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STUDY OF RECOMBINATION CENTERS IN $CdTe/Cd_{1-x}Fe_xTe$ (x=0.08) THIN FILM BY PHOTOCONDUCTIVITY RELAXATION

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Abstract: In this study, the recombination processes of charge carriers and the electrical properties of $CdTe/Cd_{1-x}Fe_xTe$ (x=0.08) thin film heterojunctions are investigated. The optimal conditions for obtaining the heterojunction were determined. XRD investigations confirm that thin films have a face-centered cubic structure with a crystal lattice parameter of a=6.47 Å. SEM images show the smooth surface of the obtained thin films. The lifetime of charge carriers was found to be τ=28-35 μs, and the surface recombination rate was s=50 cm/s. The study indicated that the decay of the photocurrent is not mono-exponential, suggesting the presence of several types of recombination. Depending on the energy state of these centers, the effective lifetime was 10^{-6} -10^{-3} s. VAC analysis confirmed the heterojunction structure of the investigated samples. Studies of the photoelectric characteristics of $CdTe/Cd_{1-x}Fe_xTe$ (x=0.08) heterojunction samples have shown that the process of defect formation during irradiation with gamma quanta leads to a strong change in the concentrations of local levels, including n-centers of photosensitivity.

Keywords: semimagnetic semiconductor, $CdTe/Cd_{1-x}Fe_xTe$ (x=0.08) heterojunction, electrical, lifetime, XRD, SEM, VAC.

1. Introduction

One of the current directions in the development of alternative energy is building-integrated photovoltaics, which involves the integration of solar panels with residential buildings or industrial facilities. Typically, such devices are assembled on a rigid base, however, assembling panels on a flexible base would significantly reduce their specific weight and facilitate installation. Thin films based on cadmium telluride can serve as a material for the absorbing layer of flexible solar cells. This material has advantages such as an optimal band gap value of ~1.45 eV, and a high absorption coefficient of solar radiation (~$5\cdot10^5$ cm^{-1}). Thin films of semimagnetic semiconductors (SMSC) based on CdTe are of particular interest for use in photovoltaics [1–4, 8].

2. Experimental part

In this work, a $CdTe/Cd_{1-x}Fe_xTe$ (x=0.08) heterojunction (HJ) was grown on a glass substrate with a SnO_2 conductive layer. This was achieved using the molecular beam condensation method in a UVN-71-P3 vacuum assembly at a vacuum pressure of 10^{-4} Pa. The source temperature was T_{sour}=1100 K, and the substrate temperature was T_{sub}=670 K. Ni contacts were deposited on both the front and back sides (Fig.1).

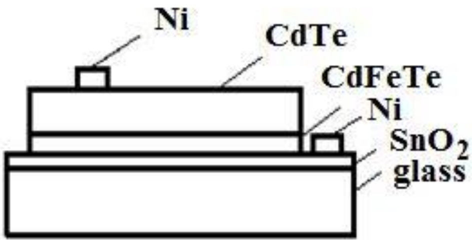

Fig. 1. Formation of thin film CdTe:CdFeTe heterojunction.

The samples were irradiated with γ-quanta using a Co^{60} installation at 300 K. During irradiation, the crystals were cooled with liquid nitrogen vapor, and their temperature did not rise above 290 K.

The crystal structure of the obtained thin films was studied on Bruker D8 ADVANCE (Germany) X-ray diffractometer (XRD). X-ray diffraction patterns of $Cd_{1-x}Fe_xTe$ (x=0.08) thin films show all diffraction peaks (111), (220), (311), (400), (331) and (422) which confirm that thin films have a face-centered cubic structure with a crystal lattice parameter of a=6.47 Å (Fig. 2).

