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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

EPITAXIAL FILMS OF $Cd_{1-x}Fe_xTe$ AND RADIATION RESISTANT PHOTOSENSITIVE STRUCTURES BASED ON THEM

Speciality: 3361.01 - Solid state electronics, radioelectronics components, micro and nanoelectronics

Field of science: Technical

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The work was perfomed at the “Engineering physics and electronics” department of Azerbaijan Technical University

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Dissertation council ED 2.01 of Supreme Attestation Commission under the President of the Republic of Azerbaijan operating at the National Aviation Academy.

Chairman of the Dissertation council:	Academician of ANAS, Doctor of Physical and Mathematical Sciences, professor
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GENERAL CHARACTERISTICS OF THE WORK

The actuality of the subject. The dissertation is dedicated to the study of a number of electrophysical, photoelectric, optical properties of $Cd_{1-x}Fe_xTe$ semimagnetic semiconductor (SMSC) epitaxial films and the possibilities of obtaining radiation-resistant and radiation-sensitive structures based on them.

SMSC is a relatively new material and is widely used in modern electronics. They combine the properties of conventional and magnetic semiconductors. The presence of magnetic elements in these semiconductors makes it possible to obtain structures controlled by a magnetic field based on them.

Epitaxial films of SMSC, included in the $A^{II}B^{VI}$ group semiconductors, are considered materials of special importance for fundamental research and practical application. $Cd_{1-x}Fe_xTe$ epitaxial films included in this group are new and little-studied SMSC materials with application prospects.

The growth characteristics, crystal perfection, electrophysical, photoelectric and optical properties of $Cd_{1-x}Fe_xTe$ epitaxial films, the characteristics of obtaining structures based on them have been little investigated and the information about them in the literature is limited. In this regard, it is appropriate to develop the technology of obtaining epitaxial films of $Cd_{1-x}Fe_xTe$ SMSC and to prepare high-quality structures based on them. Growing epitaxial layers of $Cd_{1-x}Fe_xTe$ SMSC with perfect crystal structure, required electrophysical, photoelectric, optical properties, obtaining photosensitive structures based on them, including p-n junctions, is an urgent issue of interest for modern science and technology.

Since many physical properties of semiconductors depend on their crystal structures, it is very important to study the structural properties and surface morphologies of thin films with different compositions using modern research methods. Modern research methods, such as X-ray diffraction and electron microscopy, allow obtaining fairly accurate information about the crystal structures and surface conditions of thin-film solids.

Crystal structure and surface morphology of thin films of $Cd_{1-x}Fe_xTe$ SMSC grown by molecular beam condensation (MBC) method were studied by XRD, SEM and AFM methods.

It should be noted that the study of electrical, optical and photoelectric properties of semiconductor materials allows determining many parameters that are important for creating devices of various purposes based on them. The properties mentioned in the dissertation and the effect of radiation on them were studied. Some of the physical properties of the materials gradually deteriorate as a result of being exposed to external influences over time. Therefore, it is important to study the resistance of materials to external influences, including ionizing radiation radiation, and related research works are also studied in the dissertation..

The purpose of the dissertation. Determining the growth characteristics of $Cd_{1-x}Fe_xTe$ epitaxial films having perfect crystal structure and surface morphology, and studying the effect of γ-irradiation on their electrophysical, photoelectric, and optical properties in order to prepare radiation-resistant and photosensitive structures based on them.

The following tasks have been fulfilled to achieve the set goal:

• Theoretical calculations of the electronic band structure of ideal and defective $Cd_{1-x}Fe_xTe$ (x=0.01÷0.25) SMSC;

• Obtaining $Cd_{1-x}Fe_xTe$ thin films with the required chemical composition (x=0.01-0.08) and physical parameters in a 10^{-4} Pa vacuum by the Molecular Beem Condensation (MBC) method;

• Studying the crystal structure, surface morphology, electrophysical, photoelectric and optical properties of $Cd_{1-x}Fe_xTe$ (x=0.01-0.08) thin films;

• Study of the effect of γ-radiation (E=1.17MeV, E=1.33MeV) on the electrophysical, photoelectric and optical properties of $Cd_{1-x}Fe_xTe$ (x=0.01-0.08) thin films;

• $Cd_{1-x}Fe_xTe$ (x=0.01-0.08) thin films and determination of application possibilities of structures based on them.

Research methods.

- The electronic band structure and density of states of ideal and defective $Cd_{1-x}Fe_xTe$ (x=0.01÷0.25) SMSC were calculated within the framework of the Density Functional Theory (DFT) theory;
- $Cd_{1-x}Fe_xTe$ (x=0.01-0.08) thin films and heterojunctions based on them were grown by Molecular Beem Condensation method in a vacuum of 10^{-4} Pa;
- The crystal structure of solid solutions and thin films was studied by the X-ray diffractometry (XRD) method on the BRUKER XRD D8 ADVANCE device;
- The study of the surface morphology and compositional analysis of the thin films was carried out using the SEM method in Carl Zeiss Sigma VP Field Emission Scanning Electron Microscopes and JEOL JSM-7600F Scanning Electron Microscopes (SEM);
- The surface morphology, particle size and particle size distribution of the thin films were studied in the Nntegra Prima Atomic Force Microscope (AFM);
- γ-irradiation of the samples was carried out in the ^{60}Co isotope source (E=1.17MeV, E=1.33MeV);
- The dielectric properties of the samples were studied in the E7-25 device;
- To measure the electrophysical and photoelectric properties of the samples, the stability of the current passing through the sample was checked by means of a V7-21A digital universal millivoltmeter. A Q6-28 type voltage generator was used as a source. U5-9 or U5-11 type electrometric amplifiers were used to measure the current. A digital voltmeter H1312 was used to measure the voltage. When VAC was measured for individual points, a TES-23 type standard source was used as the source.
- Optical properties were measured on a SPECORD 210 PLUS UV-Vis spectrophotometer.

