Photovoltaic Potentials of Some Chemical Bath Deposited PdS and Bi_2S_3 Thin Films

Fabian Ifeanyicukwu Ezema, Ph.D.

Department of Physics and Astronomy, University of Nigeria, Nsukka, Enugu State, Nigeria.

ABSTRACT

Spectral, optical and electronic characterization of some PdS and Bi_2S_3 thin films show that these films have potential applications in photovoltaic power generation. Thin film of PdS shows band gap of 2.50 eV and Bi_2S_3 thin film show band gaps ranging between 1.50 and 1.70 eV. These band gaps coupled with high electrical conduction and high solar absorption combine to make both materials suitable for solar cell applications.

(Key words: solar cells, band gaps, solar adsorption, optical properties)

INTRODUCTION

Photovoltaic generation systems have been described to consist of photovoltaic cells mounted in modules that form part of array and electrical contacts, which connect the modules, as well as interconnect the cell, in a grid like form [1-2]. These systems convert solar energy directly into electrical energy and hence supply the same to the load. The most popular material in the area of solar cell fabrication is single crystal, polycrystalline, or even amorphous silicon, germanium, or gallium arsenide [3].

In the research characterized in this paper, attempts were made to fabricate and characterize PdS and Bi_2S_3 thin films and examine materials other than those solar cell materials conventionally examined.

EXPERIMENTAL METHOD

The films were fabricated by growing them on a glass substrate from solutions of salt using thiourea and sodium thiosulphate as sources of anions. The glass slides, which were used as substrates for the deposition of the thin films, were degreased in nitric acid for 48 hours. This created functional groups on the surfaces of the slides called nucleation centers for the deposition of the films. The slides were then removed from the acid and washed with detergent, rinsed with distilled water, and drip dried in air, after which the substrates were immersed vertically into and at the center of the reaction baths that contained the necessary solutions. In the deposition of PdS thin films, sodium thiosulphate acted as complexing agent while EDTA was used as complexing agent for the deposition of Bi_2S_3 thin films. The preparatory conditions employed in this work were those described and used by several authors for the deposition of chalcogenides [3-6].

After the films had been deposited they were characterized using the PYE UNICAM SP8-100 UV spectrophotometers to obtain the spectral absorbance/transmittance/reflectance. Spectral parameters such as absorption threshold or wavelength of onset of absorption (λ_A), the fundamental absorption or minimum absorption wavelength (λ_o), band gap wavelength (λ_g), wavelength of minimum absorption (λ_a), wavelength of maximum transmission (λ_t), and wavelength of maximum reflection (λ_r) were observed.

Optical parameters such as absorption (A), transmittance (T), reflectance (R), transmission coefficient (τ), absorption coefficient (α), refractive index (n), extinction coefficient (k), and the electronic/electrical parameters such as the real (ε_r) and imaginary (ε_i) dielectric constants, the optical (σ_o) and electrical conductivities (σ_e), and band gap (Eg) were obtained by method of analysis given in literatures [3, 7-11].

RESULTS AND DISCUSSION

Figure 1 show the spectral absorbance of the films while Figure 2 shows the spectral transmittance. They exhibit spectral characteristics with very high absorption in the

