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The Development of Crystalline Sb_2S_3 Thin Films as A Component of The Three-Dimensional (3D) Solar Cells

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Abstract. The paper present the research made in order to develop crystalline Sb_2S_3 thin films by Spray Pyrolysis Deposition technique, SPD. The films were developed by varying the deposition parameters: the deposition temperature, the number of sequences and the type of solvents (water and mixed: water-ethanol). The obtained films were analyzed by XRD, AFM, UV–VIS Spectroscopy and current-voltages (I–V) measurements in dark and under illumination. The results prove the formation of crystalline Sb_2S_3 thin films with proper electrical properties to be used as buffer layer and/ or as absorber material in the 3D cells.

Key words: crystalline Sb_2S_3 thin film, Spray Pyrolysis, buffer layer, absorber material, 3D solar cells.

1. Introduction

As the researches shows, in the field of the three (3D) dimensional solar cells, improvements in the solar conversion efficiency can be possible by using buffer layer materials between the n-type transparent semiconductor and the p- type absorber semiconductor, [1, 2, 3] (for a better aligniament of the n and p type semiconductor energy bands) and/ or by finding new absorber materials capable to replace the notorial $CuInS_2$ p-type material. The best efficiency reported until now are 3D cells made from $CuInS_2$ absorber material in structures as: transparent conducting oxides

(ITO)/ dense TiO_2 (anatase)/ In_2S_3(buffer layer)/ $CuInS_2$/ Au, 7%, [4]; transparent conducting oxides/ dense TiO_2 (anatase)/ nanoporous TiO_2 (anatase)/ Al_2O_3 (tunnel layer)/ In_2S_3(buffer layer)/ $CuInS_2$/ Au or Pt, 4%, [5].

This paper is proposed to present crystalline Sb_2S_3 thin film material as a possible buffer layer, Fig. 1 and/or as absorber material for the 3D solar cells, Fig. 2.

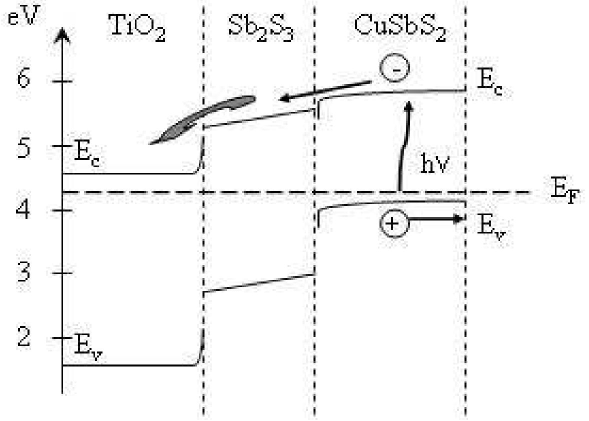


Fig. 1. Energy diagram of a 3D solar cells with Sb_2S_3 as buffer layer and $CuSbS_2$ as absorber layer.

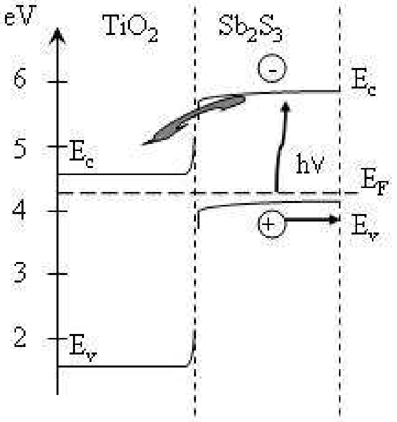


Fig. 2. Energy diagram of a 3D solar cells with Sb_2S_3 as absorber layer.

In the old history of double chalcopyrite materials research, amorphous and crystalline Sb_2S_3 thin films were obtained for different application in: television cameras, microwave devices, switching devices, and optoelectronic devices, using different deposition techniques: electrodeposition, [6], chemical bath deposition, [7, 8], successive ionic layer adsorption and reaction, SILAR, [9], sol-gel process, [10], Thermal evaporation, [11–14], radio frequency sputtering, [15], and spray pyrolysis deposition, [16–20].

The researches published in literature present the development of crystalline Sb_2S_3 thin films with orthorhombic structure, variable band gaps between 1.2 eV and 2.13 eV and n-type semiconductor, [15, 21–25]. In 2005 N. Ticau *et al.* present the Sb_2S_3 material to be a promising semiconductor material for solar cells due to the high absorption coefficient ($\alpha > 10^3$ cm^{-1}) and an optimum band gap (1.8 eV), [11]. The latest researches present Sb_2S_3 as near-intrinsic Sb_2S_3 thin films into a p-i-n solar cell structure: SnO_2:F-(n)CdS:In-(i)Sb_2S_3-(p)$CuSbS_2$-Ag, [26] and a possible absorber in the development of photovoltaic cells, [27–29]. These results represent a motivation to continue the development of Sb_2S_3 thin films, as important component in 3D cells, using a relative simple and low cost deposition method, suitable for large area thin films deposition and tailoring of structural, morphological and electrical properties as is Spray Pyrolysis Deposition technique, SPD, [30–32].