The main provisions of the defense:

1. Ab initio calculations of electronic band structure and density of state of ideal and defective $Cd_{1-x}Fe_xTe$ (x=0.01÷0.25) SMSC.

2. Synthesis of $Cd_{1-x}Fe_xTe$ (x=0.01÷0.08) solid solutions and characteristics of obtaining epitaxial films based on them.

3. Effect of the concentration of Fe atoms on the electrophysical, photoelectric and optical properties of $Cd_{1-x}Fe_xTe$ thin films;

4. Effect of γ-radiation on the electrophysical, photoelectric and optical properties of $Cd_{1-x}Fe_xTe$ (x=0.01÷0.08) thin films;

5. Optimal acquisition characteristics of CdTe/ $Cd_{1-x}Fe_xTe$ thin-film heterojunctions (HJ) and determining the possibilities of developing photoconverters, photoreceivers, and ionizing radiation detectors based on them.

Scientific innovation:

1. For the first time, the electronic band structure of ideal and defective $Cd_{1-x}Fe_xTe$ (x=0.01÷0.25) SMSC was ab initio calculated. The influence of Fe concentration and the vacancy-type defects on the band structure and band gap was determined.

2. The characteristics of $Cd_{1-x}Fe_xTe$ thin films growing with the required chemical composition (x=0.01-0.08), thickness and electrophysical parameters in a 10^{-4} Pa vacuum were determined by the MBC method.

3. The effect of γ-radiation (E=1.17MeV, E=1.33MeV) on the surface morphology and crystal structure of $Cd_{1-x}Fe_xTe$ thin films was determined.

4. The effect of γ-irradiation on the electrophysical, photoelectric, and optical properties of $Cd_{1-x}Fe_xTe$ (x=0.01-0.08) thin films was studied.

5. The optimal mode of obtaining HJ on the basis of $Cd_{1-x}Fe_xTe$ (x=0.01-0.08) without breaking the vacuum in a single technological cycle by the MBC method was determined. Based on them, the possibilities of making photoreceivers and photoconverters were studied.

Practical and theoretical significance.: The results obtained in the dissertation can be widely used in preparation of solar cells, radiation detectors, IR detectors, photoreceivers, optical isolators and etc.

The results of the dissertation are of great importance in the training of highly qualified specialists in the field of radiation materials science, physics of solid states, physics of semiconductors and dielectrics.

The theoretical studies conducted in the dissertation confirm the accuracy of the experimental studies and are also can predict the results earlier.

Approbation of dissertation work. The main results of the dissertation were presented at the following conferences and symposiums:

–XXI republican scientific conference of doctoral students and young researchers (October 24-25, 2017, Baku, Azerbaijan),

–International scientific and technical conference dedicated to the 100th anniversary of the Azerbaijan Democratic Republic (Sumgait, Azerbaijan, 2018),

–XXVII Russian Conference on Electronic Microscopy, RCEM, Chernogolovka, Russia, 2018),

–International Scientific and Technical Conference and School of Photoelectronics and Night Vision Devices (Moscow, Russia, 2018),

–7th Rostocker International Conference "Thermophysical Properties to Technical Thermodynamics" (Rostock, Germany , 26th – 27th July 2018, 9 September 2021),

–International conference and school dedicated to the 100th anniversary of Academician H.B.Abdullayev. Modern trends in condensed matter physics (Baku, Azerbaijan, 2018),

–Measurement and quality: problems, perspectives, International Scientific and Technical Conference (Baku, Azerbaijan November 21-23, 2018),

–Radiation processes and their applications, International Conference dedicated to the 70th anniversary of Academician M.K. Karimov (Baku, Azerbaijan, November 13-14, 2018),

–RAD7-Seventh international conference on radiation in various fields of research. (Hercheg Novi, Montenegro, June 10-14, 2019),

–11th Conference on Modern Trends in Physics (Baku, Azerbaijan, May 1-3, 2019),

–Modern Trends In Physics (Baku, Azerbaijan, May 01-03, 2019),

–International conference on Mechanisms and non-linear problems of nucleation and growth of crystals and thin films (Saint Petersburg, Russia, July 1-5, 2019),

–2nd International Turkish World Engineering and Science Congress (Turkey, November 7-10, 2019),

–"Prospects of application of magnetic soft alloys in the military field" International scientific-practical conference, (Baku Azerbaijan, October 9-10, 2019),

–International congress on natural sciences (Kayseri, Turkey, February 26-28, 2021),

–Joint conference "Electronic- beam technologies and x-ray optics in microelectronics", Zelenograd, Moscow, 2021),

