

THE ELECTRICAL TRANSPORT MECHANISM IN THE (*n*CdS–*p*As₂Se₃) HETEROJUNCTIONS

T. Goglidze, I. Dementiev, S. Dmitriev, N. Nasedkina, and N. Matskova

*Physics department, Moldova State University, 60, A. Mateevich str., MD-2009,
Chisinau, Moldova, Tel: (373-22)-57-76-58*

E-mail: igor_dementiev@yahoo.com or dementiev@usm.md

(Received 24 September 2008)

Abstract

In the given paper we present results of I-V characterization of thin film heterojunctions on the basis of (*n*CdS)–(*p*As₂Se₃). Structures have been obtained via spray pyrolysis deposition of polycrystalline *n*CdS layers on glass substrate and consecutive thermal vacuum deposition of the amorphous *p*As₂Se₃ layers. The possible mechanisms of the current passing through obtained structure are discussed on the basis of results of I-V measurements performed at the different polarities and electrical field intensities in the heterojunction.

Introduction

In the last time the intensive search of a new measures and materials for optical information recording and processing is observed. For these purposes, heterojunctions and multi-layered structures on the basis of glassy and amorphous semiconductors [1, 2] are utilized very often. Heterostructures, in which heterojunction is formed by polycrystalline and chalcogenide glassy semiconductor (ChGS) represent particular group of the structures [2]. A common opinion regarding the electric transport mechanism in such structures still does not exist; at that, as a rule, every investigated pair of materials is described by its own physical model. The latter, in its turn, is determined by the technology of heterojunction creation.

In the given work, we present the results of study of the electrical current passing through thin film (*n*CdS)–(*p*As₂Se₃) heterostructure prepared by the combining of the chemical pulverization and vacuum thermal evaporation methods.

Experimental

*n*CdS layers were deposited by the spray pyrolysis technique under atmospheric pressure on glassy substrates with already formatted bottom low-resistive SnO₂ electrode (*T*_{dep}=450°C). Solutions of SC(NH₂)₂ and CdCl₂ were used as precursors for thin *n*CdS film formation [3]. Chemical reaction of *n*CdS film formation undergoes in accordance with the following reaction



The thickness of deposited *n*CdS layers ranged from 1 to 3 μm.

At the next stage, the amorphous *p*As₂Se₃ film with thickness from 0.3 to 3.0 μm was deposited over *n*CdS layer via vacuum thermal evaporation technique at the residual vacuum pressure in a chamber *P*=1×10^{−4} Torr. Substrate temperature was kept at 25°C. At such temperatures the chemical interaction and atomic interdiffusion between two deposited layers can be considered ignorable. So, we consider the heterojunction structures obtained in accordance with described procedure as a junction with “sharp” interface.

The topology of investigated samples, shown in Fig. 1, has allowed studying the properties of the separate $n\text{CdS}$, $p\text{As}_2\text{Se}_3$ layers as well as of heterojunctions ($n\text{CdS}$)–($p\text{As}_2\text{Se}_3$) in the whole. Self-transparent Al pads ($2 \times 2 \text{ mm}^2$) served as top electrodes. At the room temperature the resistance of As_2Se_3 layer amounted to $10^{12} \text{ Ohm}\cdot\text{cm}$.

I-V characteristics of the ($n\text{CdS}$)–($p\text{As}_2\text{Se}_3$) heterostructure were studied in the temperature interval from 20 to 100°C and applied voltage ranged from 0 to 50 V.

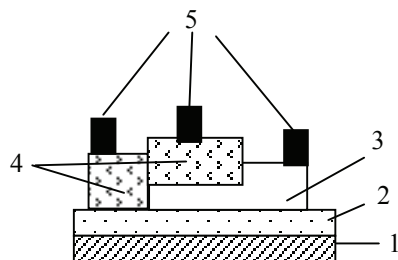


Figure. 1. ($n\text{CdS}$)–($p\text{As}_2\text{Se}_3$) heterostructure topology: 1) glass substrate; 2) SnO_2 electrode; 3) ($n\text{CdS}$) film; 4) ($p\text{As}_2\text{Se}_3$) layer; 5) Al top electrodes.

Results and discussion

A considerable rectifying effect is observed on studied structures (Fig. 2). At that, the positive potential is on the $n\text{CdS}$ layer at the reverse bias applied to the structure. The thickness of arsenic sulfide layer has also noticeable influence on the rectifying coefficient magnitude. Its growth is accompanied by the direct and reverse I-V curve branches approaching to the abscissa axis. It was found that the maximal value of the rectification coefficient $K_{\text{max}} \approx 10^3$ is observed at As_2Se_3 layer thickness $d \approx 0.3 \text{ }\mu\text{m}$ (see insert

in Fig. 2).

