# Journal of Solar Energy Engineering

Copy of e-mail Notification

Journal of Solar Energy Engineering Published by ASME
Dear Author,

Congratulations on having your paper accepted for publication in the ASME Journal Program.
Your page proof is available in PDF format from the ASME Proof Download & Corrections site here:
http://115.111.50.156/jw/AuthorProofLogin.aspx?pwd=ac7aa72d2aef

Login: your e-mail address
Password: ac7aa72d2aef

Please keep this email in case you need to refer back to it in the future.
You will need Adobe Acrobat Reader software to view the file. This is free software and a download link is provided when you log in to view your proofs.

Responsibility of detecting errors rests with the author. Please review the page proofs carefully and:

1. Answer any queries on the first page “Author Query Form”
2. Proofread any tables and equations carefully
3. Check to see that any special characters have translated correctly
4. Publication will not proceed until a response is received. If there are no corrections, a response is still required.

RETURNING CORRECTIONS:
Corrections must be returned using the ASME Proof Download & Corrections Submission Site (link above). You will be able to upload:

1. Annotated PDF
2. Text entry of corrections, with line numbers, in the text box provided
3. Additional files, if necessary.

SPECIAL NOTES:
Your Login and Password are valid for a limited time. Please reply within 48 hours.

Corrections not returned through the above website will be subject to publication delays.
This e-proof is to be used only for the purpose of returning corrections to the publisher.
If you have any questions, please contact: asme.cenveo@cenveo.com, and include your article no. (SOL-13-1289) in the subject line. This email should not be used to return corrections.

Sincerely,
Isabel Castillo, Journal Production Manager

**STATEMENT OF EDITORIAL POLICY AND PRACTICE**

The Technical Committee on Publications and Communications (TCPC) of ASME aims to maintain a high degree of technical, literary, and typographical excellence in its publications. Primary consideration in conducting the publications is therefore given to the interests of the reader and to safeguarding the prestige of the Society.

To this end the TCPC confidently expects that sponsor groups will subject every paper recommended by them for publication to careful and critical review for the purpose of eliminating and correcting errors and suggesting ways in which the paper may be improved as to clarity and conciseness of expression, accuracy of statement, and omission of unnecessary and irrelevant material. The primary responsibility for the technical quality of the papers rests with the sponsor groups.

In approving a paper for publication, however, the TCPC reserves the right to submit it for further review to competent critics of its own choosing if it feels that this additional precaution is desirable. The TCPC also reserves the right to request revision or condensation of a paper by the author or by the staff for approval by the author. It reserves the right, and charges the editorial staff, to eliminate or modify statements in the paper that appear to be not in good taste and hence likely to offend readers (such as obvious advertising of commercial ventures and products, comments on the intentions, character, or acts of persons and organizations that may be construed as offensive or libelous), and to suggest to authors rephrasing of sentences where this will be in the interest of clarity. Such rephrasing is kept to a minimum.

Inasmuch as specific criteria for the judging of individual cases cannot, in the opinion of the TCPC, be set up in any but the most general rules, the TCPC relies upon the editorial staff to exercise its judgment in making changes in manuscripts, in rearranging and condensing papers, and in making suggestions to authors. The TCPC realizes that the opinions of author and editor may sometimes differ, and hence it is an invariable practice that no paper is published until it has been passed on by the author. For this purpose page proofs of the edited paper are sent to the author prior to publication in a journal. Changes in content and form made in the proofs by authors are followed by the editor except in cases in which the Society's standard spelling and abbreviation forms are affected.

If important differences of opinion arise between author and editor, the points at issue are discussed in correspondence or interview, and if a solution satisfactory to both author and editor is not reached, the matter is laid before the TCPC for adjustment.

Technical Committee on Publications and Communications (TCPC)
Reviewed: 05/2012

# AUTHOR QUERY FORM

| ASME SETTING THE STANDARD | Journal: J. Sol. Energy Eng.<br>Article Number: SOL-13-1289 | Please provide your responses and any corrections by annotating this PDF and uploading it to ASME's eProof website as detailed in the Welcome email. |
|---|---|---|

Dear Author,

Below are the queries associated with your article; please answer all of these queries before sending the proof back to Cenveo. Production and publication of your paper will continue after you return corrections or respond that there are no additional corrections.

| Location in article | Query / Remark: click on the Q link to navigate to the appropriate spot in the proof. There, insert your comments as a PDF annotation. |
|---|---|
| AQ1 | Please check and confirm the presentation of the given affiliations. |
| AQ2 | Please note that "0,4 and 0,9" have been changed to "0.4 and 0.9," respectively. Kindly check and confirm. |
| AQ3 | Please provide the caption for Table 1. |
| AQ4 | Please note that "comma" has been replaced by "decimal point" in Table 1. Kindly check and confirm. |
| AQ5 | Please provide Doi for Refs. 5, 10, 17, 18 and 20. |

Thank you for your assistance.