–USBIK 2021 online international congress on natural sciences (Turkey, Kayseri, 26-28 February 2021),

–International Social and Technical Sciences Symposium USTEK'22 (Selçuk University, Konya-Turkey 12-13 September 2022),

–"Fourth industrial revolutionary and innovative technologies" International Scientific Symposium dedicated to the 100th anniversary of Heydar Aliyev -Practical Conference (Ganja, May 3-4, 2023),

–Republican Scientific and Technical Conference "Radiation technologies and its applications" dedicated to the 100th anniversary of Heydar Aliyev (Baku, RPI, May 5, 2023),

–International Conference on "Development of theoretical and applied physicists" dedicated to the 100th anniversary of Heydar Aliyev (Baku, ETN Institute of Physics, June 8-9, 2023).

Publications. The content of the dissertation work was published in 29 scientific works, including 10 articles in national and foreign journals, 19 conference materials. 3 of the articles are included in the Web of Science platform, 3 were published by a single author.

The dissertation work was carried out in 2017-2023 at the Institute of Radiation Problems and İnstitute of Physics of MSE.

Structure and scope of the dissertation.
The dissertation consists of introduction, four chapters, including 69 figures and 6 tables, main results, list of author's scientific works and list of referenced literature, so commonly consists of 201431 symbols.

CONTENTS OF THE WORK

The introduction substantiates the relevance of the research topic and the applied method of work, shows scientific innovation, practical significance, provides information about the purpose, structure, content of the work, the main provisions to be defended and the approbation of the work.

In the first chapter, the physical properties of solid solutions of $Cd_{1-x}Fe_xTe$ SMSC and literature data related to radiation defects caused by ionizing rays were collected and analyzed. From the analyzed literature, it is known that the investigated $Cd_{1-x}Fe_xTe$ SMSC is little studied, and the effect of γ-irradiation on their physical properties has not been studied at all.

In the second chapter, the synthesis of $Cd_{1-x}Fe_xTe$ solid solutions and the method of obtaining their thin films by the MBC method were widely presented and a description of the vacuum device was given. Information on XRD and SEM and AFM methods for studying the crystal structure of the samples and for studying the surface morphology is provided. At the same time, the scheme of the device for conducting γ-radiation studies, the measurement methodology of the E7-25 impedance spectrometer for studying the electrical and dielectric properties of the studied samples, the working principle of the UV Viz spectrometer for the study of optical properties, the scheme and the working principle of the device for studying the photoelectric properties are described. The DFT theory and the pseudopotential method for ab initio calculations performed in the thesis work.

In the third chapter, the issues of synthesis of $Cd_{1-x}Fe_xTe$ ($0<x\leq0.08$) solid solutions and production of epitaxial films based on them were investigated. $Cd_{1-x}Fe_xTe$ solid solution with a composition of $0<x\leq0.08$ was synthesized by adding Fe atoms to the CdTe semiconductor compound. The composition and crystal structure of the received solid solutions were studied by X-ray diffraction method. It was shown that the synthesized solid solutions crystallize in a cubic lattice with parameter α=6.467 Å ÷ 6.481 Å. These solid solutions were used as a source for obtaining $Cd_{1-x}Fe_xTe$ semimagnetic semiconductor thin films.

The crystal composition of $Cd_{1-x}Fe_xTe$ (x=0÷0.08) solid solutions was determined by the electron paramagnetic resonance (EPR) method at room temperature on a "Bruker" EMXplus spectrometer (*x* region, frequency ν=9.9Hs, wavelength λ=3.2sm^{-1}) was studied.

An asymmetric line is observed in the EPR spectrum of $Cd_{1-x}Fe_xTe$, x = 0.03 samples, which is associated with the ferromagnetic state of iron Fe^{3+} ions (Fig. 1). It was determined by the EPR method that Fe^{3+} ions entered the crystal lattice of the solid solution evenly. $Cd_{1-x}Fe_xTe$ (x=0.03) solid solutions were irradiated with γ-rays at a dose of $D_\gamma\leq$605.6 kGy, as a result, no significant changes in EPR spectra were observed.

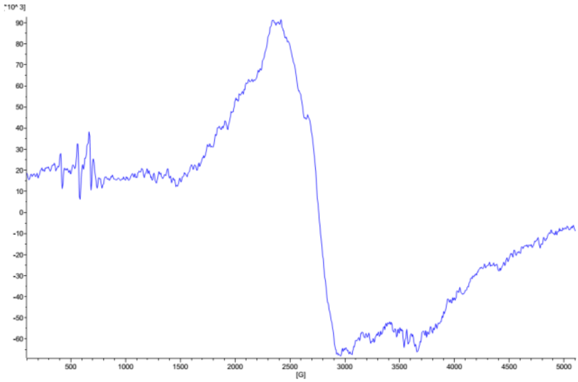
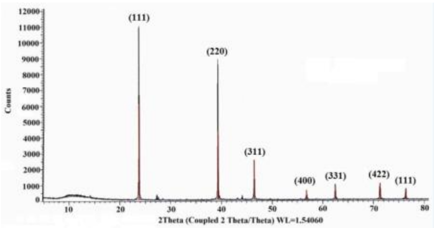
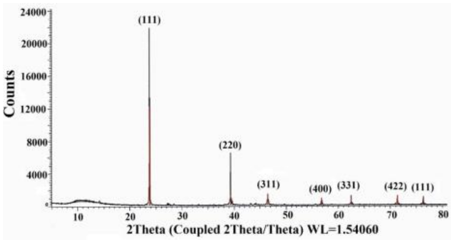