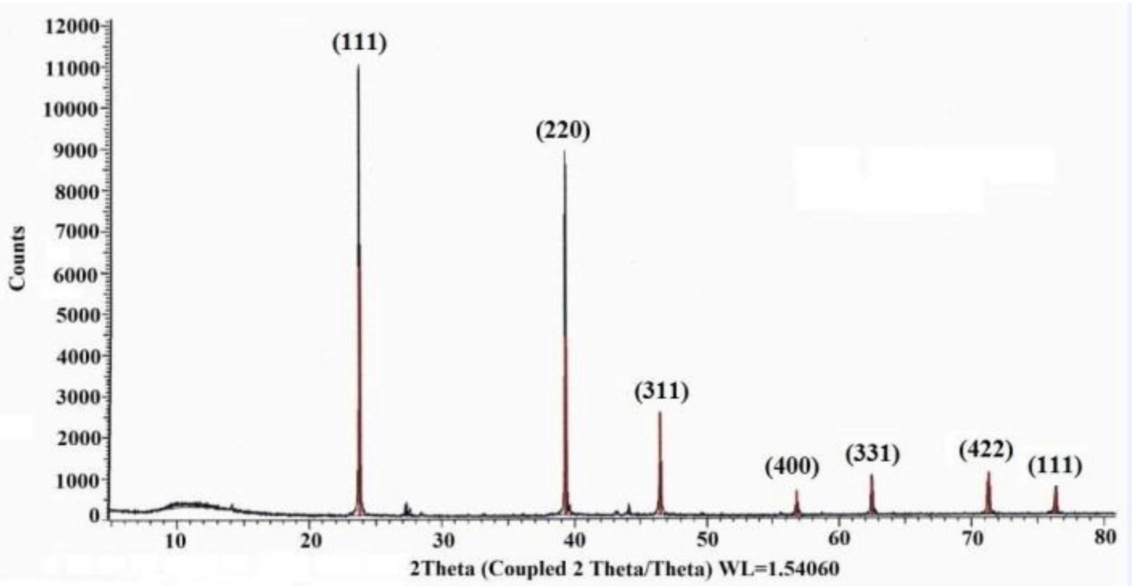

Fig. 2. XRD images of $Cd_{1-x}Fe_xTe$ thin films (x=0.08).

The surface morphology was studied using electron microscopy on a JEOL JSM-7600F Field Emission Scanning Electron Microscope (SEM), which confirms the smooth surface of the obtained thin films (Fig. 3).

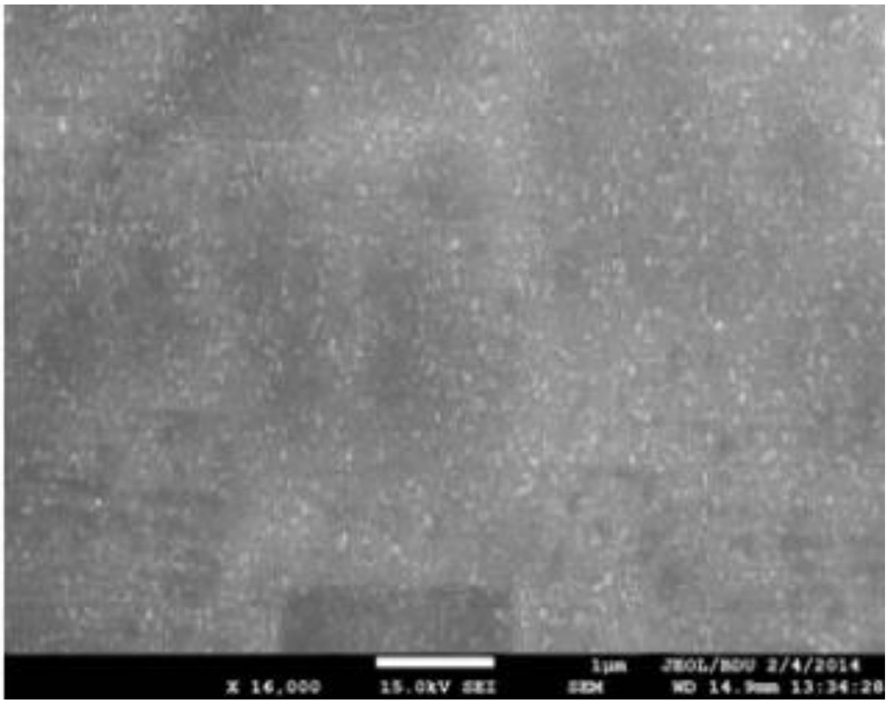

Fig. 3. SEM images of $Cd_{1-x}Fe_xTe$ thin films (x=0.08).