With further thickness growth the value of K sharply drops. It is obvious that at the thickness $d = 0.3 \text{ }\mu\text{m}$ the field of the contact potential difference (CPD) is concentrated basically in the $p\text{As}_2\text{Se}_3$ layer and the field is presented in the $n\text{CdS}$ layer some degree only. Further growth of ChGS layer thickness leads to the situation when general resistance of heterojunction will be determined by resistance of high resistive amorphous $p\text{-As}_2\text{Se}_3$ layer.

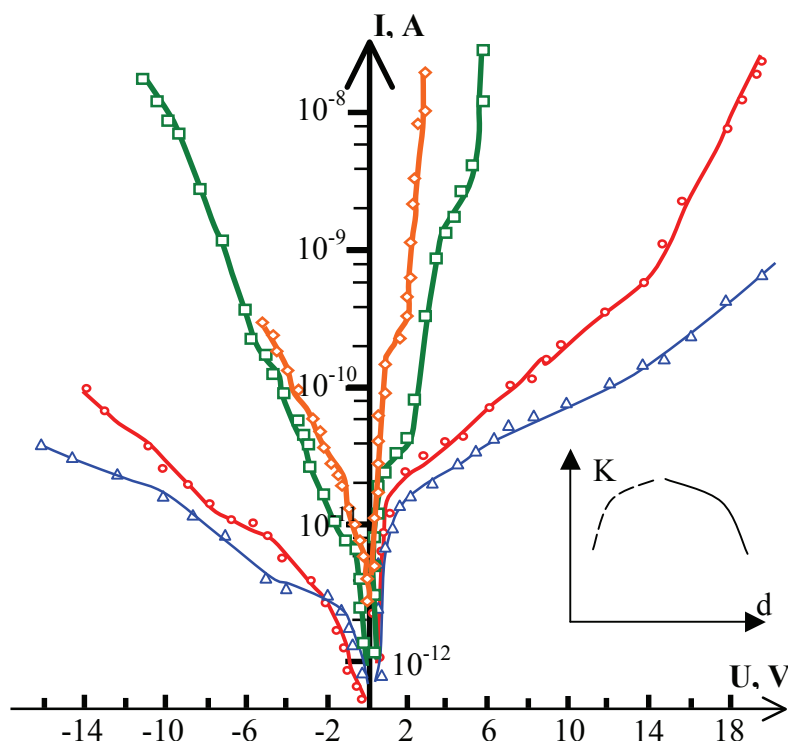


Figure 2. I-V characteristics of ($n\text{CdS}$)–($p\text{As}_2\text{Se}_3$) obtained at $T=300 \text{ K}$ and different thicknesses of As_2Se_3 layer (μm): 1–0,3; 2–0,5; 3–1,8; 4–2,6; and the thickness of CdS layer of Insert: the dependence of the rectifying coefficient on the thickness of $p\text{As}_2\text{Se}_3$ layer.

For better understanding of the mechanism of electric current passing through (nCdS)-(pAs₂Se₃) heterojunction the obtained direct I-V curves were re-built in semi-logarithmic (curve 1) and logarithmic (curve 4) scales as well as in Schottky $\ln I_{np}, \sqrt{V}$ (curve 3) and Frenkel $\ln I_{np}/\sqrt{V}, \sqrt{V}$ (curve 2) coordinates (Fig. 3). One can see that experimental points can not be fitted by the straight line in all considered cases in all voltage diapason. The I-V characteristic analysis shows that the exponential dependence of the current on applied voltage describes the curve trend up to voltages $V = 20kT/e$ fairly well (Fig. 4, curve 1) (here: k is the Boltzman constant, T is the temperature, and e is the electron charge). In other words, the beginning region of the direct I-V branch is described by the law $I_{dir} \sim \exp\left[\frac{eV}{\eta kT}\right]$. At that, the coefficient η in the degree factor is varying in the range 4÷15. With temperature growth the value of η is decreasing noticeably (cf., curves 1-4 in Fig. 4) that indicates the domination of recombination mechanism in current passing [5].