Fig. 1. EPR spectra of $Cd_{1-x}Fe_xTe$, x=0.03 solid solutions

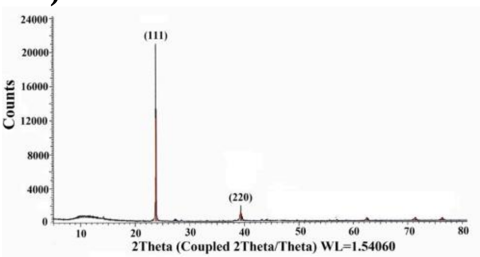
Glass plates were used as a substrate for the production of thin films and it was shown that mixed - polycrystalline and amorphous thin films grow on the substrate at the substrate temperature T_{sub}=300 K. With an increase in temperature (T_{sub} =470 K), the amorphous state becomes polycrystalline. At the substrate temperature T_{sub} =670 K, the thin film grown on the glass substrate is in monocrystalline form.

XRD analysis shows that the $Cd_{1-x}Fe_xTe$ thin films have a surface-centered cubic structure with sharp diffraction peaks (111), (220), (311), (400), (331), and (422). It can be seen from the X-ray diffraction curves of $Cd_{1-x}Fe_xTe$ thin films irradiated with γ-quanta at doses of 50 kGy, 100 kGy and 150 kGy that as the radiation dose increases, the intensity in the direction of the (111) crystal planes increases, while the intensity of the planes decreases in other directions. This shows that the number of planes arranged along the (111) direction has increased as a result of γ-radiation, and the reason for this is that the γ-quanta irradiated from the ^{60}Co source have a high-energy electromagnetic wave character (Fig. 2). When the radiation dose is large enough (100 kQr and 150 kQr), the surface energy plays an important role in the crystal growth process. In this process, atoms are easily attracted by the high surface energy (111) plane of the crystal and condense there, resulting in the predominance of the (111) plane. We assume that the effect of γ-irradiation on the intensity of reflexes is related to the change in the size of the crystallinities caused by the increase in the concentration of defects.





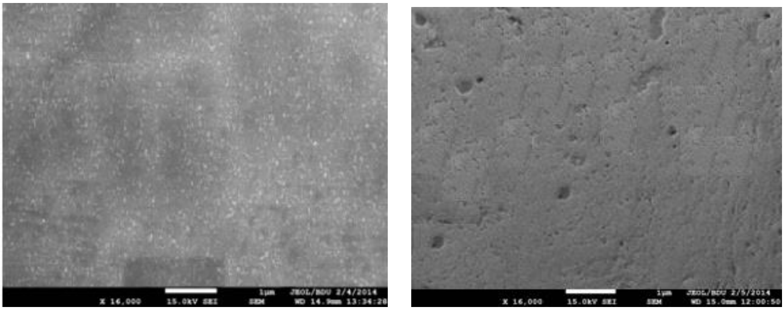
a) **b)**



c)

Fig. 2. X-ray diffraction images of $Cd_{1-x}Fe_xTe$ thin films (*x* = 0.08) on a glass substrate
a) D_γ =0, b) D_γ = 100 Gy, c) D_γ = 150 Gy

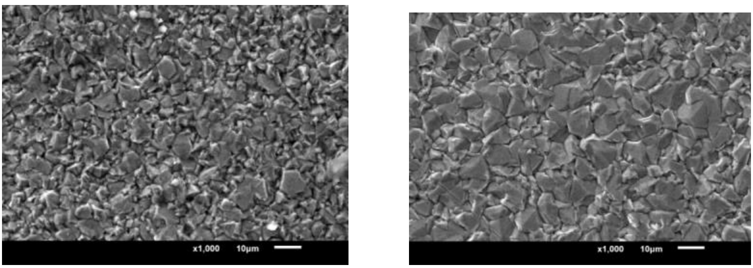
SEM and AQM studies of $Cd_{1-x}Fe_xTe$ (x=0.08) epitaxial films were studied on Carl Zeiss Sigma VP Field Emission Scanning Electron Microscope, JEOL JSM-7600F Scanning Electron Microscope and Ntegra Prima Atomic Force Microscope devices. AFM studies revealed that the films obtained without Te compensation have a rough surface. SEM studies have shown that by using an additional Te vapor source during the growth process, it is possible to compensate black spots on the films surface, and relatively smooth surface films are obtained (Fig. 3).



a) b)

Fig. 3. Electron microscopic images of the surface of $Cd_{1-x}Fe_xTe$ (x = 0.08) epitaxial films, substrate temperature Ta = 675K. a) Te- without compensation, b) Te -compensated.