In previous works, we have studied various physical properties of $Cd_{1-x}Fe_xTe$ SMSC [5-7]. In this study, we investigate the recombination processes of charge carriers and the electrical properties of the material. Understanding recombination processes is crucial for studying the physical properties of semiconductor materials and the devices based on them. The mechanism of charge carrier recombination determines the features of photoelectric, luminescent, and injection phenomena, which are essential for the practical applications of semiconductors.

To determine the recombination mechanism, the parameters of recombination centers, and the electronic transition processes in heterojunction (HJ), we employed a combination of stationary and kinetic research methods (Fig. 4). For obtaining kinetic characteristics, the HJ was illuminated with short pulses ($t \sim 10^{-6}$ s) of LEDs. The photoelectric signal resulting from a change in the HJ potential due to pulsed illumination was amplified using a broadband transistor amplifier, then fed to an oscilloscope and recorded by a computer. The temporal resolution of the electoral circuit was no worse than 10^{-8} s, enabling signal registration within the time range of $10^{-8} \div 10^{-2}$ s (Fig. 5) [1–4].

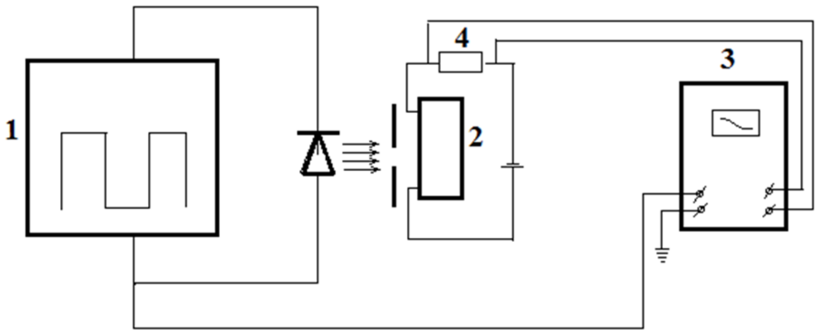

Fig. 4. Block diagram of the setup for measuring the kinetics of the photoelectric effect: 1 – pulse generator; 2 – cell; 3 – amplifier with polarization unit; 4 – oscilloscope.

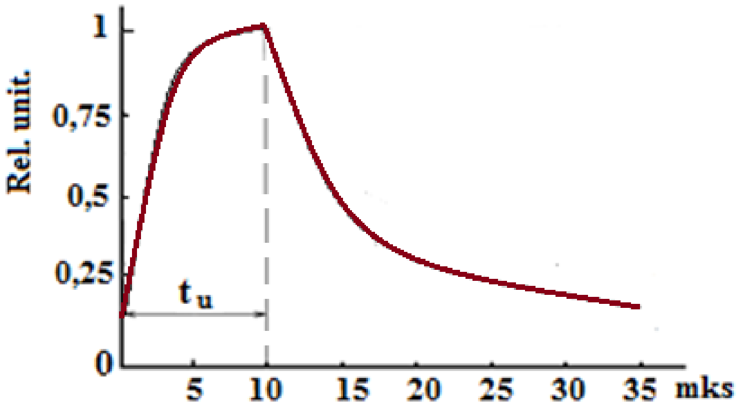

Fig. 5. Relaxation of the photoconductivity of a sample excited by rectangular light pulses in CdTe/CdFeTe thin film heterojunction before irradiation.