2. Experimental part

The development of crystalline Sb_2S_3thin films by SPD have represented and represent a challenge for science; the obtaining of amorphous structures being frequently presented in literature. If until 2002 the depositions of crystalline films were only obtained from non-aqueous solutions, S.R. Gadakh and C.H. Bhosale present for the first time the deposition of crystalline films from aqueous solution rich in complexing agent, [19].

The paper presents the development of crystalline Sb_2S_3 thin films from aqueous and mixed solvent solutions (water-ethanol) using as precursors antimony (III) acetate $(CH_3COO)_3Sb$, (99.99%, E. Merck, Darmstadt), and thiourea H_2NCSNH_2, (99%, Aldrich Chemical Company, Inc) in weight ratio of 1:2.22. Small amount of HCl are used to increase the solubility of $(CH_3COO)_3Sb$ and to prevent the precipitation of the Sb_2S_3 in aqueous solution by formation of $Sb(OH)_3$ as white precipitate.

The Sb_2S_3 thin films are deposition on FTO (fluorine doped tin oxide, 5×5 cm^2 SnO_2:F, TEC 8, Libbey Owens Ford) and FTO/TiO_2 substrates [30], on a heated plate (CERAN 500 ± 1°C), in open atmosphere at the deposition parameters (deposition temperature, T_{dep}(°C), number of sequences, no. sq., and mixed solvent: water-ethanol, H_2O-EtOH) presented in Table 1, having fixed the spray height at 25 cm and the pressure of the carrier gas (N_2) at 1.2 bar.

The Sb_2S_3 thin films deposited on FTO were analyzed using X-Ray Diffraction (XRD, Bruker D8 Advance Diffractometer), Atomic Force Microscopy (AFM, NT-MDT model BL222RNTE), in contact mod, with Si-tip (CSG10, force constant 0.15 N/m, tip radius10 nm) and UV - VIS Spectroscopy (UV - VIS spectrophotometer Perkin Elmer Lambda 25 UV/VIS).

The Sb_2S_3 thin films deposited on FTO/ TiO_2 structure were analyzed by current-voltage (I–V) measurement recorded in dark and under illumination using an DC Source Meter, Keithley, model 2400 and an calibrated solar simulator SolarConstant 1200 (K.H. Steuernagel Lichtechnik GmbH) as visible light source. Graphite paste (graphite conductive adhesive aqueous based, Alfa Aesar) is used for contacts.

Table 1. The deposition parameters varied in the development of Sb_2S_3 thin films

Test	T_{dep} (°C)	No. of sequences	Mixed solvent (H_2O-EtOH)
1	220	16	100% H_2O
2	240		
3	260		
4	260	8	100% H_2O
5		12	
6		16	
7	260	16	10% EtOH
8			20% EtOH

3. Results and discussions

The Sb_2S_3 films were deposited by SPD and varying the deposition parameters in conformity with Table 1. The structural investigations of the films by XRD patterns reveal formation of crystalline, orthorhombic Sb_2S_3 thin films in conformity with JCPDS: 74-1046, Fig. 3 and Fig. 4, and a = 11.2, b = 11.28, c = 3.83.

Figure 3 presents the XRD patterns of the Sb_2S_3 thin films deposited from aqueous solutions at different temperature and show the formation of more crystalline and single phase films with the increasing of the temperature, confirmed by the increased peaks presented for the sample deposited at temperature of 260°C. At temperature below 260°C crystalline Sb_2S_3 films are formed along with $Sb_{9.8}S_{15}$.