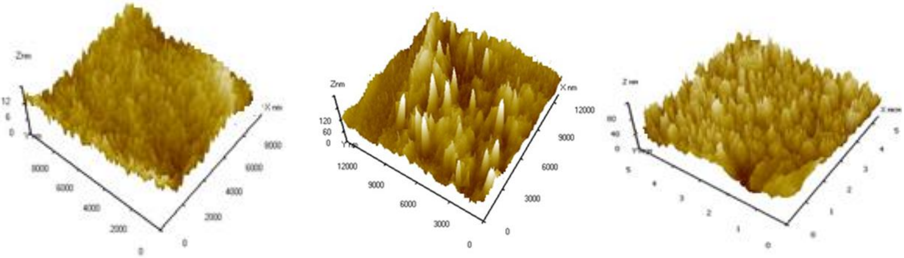
Using the SEM method, the effect of γ-irradiation on the surface morphology of $Cd_{1-x}Fe_xTe$ (x = 0.08) epitaxial films was studied ($D\gamma$=100 kGy). After irradiation, an increase in crystallinity size was observed (Fig. 4), which is consistent with the results obtained from XRD studies.



a) b)

Fig. 4. SEM images of surface morphology of $Cd_{1-x}Fe_xTe$ (x=0.08) epitaxial films: a) D_γ=0, b) D_γ=100 kGy

Surface morphology of $Cd_{1-x}Fe_xTe$ (x=0.05) epitaxial films before and after irradiation was also studied in Ntegra Prima Atomic Force Microscope (D_γ =50 kGy). After irradiation with γ-quanta at a dose of D_γ =25 kGy, unevenly distributed large-sized defects with a height of 140 nm are observed (Fig. 5).

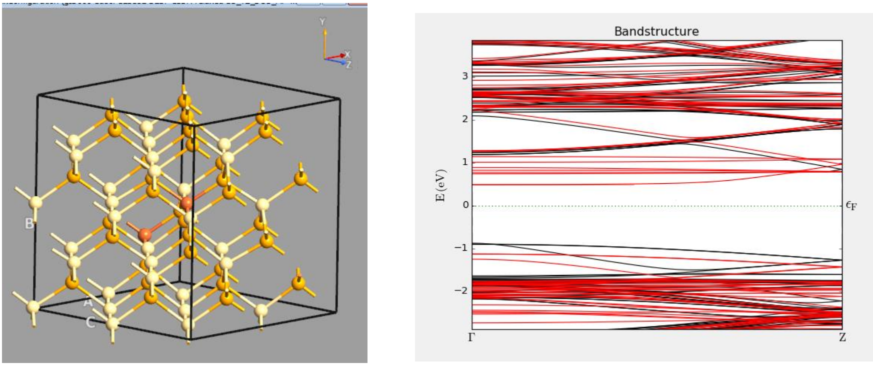


a) b) c)

Fig. 5. AFM images of $Cd_{1-x}Fe_xTe$ (*x*=0.06) epitaxial films: a) D_γ =0, b) D_γ =25 kGy, c) D_γ =50 kGy

The size and height of defects decrease to 80 nm after irradiation at a dose of D_γ =50 kGy and their distribution on the surface becomes homogeneous. Thus, there are structural defects in the initial sample, during irradiation with γ-quanta, second electrons are generated, which causes surface ionization and change of charge state. In this case, redistribution of carriers occurs. We believe that the formation of a Frenkel pair is more likely. Thus, the energy of the radioactive irradiation penetrating the crystal is in the minimum energy required to displace the atom.

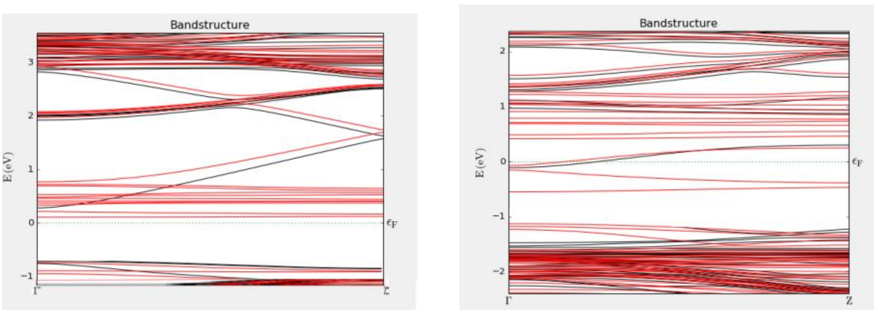
Electronic band structure of ideal and defective $Cd_{1-x}Fe_xTe$ (*x* = 0.01-0.25) semiconductors, density of states based on the first principles of the DFT theory using the pseudopotential method in the Double Zeta Double Polarized (DZDP) basis in the Local Spin Density Approximation (LSDA), taking into account the Hubbard-U potential calculated in the Atomistix ToolKit (ATK) program. The band gap was calculated for the full energy antiferromagnetic (AFM) and ferromagnetic (FM) cases (Fig. 6). It was determined that with increasing Fe concentration, the band gap linearly increases, the total energy decreases, a slight decrease in the lattice parameter occurs, and the ferromagnetic state becomes more stable.



a) b)

Fig. 6. $Cd_{30}Fe_2Te_{32}$ (*x*=0.06) supercell
a) crystal structure, b) electronic band structure.