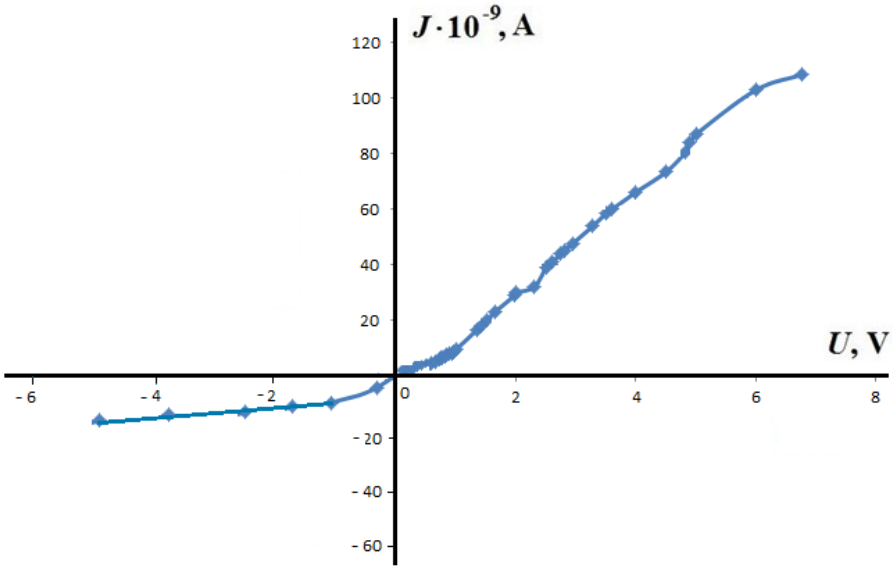

Fig. 6. Volt-ampere characteristic of CdTe:CdFeTe thin film heterojunction.

It was considered the possibility of estimating the lifetime of nonequilibrium charge carriers in a near-surface layer with defects. In the presence of several types of recombination, the effective carrier lifetime can be found from the following expression.

For a thin film heterojunction CdTe/CdFeTe, taking into account structural defects and the influence of the surface, the effective lifetime can be determined by the following equation:

$$\frac{1}{\tau_{eff}} == \sum_i \frac{1}{\tau_l}$$

$$\frac{1}{\tau_{eff}} = \frac{1}{\tau_l} + \frac{1}{\tau_s}$$

Where $\frac{1}{\tau_s} = \frac{2s}{d}$; τ_l -lifetime considering carrier recombination at structural defects in the CdTe:CdFeTe HJ; τ_s - is the surface lifetime; s - is the rate of surface recombination; d - is the thickness of the plate. Analysis of Fig.6 showed that the lifetime of charge carriers is τ=28-35 µs, and the surface recombination rate is s=50 sm/s.

The dose dependence of the charge carrier lifetime in the range from 0÷200 krad. passes through a peak and then decreases. The sensitivity region is 0÷150 krad and is explained by an increase in the degree of orderliness of the system, while at doses above 100 krad due to defect formation, the number of r-centers responsible for photosensitivity drops significantly, which leads to a sharp decrease in the lifetime (Table 1).

Table 1

Dependence of lifetime on radiation dose

D (krad)	0	50	100	150
τ(mks)	30	39	28	20

3. Conclusion

The study demonstrated that the decay of the photocurrent is not mono-exponential, indicating the presence of several types of recombination. Depending on the energy state of these centers, the effective lifetime was 10^{-6}-10^{-3} s. Under pulsed illumination, the lifetime of charge carriers was determined from the kinetic decay of the photocurrent [5–7, 9].

In the irradiated CdTe/$Cd_{1-x}Fe_xTe$ (x=0.08) heterojunction samples at low doses (up to 10 krad) of irradiation, the photosensitivity changes insignificantly, which is due to the high density of structural defects in the original crystals. With an increase in the gamma irradiation dose to 50 krad, the photosensitivity of the samples increased, and above 50 krad it decreased. The effect of radiation-induced change in photosensitivity is due to both a change in the lifetime of nonequilibrium holes as a result of the rearrangement of defects in the band gap of the crystal and the concentration of photosensitivity centers, and their holefilling. The energy position of radiation defects responsible for photoconductivity was 0.17-0.22 eV and their concentrations were 10^{13}-10^{15} cm^{-3}. Thus, studies of the photoelectric characteristics of CdTe/$Cd_{1-x}Fe_xTe$ (x=0.08) heterojunction samples indicated that the process of defect formation during irradiation with gamma quanta leads to a strong change in the concentrations of local levels, including the p-centers of photosensitivity.