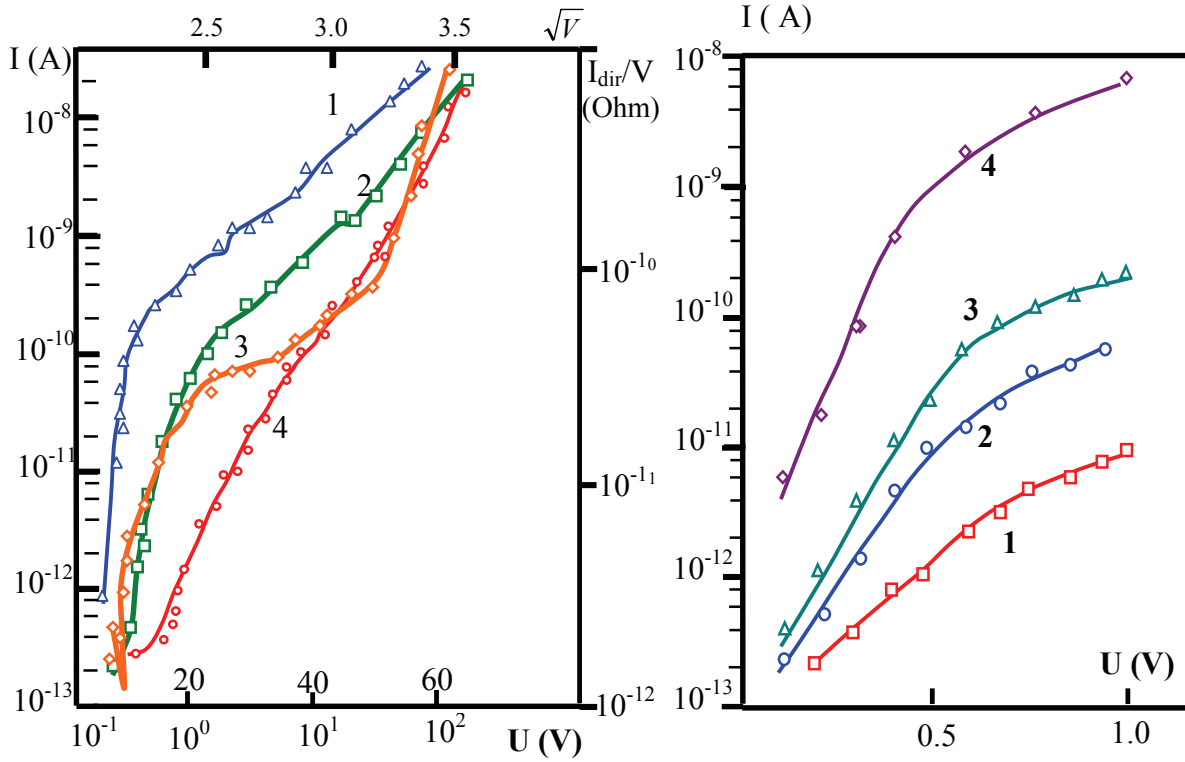


Figure 3. (n-CdS) – (p-As₂Se₃) heterostructure at the direct bias. I-V curves built in the different coordinates: 1) $\ln I_{dir} = f(V)$; 2) $\ln I_{dir}/V = f(\sqrt{V})$; 3) $\ln I_{dir} = f(\sqrt{V})$; 4) $\ln I_{dir} = f(\ln V)$.

Figure 4. I-V curves of the (n-CdS) – (p-As₂Se₃) heterostructure at the direct bias for different measurement temperatures (°C): 1- 20; 2 - 38; 3 - 47; 4 - 107.

Another one exponent region is observed on the $\ln I_{dir} = f(V)$ curves at the voltage higher than 0.5 V. In this region current is described by the expression $I_{dir} = I_0 \cdot \exp\left[\frac{eV}{\eta kT}\right]$ (Fig. 4). Also, one can see, that in this region the I-V curves slop, built in logarithmic scale, is ignorably changed with temperature and determined by the value of η ranged from 15 to 20.

The obtained experimental results can serve as the evidence of the potential barrier existence on the interface between amorphous and polycrystalline layers with height $e\phi$ about

0.40 eV. Its presence is confirmed by the observable asymmetry of I-V curves. Thus, we can consider that a general expression for (nCdS)-(pAs₂Se₃) heterojunction has the following form

$$I_{dir} = B \exp \left(- \frac{q \phi}{kT} \right) \left(\exp \frac{qV}{\eta kT} \right). \quad (2)$$

Linear dependence $\ln I_{dir}/T^2 = f \left(\frac{10^3}{T, K} \right)$ for different thicknesses of the As₂Se₃ layer

(Fig. 5) serves an additional confirmation of the Schottky emission effect. Therefore, the emission mechanism for the direct electrical current passing through (nCdS)-(pAs₂Se₃) heterojunction is very probable.