# Preparation and Investigation of p-GaAs/n-$Cd_{1-x}Zn_xS_{1-y}Te_y$ Heterojunctions Deposited by Electrochemical Deposition

**Huseyn M. Mamedov**
Faculty of Physics,
Department of Physical Electronics,
Baku State University,
Z.Khalilov street, 23,
Baku Az1148, Azerbaijan
e-mail: mhhuseyng@gmail.com

**Zoltan Konya**
Department of Applied and
Environmental Chemistry,
University of Szeged,
H-6720 Szeged, Rerrich Bela ter 1.,
Hungary
e-mail: konya@chem.u-szeged.hu

**Mustafa B. Muradov**
Faculty of Physics,
Nanomaterials Laboratory,
Baku State University,
Z.Khalilov street, 23,
Baku Az1148, Azerbaijan
e-mail: mbmuradov@gmail.com

**Akos Kukovecz**
Department of Applied and
Environmental Chemistry,
University of Szeged,
H-6720 Szeged, Rerrich Bela ter 1.,
Hungary
e-mail: kakos@chem.u-szeged.hu

**Krisztian Kordas**
Microelectronics and Materials
Physics Laboratories,
University of Oulu,
P.O. Box 8000FI-90014, Oulu, Finland
e-mail: lapy@ee.oulu.fi

**Daniel P. Hashim**
Department of Mechanical Engineering and
Materials Science,
Rice University,
6100 Main Street, MS-321,
Houston, TX 77005
e-mail: danielpaul3@gmail.com

**Vusal U. Mamedov**
Faculty of Physics,
Department of Physical Electronics,
Baku State University,
Z.Khalilov street, 23,
Baku Az1148, Azerbaijan
e-mail: mammadovv@gmail.com

*Anisotype heterojunctions of p-GaAs/n-$Cd_{1-x}Zn_xS_{1-y}Te_y$ have been fabricated by preparing n-type $Cd_{1-x}Zn_xS_{1-y}Te_y$ thin films onto p-GaAs single crystal wafers using an electrochemical deposition method. The voltammetric behavior of the $Cd_{1-x}Zn_xS_{1-y}Te_y$ thin films on GaAs substrates from aqueous solutions was studied. Electrical and photoelectrical properties of heterojunctions were studied depending on the $Cd_{1-x}Zn_xS_{1-y}Te_y$ films composition ($x = 0.1 \div 0.8$; $y = 0.2$; 0.4; 0.9) and heat treatment (HT) regime in argon atmosphere (100–450 °C during 3–16 min). Under AM1.5 conditions, the open-circuit voltage, short-circuit current, fill factor, and efficiency of our best cell, was $V_{oc} = 584$ mV, $J_{sc} = 14.54$ mA/cm$^2$, FF = 0.6, and $\eta = 6.7\%$, respectively.*
[DOI: 10.1115/1.4027694]

*Keywords: electrochemical deposition, thin film, heterojunction, heat treatment, solar cell*

## Introduction

Thin films of II-VI compounds (CdS, CdTe, $Cd_{1-x}Zn_xS$, $Cd_{1-x}Zn_xS_{1-y}Se_y$, and $Cd_{1-x}Zn_xS_{1-y}Te_y$ (CZSTE), etc.) have attracted considerable attention from the research community due to their wide uses in the fabrication of semiconductor device technology and solar cells [1–5]. In photovoltaic systems, the replacement of CdS with the higher energy band gap of $Cd_{1-x}Zn_xS$, $Cd_{1-x}Zn_xS_{1-y}Se_y$, and CZSTE alloys has led to a decrease in window absorption losses and has resulted in an increase in the short-circuit current. The II-VI quaternary semiconductors seem to be useful materials with photosensitivity in the visible and ultraviolet wavelength regions [6–10]. Since single crystals of GaAs are well-studied materials, their use at manufacturing of heterojunctions p-GaAs/CZSTE will be a good way to deeply study the physical properties of CZSTE films.