To investigate the mechanism of current flow in the HP, we studied the dark current-voltage characteristics (Fig.6) and photoconductivity at room temperature. The results showed that the obtained HJs can be used as photoconverters for solar energy.

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ИССЛЕДОВАНИЕ РЕКОМБИНАЦИОННЫХ ЦЕНТРОВ В $CdTe/Cd_{1-x}Fe_xTe$ ПО РЕЛАКСАЦИИ ФОТОПРОВОДИМОСТИ

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Резюме: Выращен гетеропереход $CdTe/Cd_{1-x}Fe_xTe$ (x=0.08) на стеклянной подложке с проводящим слоем SnO_2. С целью определения механизма рекомбинации, параметров рекомбинационных центров и процесс электронных переходов использованы комплекс стационарных и кинетических методов исследования. При импульсном освещении, по кинетическому спаду фототока, определено время жизни носителей заряда. Исследования показали, что спад фототока не является моноэкспонентной, что показывает о наличии нескольких типов рекомбинации. В зависимости от энергетического состояния этих центров эффективные время жизни составляло 10^{-6}-10^{-3} с. Исследования фотоэлектрических характеристик образцов $CdTe/Cd_{1-x}Fe_xTe$ (x=0.08) показали, что процесс дефектообразования при облучении гамма–квантами приводит к сильному изменению концентраций локальных уровней, в том числе n- центров фоточувствительности.

Ключевые слова: тонкая плёнка полумагнитого полупроводника $CdTe/Cd_{1-x}Fe_xTe$, время жизни, рекомбинационный центр, фотоэлектрический сигнал, облучение гамма квантами.

FOTOKEÇİRİCİLİYİN RELAKSASİYASINA GÖRƏ $CdTe/Cd_{1-x}Fe_xTe$ REKOMBİNASİYA MƏRKƏZLƏRİNİN TƏDQİQİ

N.İ. Hüseynov, M.A. Mehrabova, O.M. Salamov, A.M. Ələkpərov, R.M. Sadıqov, F.P. Abasov

Xülasə: $CdTe/Cd_{1-x}Fe_xTe$ nazik təbəqəli yarımkeçirici elektrik keçiricili SnO_2 təbəqəsi olan şüşə altlıq üzərində alınmışdır. Rekombinasiya mexanizmini, rekombinasiya mərkəzlərinin parametrlərini və elektron keçid proseslərini müəyyən etmək üçün stasionar və kinetik tədqiqat metodları kompleksindən istifadə edilmişdir. İmpulslu işıqlanma altında, fotocərəyanin kinetik azalmasına əsasən yük daşıyıcılarının yaşama müddəti müəyyən edilmişdir. Tədqiqatlar göstərmişdir ki, fotocərəyanın azalması monoeksponensial deyil və bu da bir neçə növ rekombinasiyanın mövcud olduğunu göstərir. Bu mərkəzlərin energetik halından asılı olaraq effektiv yaşama müddəti 10^{-6}-10^{-3} s təşkil etmişdir. $CdTe/Cd_{1-x}Fe_xTe$ (x=0.08) heterostruktur nümunələrinin fotoelektrik xarakteristikalarının tədqiqi göstərmişdir ki, qamma şüaları ilə şüalanma zamanı defekt əmələ gəlmə prosesi lokal səviyyələrin, o cümlədən n-fotohəssaslıq mərkəzlərinin konsentrasiyalarının dəyişməsinə səbəb olur.

Açar sözlər: nazik təbəqəli $CdTe/Cd_{1-x}Fe_xTe$ (x=0.08) heterostruktur yarımmaqnit yarımkeçirici, yaşama müddəti, rekombinasiya mərkəzi, fotoelektrik siqnal, qamma şüalanma.