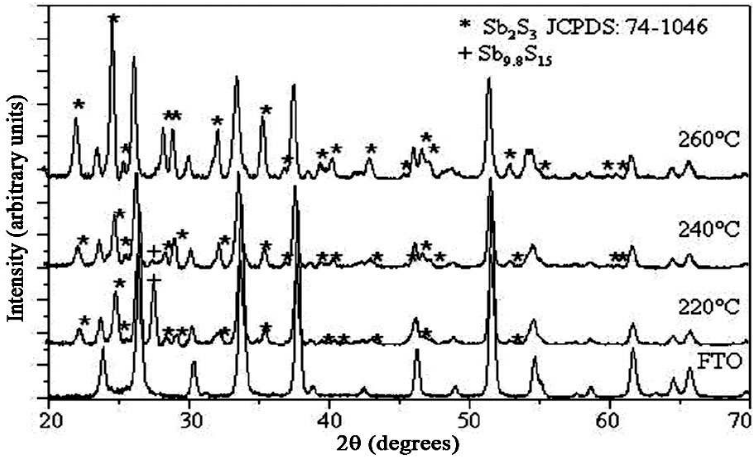


Fig. 3. XRD pattern of Sb_2S_3 thin films deposited on FTO at: 220°C; b) 240°C and c) 260°C.

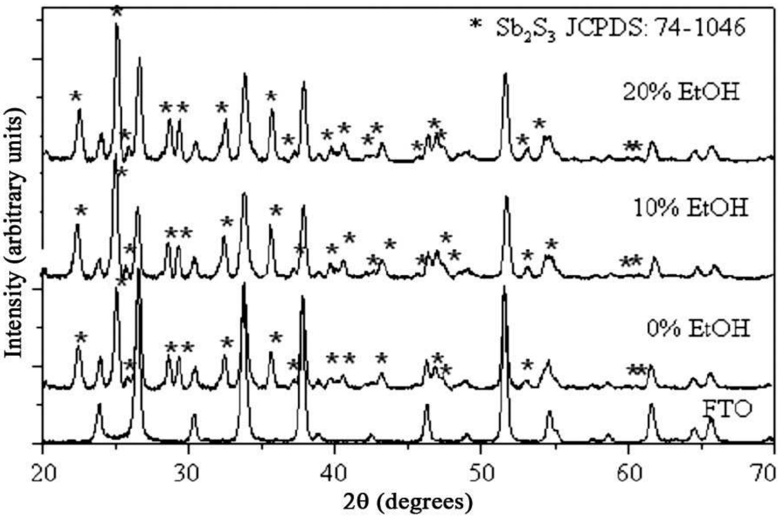
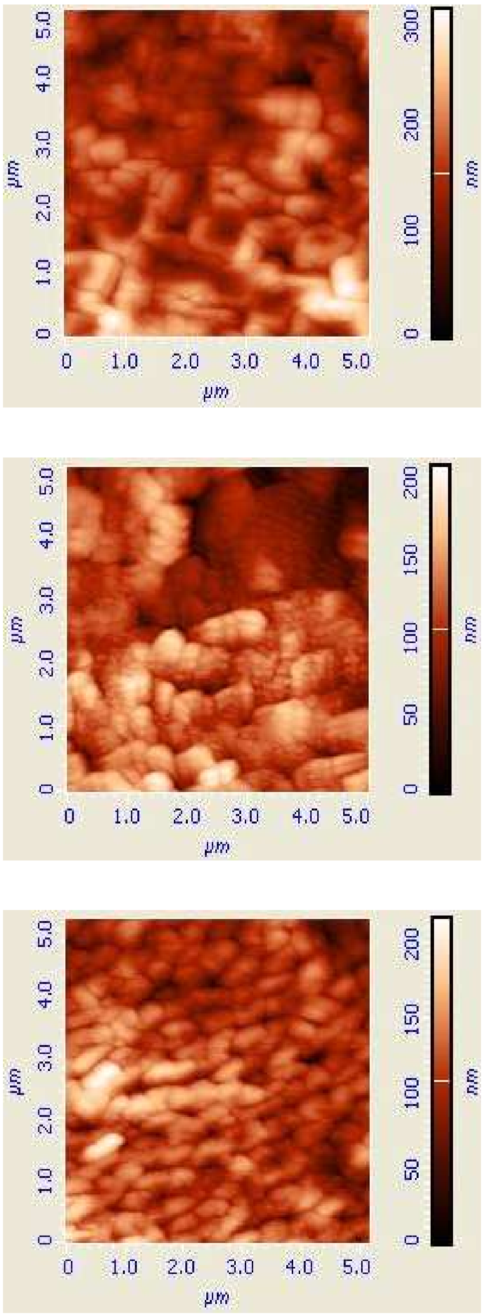


Fig. 4. XRD pattern of Sb_2S_3 thin films deposited at 260°C on FTO from solutions with: 0%; b) 10% and c) 20% EtOH.