There are many techniques used to synthesize thin films of II-VI compounds, such as thermal evaporation, chemical bath deposition, successive ionic layer absorption and reaction, magnetron sputtering, metalorganic vapor phase epitaxy, etc. [11–17]. In photovoltaic applications, where semiconductor films over large areas are required, the electrodeposition technique is specially adequate. In addition, for application in solar cells, electrodeposition allows one to easily alter both the bandgap and lattice constant by composition modulation through the control of growth parameters such as applied potential, *p*H, and temperature of the bath [11,18–20]. Thus, it is at least in principle possible to easily grow large areas of tandem cells designed for the most efficient conversion of the solar spectrum.

In the present work, anisotype heterojunctions of p-GaAs/n-CZSTE were fabricated by depositing CZSTE thin films as a window using the electrochemical deposition method onto the p-GaAs single crystals.

## Experimental

Electrodeposition of the CZSTE films onto the p-GaAs substrates was carried out at a temperature of 80 °C from aqueous solution containing cadmium ($CdSO_4$), zinc ($ZnSO_4$), sodium ($Na_2S_2O_3$), and tellurium ($TeO_2$ or $Na_2Te_2O_3$) salts. The thickness and resistivity of the monocrystalline p-GaAs substrates were 0.4 mm and $\rho = 0.2$–0.23 Ω cm, respectively. Before the deposition process, the surfaces of the GaAs substrates were etched in an aqueous solution of hydrochloric acid and KOH-$KNO_3$ (1:3) composition for 3 min. After etching, the GaAs wafers were washed for 2 min in pure alcohol and distilled water maintained at high temperatures (≥300 °C).

Contributed by the Solar Energy Division of ASME for publication in the Journal of Solar Energy Engineering: Including Wind Energy and Building Energy Conservation. Manuscript received October 2, 2013; final manuscript received April 25, 2014; published online xx xx, xxxx. Assoc. Editor: Santiago Silvestre.