It was determined that vacancy-type defects lead to a slight decrease in the band gap of the $Cd_{30}Fe_2Te_{32}$ supercell (for the 0.01 - 0.03 eV), the creation of local levels in the band gap, and the shift of the Fermi level (Fig. 7).



a) b)

Şək. 7. $Cd_{30}Fe_2Te_{32}$ (x=0.06) superözəyi, elektron zona quruluşu a) Cd vakansiyası, b) Te vakansiyası

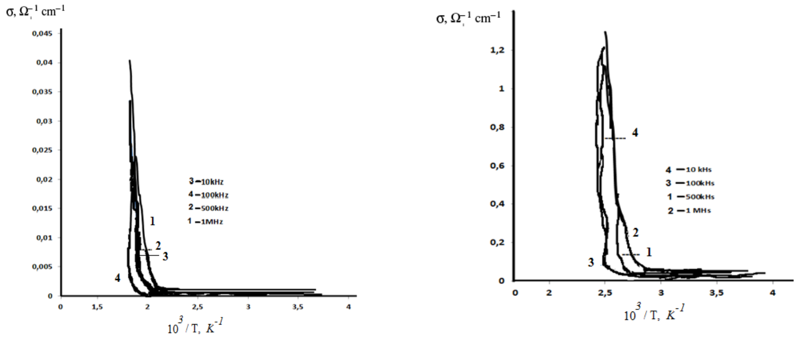
In the fourth chapter, the electrical, photoelectric and optical properties of $Cd_{1-x}Fe_xTe$ SMSC and the effect of γ-irradiation on these properties were studied.

The temperature dependences of capacitance, dielectric permeability and conductivity and impedance of $Cd_{1-x}Fe_xTe$ SMSC (x=0.03÷0.08) at the measurement frequency of 1 Hz – 1 MHz and in the temperature range *T*=294 K – 550 K were studied, also the effect of γ-radiation on these properties was studied. .

Dielectric permeability and conductivity *x*=0.03÷0.08 decrease with increasing Fe concentration. For the concentration of Fe ions *x*=0.08, it was found that significant structural changes occur, which is mainly associated with the displacement of Cd atoms from their previous positions. As the temperature increases to a certain critical value, the conductivity and dielectric permeability increase. The maximum of the curves in their temperature-frequency dependence shifts towards lower temperatures. In the temperature dependences of the conductivity, a sharp increase in σ occurs up to the frequency *f* = 500 kHz and at the temperature *T* = 480K (Fig. 8,a). The dependence of ln(ε) on ~1000/T is linear, and also the dispersion of the dielectric constant is relaxational.

The nature of the *ε(T)* dependences of $Cd_{1-x}Fe_xTe$ YMYK irradiated with γ-quanta at a dose of D_γ=605.6 kGy changes, a decrease is observed in the curves in the temperature range *T*=300 K ÷400 K at the measurement frequencies *f*=1Hz÷1MHz, and *ε* is 20 times increases. In the dependences of *σ (T),* a maximum appears at a temperature of 400 K at all measurement frequencies, and the conductivity increases 40 times at all measurement frequencies (Fig. 8,b).

The increase in dielectric permittivity and conductivity after γ-irradiation can be assumed to be related to the formation of defect-related levels in the energy band. Thus, the jumping electrons exchange between defects in the crystal can lead to the formation of dipoles and, as a result, the increase in dielectric permeability.



a) b)

Fig. 8. Temperature-frequency dependences of the conductivity of $Cd_{1-x}Fe_xTe$ (x=0.03) SMSC: 1) 10 kHz, 2) 100 kHz, 3) 500 kHz, 4) 1 MHz, a) D_γ=0, b) D_γ=605.6 kGy

The effect of γ-irradiation on the VAC of $Cd_{1-x}Fe_xTe$ thin films was studied at temperature T=300 K. VAC measurements were performed at irradiance $D_\gamma \leq 1$ kGy. After γ-irradiation at a dose of D_γ < 100 Gy, the conductivity increases depending on the voltage, while the nature of the dependence does not change (Fig. 9). The observed dependence shows that if $Cd_{1-x}Fe_xTe$ (x=0.08) thin films are irradiated with small doses, deep levels are formed in the band gap, and these levels are occupied by a part of the electrons involved in conduction, and the current increases. When samples are irradiated with a dose of D_γ = 500 Gy, a parallel downward shift of the curve and a decrease in permeability are observed in VAX, which is associated with an increase in the concentration of defects. At doses $D_\gamma \geq$ 1 kGy, radiation reduces permeability. The decrease in conductivity is explained by the increase in the concentration of defects and thus the violation of the crystal structure. The obtained results are agreement with literature dates.

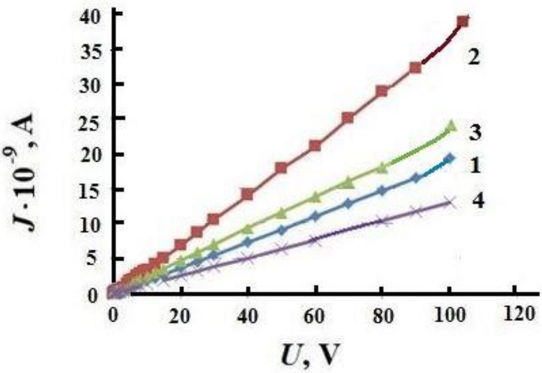


Fig. 9. VAC of $Cd_{1-x}Fe_xTe$, x=0.08 thin films: 1) D_γ =0, 2) D_γ = 100 Gy, 3) D_γ = 500 Gy, 4) D_γ = 1 kGy

It was determined that as the concentration of Fe ions increases, the lattice constant decreases. $Cd_{1-x}Fe_xTe$ (x=0.01÷0.03) SMSC thin films had p-type conductivity. Resistance and activation energy decreased with increasing Fe concentration in the crystals.