Figure 4 presents the XRD patterns of the films deposited at 260°C but from sprayed solutions obtained with mixed solvents: water–ethanol. In the development of an efficient 3D cell an important part is the n and absorber semiconductors interface. A good interface lied to a good contact on large surfaces and avoids recombination. This can be obtained by tailoring the films morphology and a way to do this is represented by the variation of the alcohol proportion in the aqueous solvent, along to the deposition parameters as was presented in latest research of our group, [30, 31, 33, 34]. Generally, the alcohol in the solvent determines a faster solvent evaporation, a higher reaction rate and formation of denser and homogeneous films as can be seen from the AFM images, Fig. 5 for the Sb_2S_3 films. In the case of Sb_2S_3 thin films the use of mixed water-ethanol solvents in different proportions lied to formation of Sb_2S_3 thin films with increased crystallinity, as well as the crystallites size increase and the thickness of the films with the increased of the ethanol proportion in the sprayed solution.

The crystallites size was calculated using Scherrer formula: $D = \frac{k\lambda}{\beta \cos \theta} = \frac{0.9\lambda}{\beta \cos \theta}$ (1), where: λ – the wavelength ($\lambda = 1.54060$ Å), k – shape coefficient (usually is 0.9), β - the full-width at half-maximum of the peak in radian, and θ - the Bragg angle; and the thickness of the films from the UV-VIS Spectroscopy analysis.

The calculation of Sb_2S_3 thin films thicknesses was made from absorption date using the following relation: $a = p\frac{\lambda_1 \cdot \lambda_2}{\lambda_1 - \lambda_2} \cdot \frac{1}{2n_d}$ (2), where λ_1 and λ_2 represent the wavelengths where the absorption has a maximum or a minimum, n_d is the reflective index (for Sb_2S_3 the reflective index is 3), "p" is the number of the waves (between two adjacent maxima, p = 1), and "a" is the thickness of the film. The values of crystallites size and film thickness are presented in Table 2 and Table 4.



a)

b)

c)

Fig. 5. AFM image of Sb_2S_3 films deposited at 260°C from solutions with: 0% EtOH; b) 10% EtOH and c) 20% EtOH.

Table 2. Crystallite size of the crystalline Sb_2S_3 thin films deposited at the varied parameters

T(°C)/ mixed solvent (H_2O: EtOH)	(hkl)	D (nm)
220/ 100% H_2O	(130)	43.43
240/ 100% H_2O	(130)	58.36
260/ 100% H_2O	(130)	49.21
260/ **10%** EtOH	(130)	43.32
260/ **20%** EtOH	(130)	42.18

In order to identify the electrical properties of the obtained Sb_2S_3 films and the photovoltaic response of the developed cells at the varied parameters the current-voltage measurements in dark and under illumination were performed.

The I–V curves recorded in dark show formation of semiconductor Sb_2S_3films without pinholes and with the best conductivity for the films deposited at 260°C, 16 numbers of sprayings, and aqueous solutions, as can be seen in Fig. 6, Fig. 7 and Fig. 8. This film will be used for next researches in the development of a 3D solar cell with Sb_2S_3 films as buffer layer and $CuSbS_2$ as absorber layer.

The I–V curves recorded in dark and under illumination for the obtained cells: FTO/ TiO_2 (n-type semiconductor)/Sb_2S_3 (absorber layer, deposited at the varied parameters)/ graphite, show the diode behaviours for the all cells, without shunts and with the best cell characteristics for the cell developed with Sb_2S_3 films at 260°C, 16 numbers of sprayings, with 20% ethanol in the sprayed solution, Fig. 9: V_{oc} = 264.22 mV, $I_{sc} = 2.63 \cdot 10^{-6}$ A, V_{max} = 163.31 mV, $I_{max} = 1.63 \cdot 10^{-6}$ A and FF = 0.383. The cell parameters for the all cells are presented in Table 3.

In order to find responses in the values of the photovoltaic characteristics, obtained for the developed cells, the band gaps values of the Sb_2S_3 thin films were investigated.

Table 3. Cells characteristics V_{oc}, I_{sc}, V_{max}, I_{max} and FF

T (°C)/ No. of sprays/ mixed solvent	V_{oc} (mV)	I_{sc} (A)	V_{max} (mV)	I_{max} (A)	FF
220/ 16/ 100% water	347.7	$1.49{\cdot}10^{-7}$	203	$8.73{\cdot}10^{-8}$	0.342
240/ 16/ 100% water	216.34	$4.65{\cdot}10^{-7}$	128	$2.84{\cdot}10^{-7}$	0.361
260/ 16/ 100% water	224	$1.69{\cdot}10^{-6}$	133	$1.02{\cdot}10^{-6}$	0.358
260/ **8**/ 100% water	174.61	$1.45{\cdot}10^{-7}$	90	$7.83{\cdot}10^{-7}$	0.278
260/ **12**/ 100% water	216.46	$4.77{\cdot}10^{-7}$	130	$2.81{\cdot}10^{-7}$	0.353
260/ **16**/ 100% water	224	$1.69{\cdot}10^{-6}$	133	$1.02{\cdot}10^{-6}$	0.358
260/ 16/ **10% Ethanol**	268.85	$1.99{\cdot}10^{-6}$	165.47	$1.18{\cdot}10^{-6}$	0.365
260/ 16/ **20% Ethanol**	26 4.22	$2.63{\cdot}10^{-6}$	163.31	$1.63{\cdot}10^{-6}$	0.383