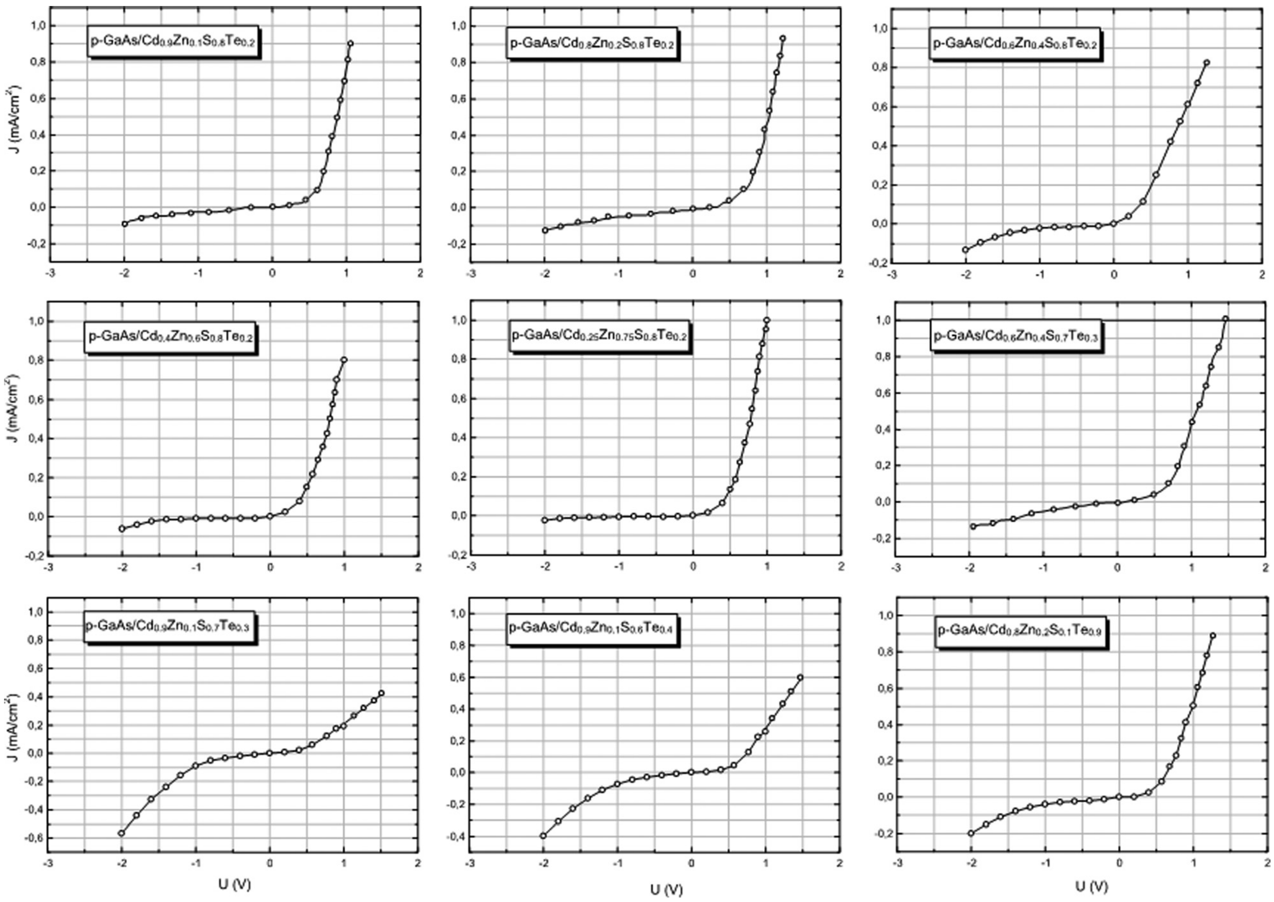


**Fig. 1 Dark *J–V* curves for as-deposited p-GaAs/CZSTE heterojunction**



Cyclic voltammetry was used to monitor the electrochemical reactions in separate solutions of $CdSO_4$, $ZnSO_4$, $Na_2S_2O_3$, and $TeO_2$, then in their combined solution at the same concentration and *p*H. The cyclic voltammogram was scanned in the potential range 1.2 V to −1.2 V versus graphite (or Ag/AgCl) electrodes. Cyclic voltammogram for mixture of $CdCl_2$, $ZnCl_2$, $Na_2S_2O_3$, and $Na_2Se_2O_3$ salts shows that wave −0.52 ÷ −0.9 V corresponded to the formation of CZSTE layers. The thickness of the CZSTE films grown by electrodeposition from a solution could be varied in a wide range from 50 to 1600 nm.

In order to fabricate the heterojunctions, an ohmic in electrode, in reticulose form was evaporated on the CZSTE films with an area of ~0.82–1 cm$^2$. An ohmic contact was performed on the side of GaAs wafers by evaporating an Al electrode.

## Results and Discussion

The dark current–voltage (*J–V*) curves of the heterojunctions were measured in the direct and reverse current modes. The experimental *J–V* curves, measured at 300 K, for as-deposited p-GaAs/CZSTE heterojunctions, using various values of $x$ and $y$, are illustrated in Fig. 1.

These curves definitely proved diode type behavior, with the forward direction corresponding to the positive potential on p-GaAs. Thus, according to this figure, the as-deposited junctions composed of CZSTE films with $x = 0.75$ and $y = 0.2$ (which is a good lattice match with GaAs layers) reaches a rectification value of $k = 700$ at voltage $U = 1.0$ V ($k$ is the rectification factor), and decreases when zinc concentration, $x$, increases. The low rectification coefficient is due to the high series resistance within the heterostructure. Plotting the natural log of the current density versus the applied voltage, we are able to identify a characteristic thermally activated recombination region up to 0.63 V. Usually, such dependencies are described by the expression

$$J = J_s\left[\exp\left(\frac{eV}{AkT}\right) - 1\right] \quad (1)$$

Here, $J_s$ is the saturation current density, $V$ is the applied voltage, $e$ is the electron charge, $A$ is the ideality factor, $k$ is the Boltzmann constant, and $T$ is the temperature.

Increasing the forward bias magnitude ($U > 0.65$ V) resulted in a less steep dependence of *J*(*V*) and its pronounced deviation from the curve calculated according to the formula (1), which can be a consequence of the changes of carrier transport mechanism. The most possible case to be considered is tunneling recombination. In the as-deposited heterojunctions, the ideality factor was determined under a forward bias, and it was normally found to range from 1.6 to 2.7 for the different $x$ and $y$. This established that the value of ideality factor was minimal for the p-GaAs/n-$Cd_{0.25}Zn_{0.75}S_{0.8}Te_{0.2}$ heterojunctions.