The temperature dependences of the complex impedance show that the maximum of the real part of the impedance shifts to the higher temperature region with increasing frequency and the amplitude decreases. The temperature dependence of the imaginary part of the impedance has a stepped form. As the measurement frequency increases, the amplitude of the "step" decreases.

Spectral characteristics of photoconductivity (PC) at T=300K were studied in $Cd_{1-x}Fe_xTe$ (x=0.08) thin films grown on glass substrates (Fig. 10). It can be seen from the dependences that the spectral range covers the wavelength range λ=400 nm – 1200 nm. A broad band is observed in the PC spectrum, the band gap calculated from the PC maximum (λ = 800 nm) is E_g=1.5 eV at temperature T = 300 K. The obtained results are agreement with our theoretical calculations.

Later, the effect of γ-irradiation at T=300 K of $Cd_{1-x}Fe_xTe$ (x=0.08) thin films on the spectral characteristics of photoconductivity was also studied (Fig. 10).

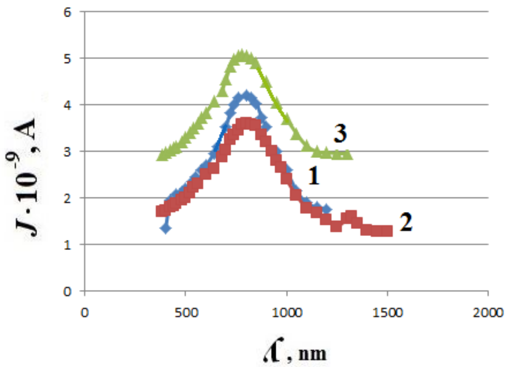


Fig. 10. Spectral characteristics of photoconductivity in $Cd_{1-x}Fe_xTe$ (x=0.08) thin films, T=300 K:
1) D_γ=0, 2) D_γ =100 Gy, 3) D_γ =500 Gy

The samples were irradiated with γ-quanta at the ^{60}Co isotope source with energies of 1.25 MeV and 1.33 MeV at ETN Institute of Radiation Problems of the MSE. The radiation dose was between 100 Gy and 1 kGy.

First, the samples were irradiated with γ-quanta at a dose of D_γ =100 Gy, after irradiation, the PC decreased and an additional peak appeared, indicating the formation of a defect level. As a result of subsequent irradiation with doses D_γ >500 Gy, an increase in PC occurs. Photosensitivity is lost after irradiation at a dose of D_γ = 1 kGy. Thus, $Cd_{1-x}Fe_xTe$ (x=0.08) thin films are photosensitive to irradiation with γ-quanta up to a dose of D_γ = 1kGy.

The effect of γ-irradiation on the optical properties of $Cd_{1-x}Fe_xTe$ (x=0.08) thin films was investigated. Absorption and transmittion spectra of $Cd_{1-x}Fe_xTe$ (x=0.03, 0.08) thin films were measured in the wavelength range of 190 nm-1100 nm on a SPECORD 210 PLUS UV-Vis spectrophotometer. It was determined that $Cd_{1-x}Fe_xTe$ (x=0.03) epitaxial films absorb light up to a wavelength of λ = 845 nm, after which a sharp decrease occurs at λ> 845 nm, the material becomes transparent. $Cd_{1-x}Fe_xTe$ (x=0.08) epitaxial films absorb light up to a wavelength of λ = 827 nm. Therefore, as the Fe cosentration increases, the absorption spectrum shifts to the short wavelength region and the band gap increases, the percentage of absorption increases, and the emission decreases. This result obtained is confirmed by theoretical calculations and literature dates.

Table 1.

Optical parameters of $Cd_{1-x}Fe_xTe$ (x=0.08) thin films

Semiconductor $Cd_{1-x}Fe_xTe$	E_g, eV	Absorption %	Transmittion %
x=0	1.43	4.2	15
x=0.03	1.47	4.5	9
x=0.08	1.5	8	4

The effect of γ-irradiation on the optical spectra of $Cd_{1-x}Fe_xTe$ (x=0.08) epitaxial films was studied. After irradiation with a dose of D_γ=100 Gy, the spectrum shifts to the long-wave range, so the band gap decreases. Subsequent irradiation D_γ =500 Gy ÷1 kGy does not change.

CdTe / $Cd_{1-x}Fe_xTe$ (x=0.03) thin-film heterojunctions were obtained on a glass substrate with a SnO_2 conductive layer in a vacuum of 10^{-4} Pa by the MBC method without breaking the vacuum in a single technological period, and the optimal mode of obtaining the heterojunction was determined: the temperature of the evaporation source for n-CdTe T_{sour} =1000 K - 1250 K, the condensation rate υ = 14-16 Å/sec, the substrate temperature was T_{sour} = 640 K - 670 K and for p- $Cd_{1-x}Fe_xTe$ υ = 18-20 Å/sec, T_{sub} = 470-520 K . It should be noted that at the substrate temperature T_{sub} = 670 K, the monocrystalline n-CdTe layer grows, and at values lower than this temperature, T_{sub} = 470 K, the crystal is polycrystalline.