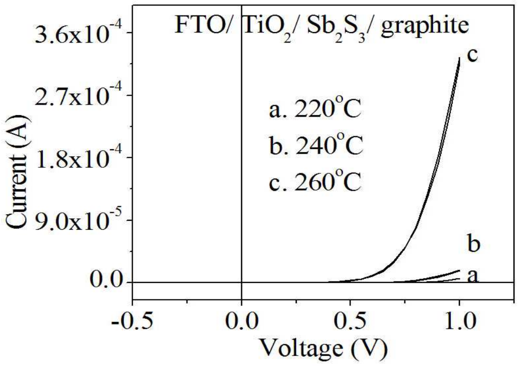


Fig. 6. I–V curves measured in dark of FTO/ TiO_2/ Sb_2S_3/ Graphite structures for Sb_2S_3 films deposited at different temperatures: a) 220°C, b) 240°C and c) 260°C.

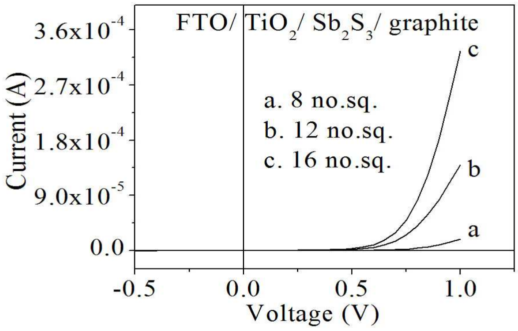


Fig. 7. I–V curves measured in dark of FTO/ TiO_2/ Sb_2S_3/ Graphite structures for Sb_2S_3 films deposited with different number of spraying: a) 8, b) 12 and c) 16 no. sq.

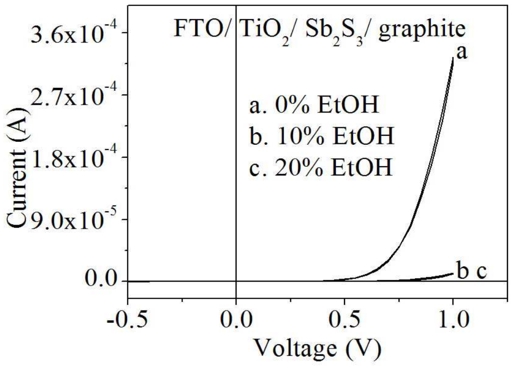


Fig. 8. I–V curves measured in dark of FTO/ TiO_2/ Sb_2S_3/ Graphite structures for Sb_2S_3 films deposited at 260°C from solutions with: a) 0% EtOH; b) 10% EtOH and c) 20% EtOH.

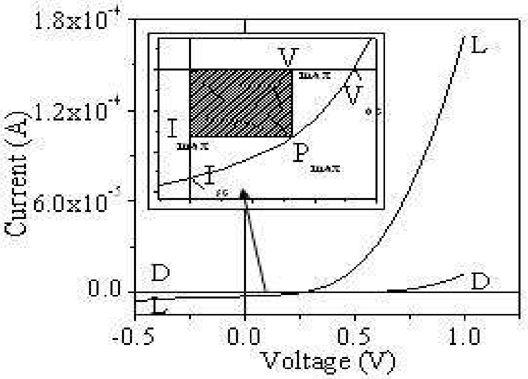


Fig. 9. I–V curves measured in dark and under illumination of FTO/ TiO_2/ Sb_2S_3(240°C, 16 no.sq., 20% EtOH in the solution)/ graphite.

The band gaps values were determinate from the absorption data, Fig. 10 and the values obtained for the films deposited at 260°C, 16 numbers of spraying from aqueous solution and mixed solvent are presented in Table 4.