The mechanism of current passage through the heterojunctions essentially changes with increasing HT temperature from 0 to 390 °C (for 14 min). Notably, tunnel currents sharply decreased with increasing HT temperature, which testifies to reduction of defects and decreasing series resistance (Table 1). After the HT in argon atmosphere at 390 °C for 14 min, the ideality factor values were approximately 1.4 for the heterojunctions with $x = 0.75$ and $y = 0.2$. It is significant to note that the best rectification for the annealed p-GaAs/n-$Cd_{0.25}Zn_{0.75}S_{0.8}Te_{0.2}$ heterojunctions was obtained at about $k = 3000$, which is attributable to the optimal HT conditions and lattice mismatch between the solid solution of $Cd_{0.25}Zn_{0.75}S_{0.8}Te_{0.2}$ and GaAs.

The capacitance versus voltage measurement results ($1/C^2$–$V$) for the heterojunctions p-GaAs/n-$Cd_{0.25}Zn_{0.75}S_{0.8}Te_{0.2}$ annealed in argon atmosphere at 390 °C for 14 min showed a linear relationship with bias voltage and indicates that the junction is abrupt.

AQ3

AQ4

**Table 1**

| HT temperature and duration | Rectification coefficient ($k$) | Nonideality factor ($A$) | Series resistance ($R_a$, $\Omega\,cm^2$) |
|---|---|---|---|
| before HT | 200 | 1.61 | 260 |
| 150 °C; 14 min | 540 | 1.54 | 200 |
| 200 °C; 14 min | 970 | 1.51 | 176 |
| 250 °C; 14 min | 1700 | 1.46 | 93 |
| 300 °C; 14 min | 2450 | 1.44 | 54 |
| 350 °C; 14 min | 2600 | 1.42 | 30 |
| 390 °C; 14 min | 3000 | 1.4 | 24 |
| 430 °C; 14 min | 6 | 2.56 | 1300 |

Also built-in potential ($V_{bi} = 0.61$ V) were calculated by extrapolating ($1/C^2$–$V$) plot to (($1/C^2$) = 0).

As-deposited (nonheat-treated) $p$-GaAs/CZSTE heterojunctions were found to possess a photovoltaic effect. As follows from Fig. 2, the efficiency of the heterojunctions depends on the film's composition $x$ and $y$. Under AM1.5 conditions, the maximal values of open-circuit voltage, short-circuit current, fill factor, and efficiency for cells p-GaAs/n-$Cd_{0.25}Zn_{0.75}S_{0.8}Te_{0.2}$, were $V_{oc} = 131$ mV, $J_{sc} = 3.4$ mA/cm$^2$, FF = 0.43, and $\eta = 0.2\%$, respectively.

To assess the effect of HT on the photoelectric properties of the heterojunctions, the films were annealed in argon atmosphere at 100–450 °C for 3–16 min. Figure 3 shows typical spectral dependences of the photocurrent for p-GaAs/n-$Cd_{0.25}Zn_{0.75}S_{0.8}Te_{0.2}$ heterojunctions before and after HT. There occurs a reconstruction of the photosensitivity spectrum after HT, i.e., the spectrum broadens. As the HT temperature increased from 0 to 390 °C for 14 min, photosensitivity in the $\lambda_m = 0.38$–$0.8\,\mu$m wavelength region sharply increased. The near infrared photosensitivity falloff for all heterojunctions indicated GaAs absorber band gaps of 1.42 eV. Figure 3 also shows that after subsequently HT in argon atmosphere for 14 min at ≥400 °C the performance of these cells deteriorated.

The observed effect of HT on the heterojunction properties can be understood in terms of electronic–molecular interaction between the surface of CZSTE films and oxygen [3–5]. It is believed that oxygen adsorption, after the removal of CZSTE films from the solution, leads to the formation of deep acceptor states in the surface layer of the films. The oxygen-related acceptors