However, Schottky emission mechanism can be observed only under the small voltage biases. At the sufficiently large direct voltage biases the complete barrier compensation and over-barrier emission should take place, leading to the increase of electron injection from CdS to As₂Se₃ layer. In its turn the increased injection electron fluxes can lead to the appearance of the Space Charge Limited Currents (SCLC).

In all studied heterostructures the thickness of As₂Se₃ never exceeded the value of a few microns, so the intensity of electrical fields higher than 10⁴ V/cm could be achieved at the applied voltages of only few volts. The I-V curves, built in logarithmic coordinates $\ln I_{dir} = f(\ln V)$ (Fig. 3), show that experimental points are properly fitted by straight line beginning from voltage $U > 10$ V; that is, the current is changed in accordance with power law $I_{dir} \sim V^n$. We observe two regions on the curve: at low voltages the power coefficient $n = 1$ and at the higher voltages the value of power coefficient is ≥ 3 . Such dependence is

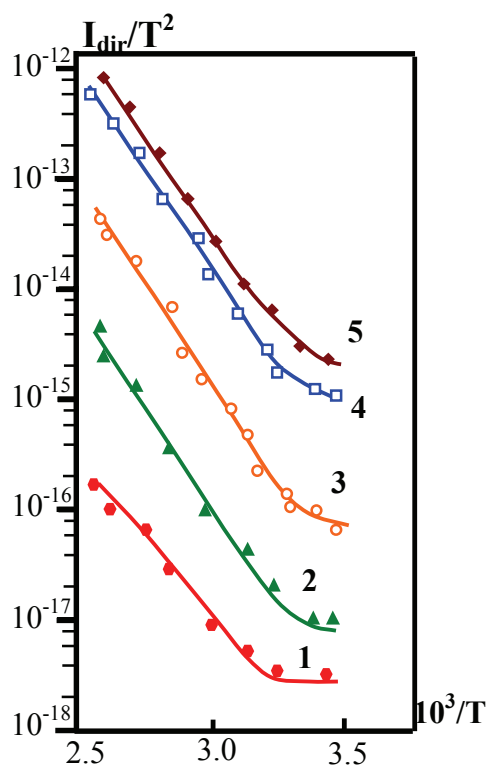


Figure 5. The direct current vs. temperature dependence of (nCdS)-(pAs₂Se₃) heterostructure obtained at the T=300K. As₂Se₃ layer thickness (μm): 1-0,3; 2-0,5; 3-1,8; 4-2,6; 5-3.

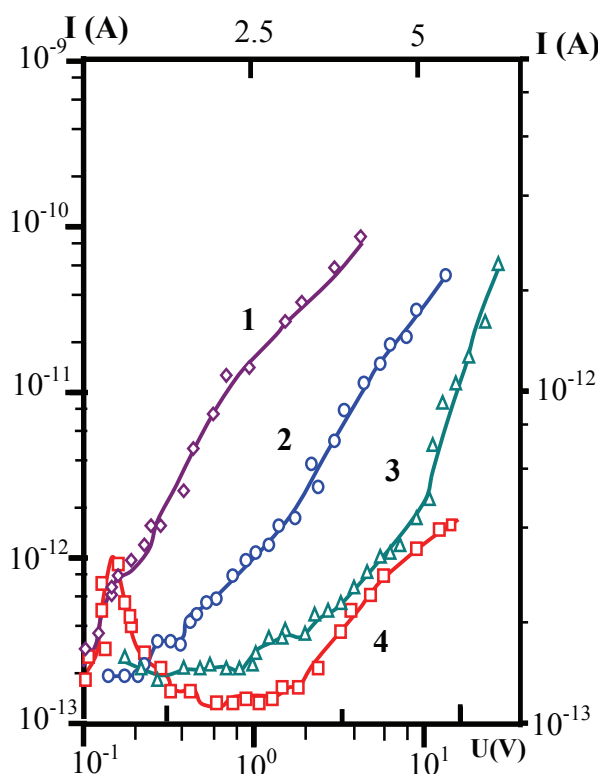


Figure 6. The reverse current of the (nCdS) – (pAs₂Se₃) heterostructure measured at T=300K and built in different coordinates: 1- $\ln I_{06p}$, V; 2- $\ln I_{06p}/V$, $\sqrt{V}$; 3- $\ln I_{06p}$, $\sqrt{V}$; 4- $1-\ln I_{06p}$, V.

characteristic of the SCLC at the continuous exponent trap distribution [6]. Investigation of the I-V curves on dependence on the As_2Se_3 layer thickness has shown that for superlinear regions of curve the current density is inversely proportional to the thickness of amorphous layer $I_{\text{dir}} \sim 1/d^5$ that also confirms the presence of SCLC.