In order to study the mechanism of current flow in n-CdTe /p-$Cd_{1-x}Fe_xTe$ (x=0.03) thin film heterojunction, dark VAC was studied at room temperature, resistance of HJ was determined. VAC is asymmetrical, forward currents exceed reverse currents by 0.5 - 1.2 mV.

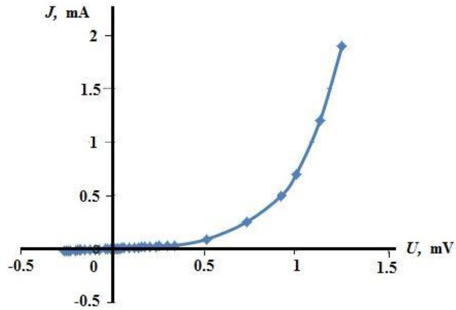


Fig. 10. Volt-ampere characteristics of CdTe/ $Cd_{1-x}Fe_xTe$ (x=0.08) thin film heterojunction

In HJ, the recombination mechanism, parameters of recombination centers and electronic transition processes were studied. It was determined that the lifetime of charge carriers was τ=28-35 μs, and the recombination speed of the surface was *s*=50 cm/s. The photocurrent decay is not monoexponential, indicating the presence of several types of recombination. Depending on the energetic state of these centers, the effective lifetime was 10^{-6} -10^{-3} s.

MAIN RESULTS

1. For the first time, first principle calculations were carried out for the the definition of electronic band structure of ideal and defective $Cd_{1-x}Fe_xTe$ (x=0.01÷0.25) semimagnetic semiconductors. It was determined that with the increase in the Fe concentration in the composition, the band gap linearly increases, the total energy decreases, a slight decrease in the lattice parameter occurs, and the ferromagnetic state becomes more stable. Vacancy-type defects in the $Cd_{1-x}Fe_xTe$ (x=0.01÷0.25) slightly decrease the band gap, form local levels in the band gap, and a shift the Fermi level.

2. The properties of growing $Cd_{1-x}Fe_xTe$ (x=0.01÷0.08) thin films with a smooth, mirror surface on glass substrates were studied by

the MBC method, using an additional compensating Te vapor source in a vacuum of 10^{-4} Pa. It was determined that polycrystalline $Cd_{1-x}Fe_xTe$ thin films mixed with amorphous phase are obtained on the glass substrate at the substrate temperature of the T_{sub}=300K. As a result of increasing the temperature of the substrate to $T_{sub} \geq 470$ K, polycrystalline films with a cubic structure begin to grow on the glass substrate, and at temperatures $T_{sub} \geq 570$ K, monocrystalline films begin to grow.

3. The effect of γ-radiation (E=1.17MeV, E=1.33MeV) on the surface morphology and crystal structure of $Cd_{1-x}Fe_xTe$ epitaxial folms was studied by AFM and X-ray diffraction methods. It was determined that irradiation of the samples at a dose of $D_\gamma < 5$ 0 kGy leads to the growth of the size and change of the shape of the crystallites.

4. Dielectric properties of $Cd_{1-x}Fe_xTe$ $0 \leq x \leq 0.08$ solid solutions were studied. It was determined that at the temperature T= 550K, a sharp increase in dielectric permeability and conductivity occurs. Irradiation by γ-quanta at a dose of D_γ =605.6 kGy causes a sharp increase in the dielectric permeability and conductivity of the samples. We assume that the exchange of jumping electrons between the defects in the crystal can lead to the formation of dipoles and, as a result, to the increase of the dielectric constant.

5. It was determined that $Cd_{1-x}Fe_xTe$ (x=0.01÷0.03) thin films have p-type conductivity, and as the concentration of Fe ions increases, the lattice constant, resistance, and activation energy decrease. It has been shown that the conductivity increases when the samples are irradiated with small doses, as deep levels are formed in the forbidden zone, and some of the electrons are captured by these levels, and some participate in the conductivity and lead to an increase in the current. At a dose of $D_\gamma \geq 500$ Gy, a decrease in conductivity occurs during γ-irradiation, which may be due to an increase in the concentration of defects.

6. It has been shown that the band gap decreases slightly with increasing Fe ions concentration. Due to the effect of γ-radiation (D_γ =30 kGy÷130 kGy), the percentage of light emission increases. It was determined that $Cd_{1-x}Fe_xTe$ (x=0.08) thin films are photosensitive in the wavelength range λ = 400 nm-1200 nm. The samples retain their

photosensitivity when irradiated with γ-quanta up to a dose of D_γ = 1 kGy.

7. The optimal mode and range of photosensitivity for CdTe/ $Cd_{1-x}Fe_xTe$ HJ acquisition without breaking the vacuum in a single technological cycle by the MBC method were determined. The lifetime of charge carriers was τ=28-35 μs, and the surface recombination speed was s=50 cm/s. It was shown that VAC is asymmetric, the forward currents exceed the reverse currents at a voltage of 0.5 - 1.2 mV.

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