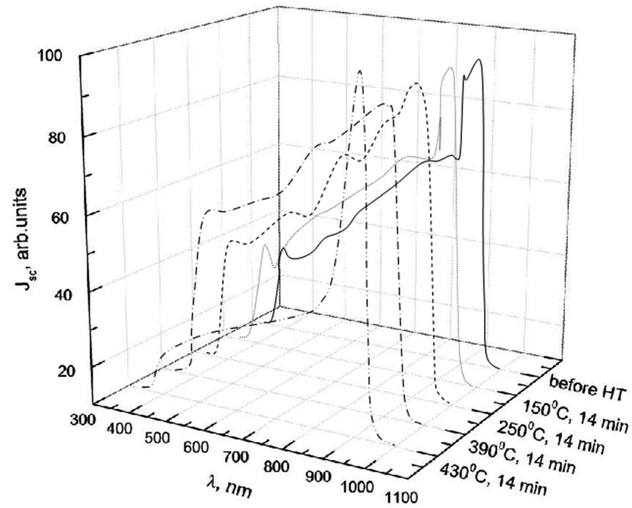


**Fig. 3 Spectral dependences of the photocurrent for p-GaAs/n-$Cd_{0.25}Zn_{0.75}S_{0.8}Te_{0.2}$ heterojunctions before and after HT**

capture electrons from the film bulk, creating a near-surface potential barrier, which is responsible for the low short-wavelength photosensitivity of the nonheat-treated heterojunctions. The small height of the intergranular barriers in polycrystalline films, as compared to the oxygen-related barriers, renders the short-wavelength photoresponse of the $p$-GaAs/CZSTE heterojunctions to be governed by the density of oxygen-related states. The observed effect of HT on the photoelectric properties of the heterojunctions demonstrates that the donor and acceptor concentrations in the films depend on HT conditions. In particular, it seems likely that, in the initial stages of HT, some of the oxygen desorbs, which enhances the short-wavelength photosensitivity of the heterojunctions. In addition, HT at 390 °C for 14 min results in preferential vaporization of Cd and Zn. The Cd and Zn vacancies forming in the surface layer of the CZSTE films act as $r$ centers. The decrease in the density of surface defects and film recrystallization during subsequent HT shifts the photosensitivity maximum to shorter wavelengths and improves the performance parameters of the films. The sharp decrease in photosensitivity upon heat treatment at 400 °C or higher temperatures indicates that some of



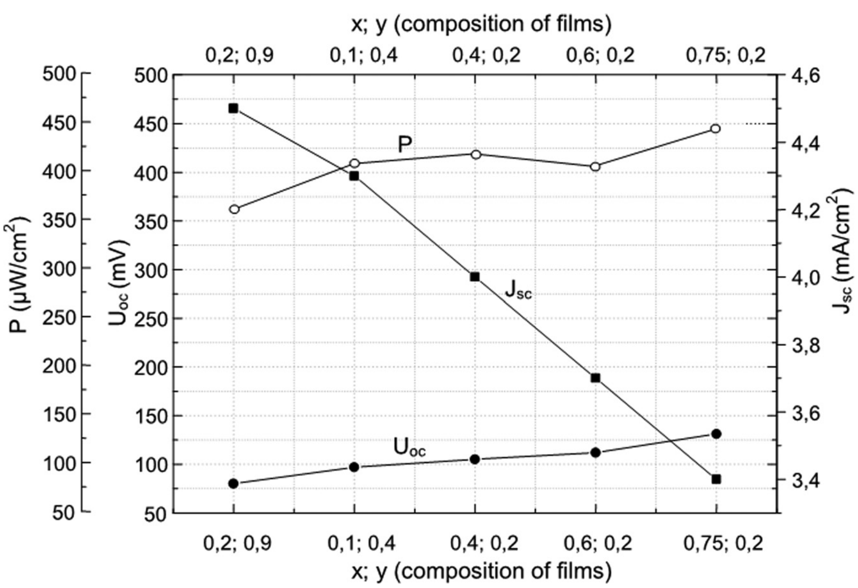


**Fig. 2 Dependence of short-circuit current ($J_{sc}$), open-circuit voltage ($U_{oc}$), and power output ($P$) of the as-deposited p-GaAs/n-$Cd_{1-x}Zn_xS_{1-y}Te_y$ cells on the films composition**

