $Cd_{1-x}Mn_xTe$ epitaxial films were roughness with a grain size of up to 10 microns.
The electrical properties of $Cd_{1-x}Fe_xSe$ (x < 0.08) and $Cd_{1-x}Mn_xTe$ (x = 0.15) epitaxial films have been studied at room temperature. It was defined that $Cd_{1-x}Fe_xSe$ SMSC epitaxial films are of *n*–type and $Cd_{1-x}Mn_xTe$ SMSC epitaxial films are of *p*–type. It was defined the electrical resistivity $14.4 \cdot 10^7$ Ohm·cm.
The effect of γ-irradiation on VAC of $Cd_{1-x}Mn_xTe$ epitaxial films is studied at doses $D_\gamma \leq 1.5$ кGy.

References:

[1] Furdyna J Diluted magnetic semiconductors. *J. Appl. Phys.* 64, 1988, pp.R29
[2] Wei S.H., Zunger A. Total energy and band structure calculations for the semimagnetic $Cd_{1-x}Mn_xTe$ semiconductor alloy and its binary constituents. *Phys. Rev. B.* 35, 1987, pp. 2340
[3] Masek J., Velicki B. Mn 3d states in photoelectron spectra from $Cd_{1-x}Mn_xTe$. *Phys. Status Solidi B.* 140, 1987, pp. 135
[4] Twardowski A. Magnetic properties of Fe based diluted magnetic semiconductors. *J. Appl. Phys.* 67, 9, 1990, pp 5108-5113
[5] Becker W.M. Band structure and optical properties of wide-gap $A^{II}_{1-x}Mn_xB^{VI}$ alloys at zero magnetic field. *Semiconductors and Semimetals.* 25**,** 1988, pp. 35
[6] Nuriyev I. R., Mehrabova M.A., Nazarov A.M., Hasanov N H, Sadigov R M, Farzaliyev S S Farajov N.V. Structure and surface morphology of $Cd_{1-x}(Mn,Fe)_xSe$ epitaxial films. *Journal of Surface Investigation: X-ray, Synchrotron and Neutron Techniques.* 11, 2019, pp. 78-80
[7] Mehrabova M.A., Nuriyev H.R., Orujov H.S., Hasanov N.H., Kerimova T.I., Abdullayeva A.A., Kazimova A.I. Effect of gamma irradiation on the conductivity of $Cd_{1-x}Fe_xTe$. *Semiconductors.* **61,** 12, 2020, pp. 2306–2309
[8] Lampert M., Mark P. *Current Injection in Solids Academic.* New York, 1970, Mir, Moscow, 1973
[9] Madatov R.S., Nadzhafov A.I., Tagiev T.B., Gazanfarov M.R. Mehrabova M.A. Effect of Ionizing Irradiation on the Mechanism of Current Passage in $TlInSe_2$ Single Crystals. *Physics of the Solid State.* 53, 11, 2011, pp. 2205–2209
[10] Frenkel Ya.I. Collection of Selected Works. *Academy of Sciences of the USSR, Moscow.* 2 1958, pp. 600

Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

Matanat Mehrabova was responsible for the experimental work of electrical properties.
Niyazi Hasanov carried out the XRD and SEM investigations
Vafa Guluzade has executed the experiments of Section 3.
Rafig Sadigov obtained thin films.