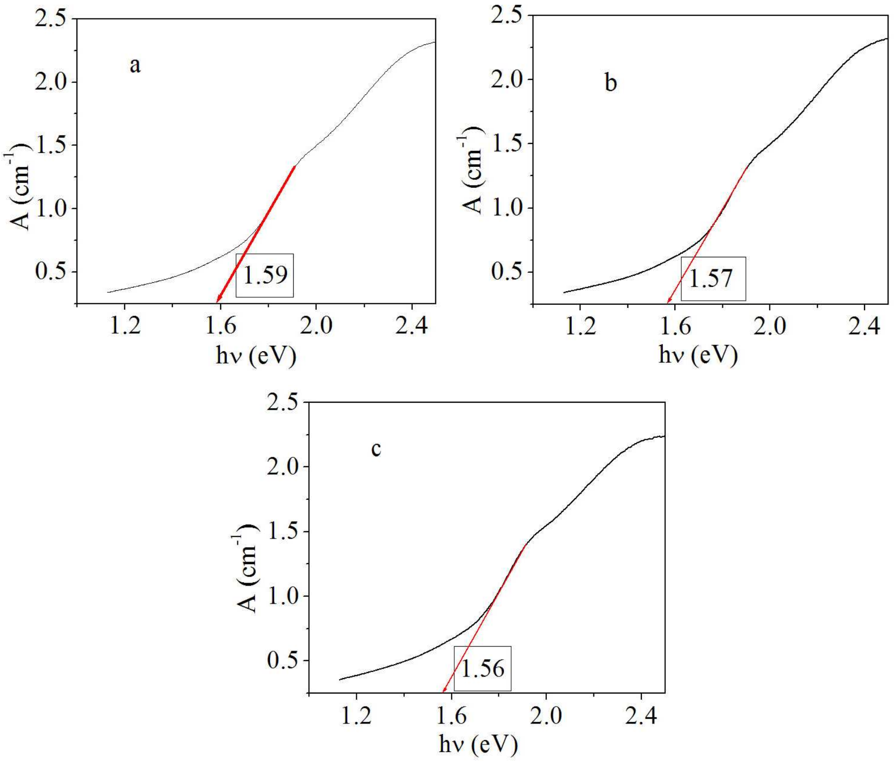


Fig. 10. Band gap energy of Sb_2S_3 thin films deposited at 260°C from solutions with: a) 0% EtOH; b) 10% EtOH and c) 20% EtOH.

Table 4. The crystallite size, the thickness and the band gaps of the crystalline Sb_2S_3 thin films deposited at different ethanol proportion

EtOH (%)	**(hkl)**	**D (nm)**	**G (nm)**	**E_g (eV)**
0	(130)	49.21	397.56	1.59
10	(130)	43.32	417.77	1.57
20	(130)	42.18	427.45	1.56

The best photovoltaic response obtained for the sample deposited from the sprayed solution with 20% EtOH is the result of a denser film (better TiO_2/ Sb_2S_3 interface) and of a lower value of the band gap 1.56 eV (value close to the photovoltaic requirement for the absorber materials) that provide o low recombination process and a better injection of the electrons from the conduction band of the Sb_2S_3 semiconductor in the conduction band of the TiO_2 (anatase).

In Fig. 11 is presented a possible energetically diagram for the 3D cell TiO_2/ Sb_2S_3.

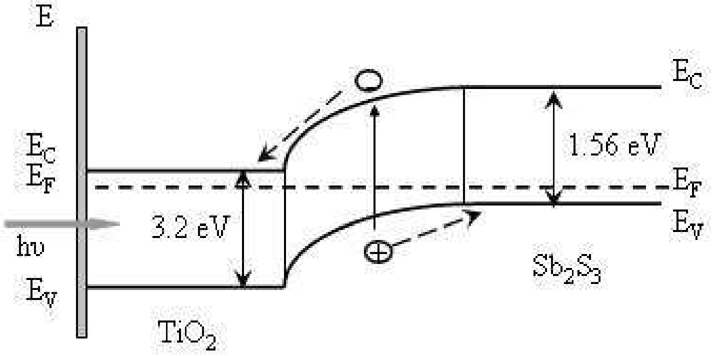


Fig. 11. A possible band diagram alignament for the FTO/ TiO_2/ Sb_2S_3/ Grafit cell.

4. Conclusions

The deposition of crystalline Sb_2S_3 thin films by an easy and cheap technique represents a challenge for the chemistry and material science researchers. This paper have succeed in presenting a new easy and cheap technique SPD and its capability in development of crystalline Sb_2S_3 thin films from aqueous solution and mixed solvent: water-ethanol solutions using as precursors antimony (III) acetate $(CH_3COO)_3Sb$, 99.99%, and thiourea H_2NCSNH_2, 99% in weight ratio of 1: 2.22. The structural, morphological and electrical properties of the crystalline Sb_2S_3 thin films deposited at the varied parameters proves that this material can be used as possible buffer layer or absorber in the development of a 3D solar cell.