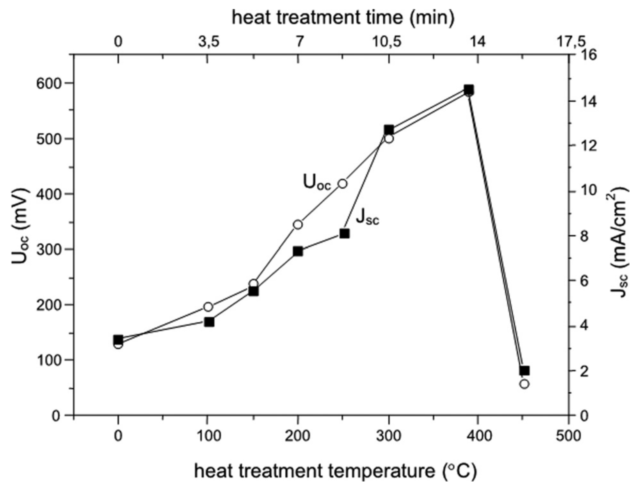


**Fig. 4 Dependence of p-GaAs/n-$Cd_{0.25}Zn_{0.75}S_{0.8}Te_{0.2}$ solar cell parameters on the heat treatment time and temperature**

the oxygen does not desorb and remains in the surface layer in atomic form. As a result, the *r* centers begin to play a crucial role in determining the recombination process, and the concentration of holes captured by the *r* centers increases sharply, reducing the photoresponse of the devices.

Note that, under the conditions of this study, the short-circuit current through the heterojunctions varies nonmonotonically not only with temperature but also with HT time and reaches a maximum after heat treatment at 390 °C for 14 min (Fig. 4). Under AM1.5 conditions the maximal values of open-circuit voltage, short-circuit current, fill factor and efficiency of our best cell, were $V_{oc} = 584$ mV, $J_{sc} = 14.54$ mA/cm$^2$, FF = 0.6, and $\eta = 6.7\%$, respectively.

During storage for more than 36 months at room temperature, the parameters of HT *p*-GaAs/CZSTE heterojunctions experienced no degradation.



## Conclusions

*p*-GaAs/CZSTE heterojunctions prepared by the method of electrochemical deposition are suitable to fabricate high efficiency solar cells. Their electrical and photoelectrical characteristics were studied depending on the composition of CZSTE films and the HT condition. It is established that HT at 390 °C for 14 min in argon atmosphere reduces the concentration of defects, results in formation of heterojunctions and minimum values of nonideality factor ($A = 1.4$) of *J–V* characteristics and serious resistance ($R_a = 24$ Ω cm$^2$). The forward current of this junction obeys tunneling-recombination model and (*C–V*) measurements revealed that heterojunctions are abrupt.

Heterojunctions with $x = 0.75$ and $y = 0.2$ possess a high photosensitivity after the HT in argon at 390 °C for 14 min. Under standard 100 mW/cm$^2$ white-light illumination at room temperature, the values of the parameters of our best cell were $V_{oc} = 584$ mV, $J_{sc} = 14.54$ mA/cm$^2$, FF = 0.6, and $\eta = 6.7\%$, respectively.

## Acknowledgment

This work was supported by FP7 NAPEP Project No. 266 600. Financial support from the TÁMOP-4.2.2.A-11/1/KONV-2012-**0047 project is acknowledged.