At the direct bias applied to the heterostructure practically all voltage drops on the high resistive amorphous As_2Se_3 layer. Its high resistance is stipulated by the large amount of the trap levels continuously distributed in the band gap. The concentration of given trap states was calculated proceeding from the SCLC theory [7] and amounted to $N(f) \sim 10^{15} \text{ cm}^{-3} \text{ eV}^{-1}$. This value is in a very good correspondence with data obtained for localized states concentration in As_2Se_3 films [6].

For more detailed investigation of the I-V curves at the reverse bias (Fig. 6) they were re-built in logarithmic (curve 4), semi-logarithmic (curve 1), Schottky (curve 3), and Frenkel (curve 2) coordinates. As one can see from the graphs, no transport mechanism considered above can be used for charge carrier transfer description. It is possible that the regions where the current is changed ignorably with applied voltage are characterized by the domination of the generation mechanism of current passing through heterostructure, stipulated by the presence of surface states on the interface.

Conclusions

Thus, we can conclude that in the heterostructures of $(n\text{CdS})-(p\text{As}_2\text{Se}_3)$ type at the direct bias and electrical field intensities up to $E < 10^4 \text{ V/cm}$ there is observed the electric current passing mechanism, stipulated by the over-barrier Schottky emission. In the case of electrical field intensities $E > 10^4 \text{ V/cm}$ the regimes of SCLC are observed.

Similar laws are characteristic for the structures of metal-dielectric-metal type at the presence of high concentration of the surface state on the interface [7]. In this case the low resistive interlayer can serve as effective injector of the charge carriers in amorphous material, leading to the SCLC appearance.

High specific resistance of the film heterostructures $(n\text{CdS})-(p\text{As}_2\text{Se}_3)$ ($\rho \geq 10^{12} \text{ Ohm}\cdot\text{m}$) and high photosensitivity [1, 8, 9] allow us to successfully utilize them as photoconductive media.

References

- [1] L. Panasiuk and I. Dementiev, *Getero-perekhody v sistemakh registratsii opticheskoi informatsii*, [in Russian], V sb. "Fotoelectr. svoistva geteroperekhodov", "Stiinta", 69-82, 1980.
- [2] I. Dementiev, V. Kolesnik, and N. Matskova, *Mold. Jour. of the Phys. Sci.*, 2, 2, 198, (2003).
- [3] T. Goglidze, E. Pocotilov, I. Dementiev, and N. Matskova, *Preobrazovateli rentgenovskogo izlucheniya na osnove A_2B_6 , poluchennyi metodom khimicheskoi pulverizatsii*, [in Russian], *Analele stiintifice ale USM. Seria "Stiinte fizico-matematice"*, 90, (2004).
- [4] S. Sze, *Fizika poluprovodnikovyx priborov*, [in Russian], "Energia", Moscow, 655, 1973.
- [5] A. Rose, *Phys. Rev.*, 97, 6, 1538, (1955).
- [6] L. Gagara, I. Dementiev et al., *Mekhanizm tokoprokhozhdzenia cherez geterostruktury na osnove kontakta amorfnykh i kristallicheskikh sloev*, [in Russian], *Tezisy dokladov Vsesoiuznoe soveshchanie po dielektricheskoi elektronike ("FAN")*, Tashkent, 41, (1973).
- [7] B. Kolomiets and E. Lebedev, *Izuchenie lokalinykh tsentrov v stekloobraznom As_2Se_3 metodom TOPZ*, [in Russian], *Fiz. Tekh. Poluprovodnikov*, 1, 6, (1967).
- [8] N. Barba, L. Berezina, et al., *Fotoelektricheskie svoistva geterostruktur prigodnykh dlea PTPZ*, III All-Union Conf. "Besserebryannye i neobychnye fotograficheskie protsessy", Vilnius, 22, (1980).
- [9] L. Bekicheva, T. Goglidze, G. Manushevich, and L. Panasiuk, *Fotoelektricheskiiye svoistva tonkikh sloev As_2S_3 bez podstilaiushchikh elektrodov iz CdS*, Abstracts Book, All-Inion Conference "Recording media, methods and apparatus", Chisinau, 42, (1980).