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References

[1] LENZMANN F., NANU M., KIJATKINA O., BELAIDI A., *Substantial improvement of the photovoltaic characteristics of* $TiO_2/CuInS_2$ *interfaces by the use of recombination barrier coatings*, Thin Solid Films, **451–452**, pp. 639–643, 2004.

[2] GRASSO C., BURGELMAN M., *Theoretical study on the effect of an intermediate layer in CIS-based ETA-solar cells*, Thin Solid Films, **451–452**, pp. 156–159, 2004.

[3] IGALSONA M., PLATZER-BJORKMAN C., *The influence of buffer layer on the transient behavior of thin film chalcopyrite devices*, Solar Energy Materials & Solar Cells, **84**, pp. 93–103, 2004.

[4] VAN DER ZANDEN B., JOANTA C., DONKER H., NANU M., MEESTER B., $CuInS_2$ *Solar Cells Produced Using an In Line Process*, 21st European Photovoltaic Solar Energy Conference and Exhibition, pp. 267–269, 2006.

[5] NANU M., SCHOONMAN J., GOOSSENS A., *Inorganic Nanocomposite of n- and p-Type Semiconductors: A new Type of Three-Dimensional Solar Cell*, Advanced Materials, Vol. **16**, No. 5, pp. 453–456, 2004.

[6] YESUGADE N. S., LOKHANDE C. D., BHOSALE C. H., *Structural and optical properties of electrodeposited* Bi_2S_3, Sb_2S_3 *and* As_2S_3 *thin films*, Thin Solid Films, Vol. 263, Issue 2, pp. 145–149, 1995.

[7] SALEM A. M., SOLIMAN SELIM M., *Structure and optical properties of chemically deposited* Sb_2S_3 *thin films*, Journal of Physics D: Applied Physics, **34**, pp. 12–17, 2001.

[8] LOKHANDE C. D.,. SANKAPAL B. R, MANE R. S., PATHAN H. M., MULLER M., GIERSIG M., GANESAN V., *XRD, SEM, AFM, HRTEM, EDAX and RBS studies of chemically deposited* Sb_2S_3 *and* Sb_2Se_3 *thin films*, Applied Surface Science, **193**, pp. 1–10, 2002.

[9] SANKAPAL B. R., MANE R. S., LOKHANDE C. D., *Preparation and characterization of* Sb_2S_3 *thin films using a successive ionic layer adsorption and reaction (SILAR) method*, Journal of Materials Science Letters, **18**, pp. 1453–1455, 1999.

[10] CHEN H., ZHU C., GAN F., *Preparation and Optical properties of* Sb_2S_3 *Microcrystallite Doped Silica Glasses by the Sol-Gel Process*, Journal of Sol-Gel Science and Technology, **12**, pp. 181–184, 1998.

[11] ŢIGĂU N., GHEORGHIEŞ C., RUSU G. I., CONDURACHE-BOTA S., *The influence of the post-deposition treatment on some physical properties of* Sb_2S_3 *thin films*, Journal of Non-Crystalline Solids, **351**, pp. 987–992, 2005.

[12] ŢIGĂU N., *Substrate temperature effect on the optical properties of amorphous* Sb_2S_3 *thin films*, Cryst. Res. Technol., Vol. **41**, No. 5, pp. 474–480, 2006.

[13] EL-SHAZLY A. A., SEYAM M. A. M., EL-SAMANOUDY M. M., AMMAR A. H., ASSIM E. M., *The effect of deposition rate and heat treatment on conduction and charge carrier transport mechanisms in* Sb_2S_3 *films*, Applied Surface Science, Vol. **189**, Issues 1–2, pp. 129–137, 2002.

[14] FRUMAROVA B., BILKOVA M., FRUMAR M., REPKA M., JEDELSKY J., *Thin films of* Sb_2S_3 *doped by* Sm^{3+} *ions*, Journal of Non-Crystalline Solids, **326–327**, pp. 348–352, 2003.

[15] VERSAVEL M. Y., HABER J. A., *Structural and optical properties of amorphous and crystalline antimony sulfide thin-films*, Thin Solid Films, Vol. **515**, Issue 18, pp. 7171–7176, 2007.

[16] BHOSALE C. H., UPLANE M. D., PATIL P. S., LOCKHANDE C. D., *Preparation and properties of sprayed antimony trisulphide films*, Thin Solid Films, **248**, pp. 131–139, 1994.

[17] KILLEDAR V. V., LOKHANDE C. D., BHOSALE C. H., *Preparation and characterization of spray deposition* Sb_2S_3 *thin films from non-aqueous medium*, Materials Chemistry and Physics, **47**, pp. 104–107, 1997.