## References

[1] Raviprakash, Y., Bangera, K. V., and Shivakumer, G. K., 2010, "Growth, Structural and Optical Properties of $Cd_xZn_{1-x}S$ Thin Films Deposited Using Spray Pyrolysis Technique," Curr. Appl. Phys., **10**, pp. 193–198.
[2] Baykul, M. C., and Orhan, N., 2010, "Band Alignment of $Cd_xZn_{1-x}S$ Produced by Spray Pyrolysis Method," Thin Solid Films, **518**, pp. 1925–1928.
[3] Abdinov, A. Sh., Mamedov, H. M., and Amirova, S. I., 2007, "Investigation of Electrodeposited Glass/$SnO_2$/$CuInSe_2$/$Cd_{1-x}Zn_xS_{1-y}Se_y$/ZnO Thin Solar Cells," Jpn. J. Appl. Phys., **46**, pp. 7359–7361.
[4] Abdinov, A. Sh., Mamedov, H. M., and Amirova, S. I., 2006, "Investigation of Electrodeposited p-Si/$Cd_{1-x}Zn_xS_{1-y}Se_y$ Heterojunction Solar Cells," Thin Solid Films, **511–512**, pp. 140–142.
[5] Abdinov, A. Sh., Mamedov, H. M., Garibov, G. I., and Ragimova, N. A., 2007, "Heat Treatment Effects in $In_2O_3$/$Cd_{0.4}Zn_{0.6}S_{0.9}Se_{0.1}$/CdTe Heterojunction Solar Cells," Optoelectron. Adv. Mater., **9**, pp. 480–483. AQ5
[6] Fujii, S., Tasaki, N., Shinomura, N., Kurai, S., Yamada, Y., and Taguchi, T., 2007, "Optical Properties of ZnCdS:I Orange and ZnSTe:I White Thin Film Phosphor for High Ra White LED," J. Light Vis. Environ., **31**, pp. 61–64.
[7] Chang, S. J., Hsiao, H. S., Wang, J. Y., Cheng, Y. C., Li, T. C., Chang, S. P., Huang, B. R., and Hung, S. C., 2009, "A Quaternary ZnCdSeTe Nanotip Photodetector," Nanoscale Res. Lett., **4**, pp. 1540–1546.
[8] Paliwal, U., Kothari, R. K., and Joshi, K. B., 2012, "Electronic and Structural Properties of $Zn_xCd_{1-x}S_ySe_{1-y}$ Alloys Lattice Matched to GaAs and InP: An EPM Study," Superlattices Microstruct., **51**, pp. 635–643.
[9] Mamedov, H., and Hasanov, H., 2005, "Photosensitivity of p-Si/n-Cd1-xZnxS Heterojunctions in Visible and Near IR Region of Spectrum," Proc. SPIE, **5834**, pp. 264–268.
[10] Mamedov, H., and Amirova, S., 2007, "Photosensitivity of $SnO_2$/$Cd_{0.8}Zn_{0.2}S_{0.1}Se_{0.9}$/p-CdTe/Cu Heterojunctions in Visible and Near IR Regions of Spectrum," Proc. SPIE, **6636**, pp. 121–124.
[11] Al-bassan, A. A., 1999, "Photoconductivity and Defect Levels in $Zn_xCd_{1-x}Se$ With ($x = 0.5$, 0.55) Crystals," Sol. Energy Mater. Sol. Cells, **57**, pp. 323–329.
[12] Laukaitis, G., Lindroos, S., Tamulevičius, S., Leskelä, M., and Račkaitis, M., 2000, "SILAR Deposition of $CdxZn_{1-x}S$ Thin Films," Appl. Surf. Sci., **161**, pp. 396–405.
[13] Yamaguchi, T., Yamamoto, Y.,,Tanaka, T., Demizu, Y., and Yoshida, A., 1996, "(Cd,Zn)S Thin Films Prepared by Chemical Bath Deposition for Photovoltaic Devices," Thin Solid Films, **281–282**, pp. 375–378.
[14] Chu, T. L., Chu, S. S., Britt, J., Ferekids, C., and Wu, C. Q., 1991, "Cadmium Zinc Sulfide Films and Heterojunctions," J. Appl. Phys., **70**, pp. 2688–2693.
[15] Chandra, S., Pandy, R. K., and Agrawal, R. C., 1980, "Solar Energy Conversion by Photoelectrochemical Cells Using Chemical-Bath-Deposited CdS Films," J. Phys. D. Appl. Phys., **13**, pp. 1757–1761.
[16] Chopra, K. L., and Das, S. R., 1983, *Thin Film Solar Cells*, Plenum Press, New York.
[17] Ezema, F. I., Ezugwu, S. C., Osuji, R. U., Asogwa, P. U., Ezekoye, B. A., Ekwealor, A. B. C., and Ogbu, M. P., 2010, "Role of Thermal Annealing on the Optical and Solid State Properties of Chemically Deposited Cadmium Sulphide Nanocrystalline Thin Film Grown in a Polymer Matrix," Non-Oxide Glasses, **2**(1), pp. 45–50.
[18] Yah, C. I., Zulkarnain, Z., Anuar, K., and Wan, M., 2011, "Electrochemical Preparation of Bilayer p-n Junction of n-CdS/p-P3HT," Int. J. Electrochem. Sci., **6**(7), pp. 2898–2904.
[19] Shen, C. M., Zhang, X. G., and Li, H. L., 2005, "Influence of Different Deposition Potentials on Morphology and Structure of CdSe Films," Appl. Surf. Sci., **240**, pp. 34–41.
[20] Saravanan, N., Teh, G., Louh, R., and Chee, K., 2011, "Cyclic Voltammetry Studies of Cadmium Zinc Sulfide Aqueous Solution," Int. J. Phys. Sci., **6**(31), pp. 7166–7170.