[18] RAJPURE K. Y., BHOSALE C. H., *Effect of composition on the structural, optical and electrical properties of sprayed* Sb_2S_3 *thin films prepared from non-aqueous medium*, Journal of Physics and Chemistry of Solids, **61**, pp. 561–568, 2000.

[19] GADAKH R., BHOSALE C. H., *Effect of concentration of complexing agent (tartaric acid) on the properties of spray deposited* Sb_2S_3 *thin films*, Materials Chemistry and Physics, **78**, pp. 367–371, 2002.

[20] RAJPURE K. Y., BHOSALE C. H., *Preparation and characterization of spray deposited photoactive* Sb_2S_3 *and* Sb_2Se_3 *thin films using aqueous and non-aqueous media*, Materials Chemistry and Physics, **73**, pp. 6–12, 2002.

[21] MANE R. S., SANKAPAL B. R., LOKHANDE C. D., *Non-aqueous chemical bath deposition of* Sb_2S_3 *thin films*, Thin Solid Films, Vol. **353**, Issues 1–2, pp. 29–32, 1999.

[22] MANE R. S., LOKHANDE C. D., *Thickness-dependent properties of chemically deposited* Sb_2S_3 *thin films*, Materials Chemistry and Physics, Vol. **82**, Issue 2, pp. 47–354, 2003.

[23] MANE R. S., LOKHANDE C. D., *Photoelectrochemical cells based on nanocrystalline* Sb_2S_3 *thin films*, Materials Chemistry and Physics, Vol. **78**, Issue 2, pp. 385–392, 2003.

[24] RAJPURE K. Y., BHOSALE C. H., *(Photo)electrochemical investigations on spray deposited n-*Sb_2S_3 *thin film/polyiodide/C photoelectrochemical solar cells*, Materials Chemistry and Physics, Vol. **63**, Issue 3, pp. 263–269, 2000.

[25] EL-SHAZLY A. A., SEYAM M. A. M., EL-SAMANOUDY M. M., AMMAR A. H.,ASSIM E. M. , *The effect of deposition rate and heat treatment on conduction and charge carrier transport mechanisms in* Sb_2S_3 *films*, Applied Surface Science, Vol. 189, Issues 1–2, pp. 129–137, 2002.

[26] RODRÍGUEZ-LAZCANO Y., NAIR M. T. S., NAIR P. K., *Photovoltaic p-i-n structure of* Sb_2S_3 *and* $CuSbS_2$ *absorber films obtained via chemical bath deposition*, Journal of the Electrochemical Society, **152**, pp. G635–G638, 2005.

[27] MESSINA S., NAIRA M. T. S., NAIRA P. K., *Antimony sulfide thin films in chemically deposited thin film photovoltaic cells*, Thin Solid Films, Vol. **515**, Issue 15, pp. 5777–5782, 2007.

[28] VERSAVEL M. Y., HABER J. A., *Lead antimony sulfides as potential solar absorbers for thin film solar cells*, Thin Solid Films, Vol. **515**, Issue 15, pp. 5767–5770, 2007.

[29] BINDU K., NAIR M. T. S., DAS ROY T. K., NAIR P. K., *Chemically Deposited Photovoltaic Structure Using Antimony Sulfide and Silver Antimony Selenide Absorber Films*, Electrochemical Solid-State Letters, Vol. **9**, Issue 6, pp. G195–G199, 2006.

[30] DUŢĂ A., MANOLACHE S. A., NANU M., GOOSSENS A., SCHOONMAN J., TiO_2 *Thin Layers with Controlled Morphology for ETA (Extremely Thin Absorber) Solar Cells*, Thin Solid Films, pp. 195–198, 2006.

[31] MANOLACHE S. A., DUŢĂ A., ISAC L., NANU M., GOOSSENS A., SCHOONMAN J., *The influence of the precursor concentration on* $CuSbS_2$ *thin films deposited from aqueous solutions*, Thin Solid Films, **515**, pp. 5957–5960, 2007.

[32] PATIL P. S., *Versatility of chemical spray pyrolysis technique*, Materials Chemistry and Physics, **59**, pp. 185–198, 1999.

[33] MANOLACHE S. A., ANDRONIC L., DUŢĂ A., *The influence of deposition parameters on* $CuSbS_2$ *thin film band gap values and morphology, used as absorber for three-dimensional (3D) solar cells*, presented at *EMRS 2007 Conference.*

[34] MANOLACHE S. A., ISAC L. A., DUŢĂ A., KRIZA A., NANU M., *Metal Based Sulfides, p-Type Semiconductors in Solid State Solar Cells*, C*AS International Semiconductor Conference*, Sinaia, Romania, 2006, pp. 141–144.