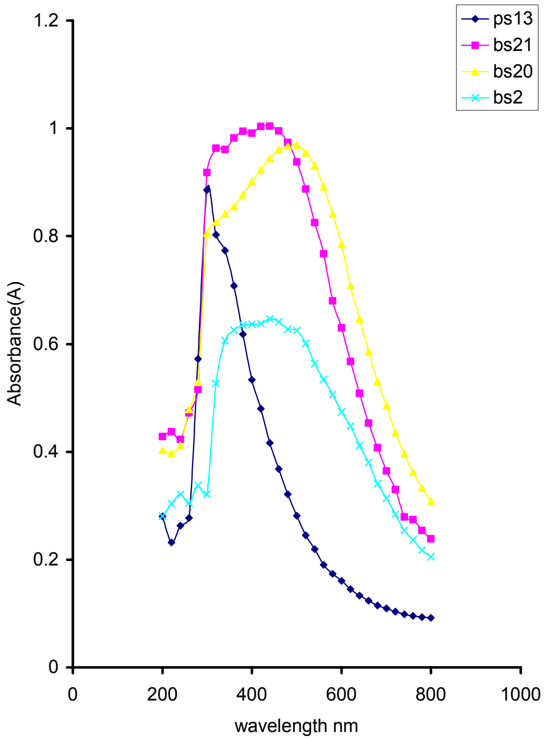

Fig. 1: Spectral Absorbance of PdS and Bi_2S_3 Thin Films prepared at 300k

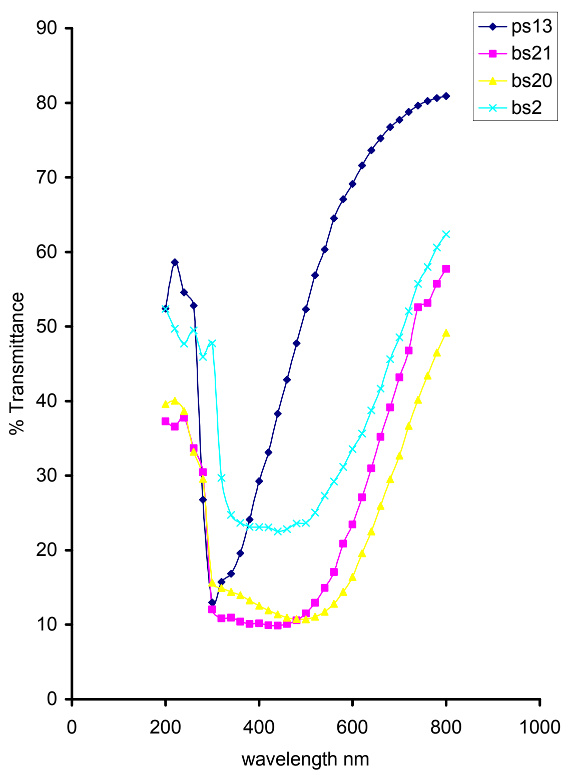

Fig. 2: Spectral Transmittance of PdS and Bi_2S_3 thin Films prepared at 300K.

UV regions, and moderately high absorption in the VIS – NIR regions.

Since absorption occurs throughout the spectral regions, especially in the NIR region, it is likely that these films might allow excitation of electrons by radiation with photon energies that are greater than those of the band gaps of the materials. Also the radiation attenuation parameters (A, R, α and k) of the films are relatively high and decrease with increasing wavelength in the VIS – NIR regions. On the other hand the radiation transmission parameters (T and τ) are relatively low and decrease only very slightly with wavelength in this regions.

Tables 1 and 2 show the radiation parameters for our study samples of PdS and Bi_2S_3 thin films. From Table 3, the onsets of absorption (λ_A) for all the films occur at the UV regions. The fundamental absorption (λ_o) occurs at the UV region for PdS while it is in the VIS region for Bi_2S_3. For all of the films, the band gap wavelength (λ_g) occurs in between λ_o and λ_a. The band gap of the films are located in the VIS regions, hence the energy of the incoming solar radiation would just be enough to create electron – hole pairs.

For these materials, the photons located to the right of the VIS region, that is in the IR region, might not be useful in generating electron – hole pairs. This is because their photon energies would be lower than that of the band gap of the films. However, the cut off of non-useful photon would be rather small and insufficient to cause any significant reduction in the electron – hole production in the films. This makes the films very useful as solar cell materials.

Radiation attenuation parameters such as n, k, and α are moderate just like the radiation transmission parameters T and τ in the spectral range and decrease with increasing wavelength immediately after the fundamental absorption wavelength. The selectivity figure of merit ($\alpha\tau$) and the optical path length (αt) for these films are also moderate and decrease with increasing wavelength after the fundamental absorption wavelength. Materials such as PdS and Bi_2S_3, which have moderately high absorption of solar radiation, would certainly allow absorption of enough radiation whose photon energies are

Table 1: Variation Of Optical And Solid State Properties With Wavelength Of Radiation And Photon Energies For PdS Thin Film.

Radiation wavelength & photon energy		Radiation transmission parameters		Radiation extinction optical parameters							Solid state properties				
λ(nm)	$H\nu$ (eV)	T(%)	τ x10^8	A	R x10^8	α x10^6 (m^{-1})	n	k x10^{-2}	αt x10^{-1}	$\alpha\tau$ x10^{14} (m^{-1})	ε_r	ε_I x10^{-1}	σ_o x10^{14} (S^{-1})	σ_ex10^2 ($\Omega^{-1}m^{-1}$)	σ_t x10^{-1} ($Wm^{-1}k^{-1}$)
200	6.21	52.4	5.24	0.28	1.95	0.65	2.58	1.03	2.29	3.38	6.66	0.53	0.40	3.52	2.59
220	5.64	58.6	5.86	0.23	1.82	0.53	2.49	0.93	1.90	3.13	6.19	0.46	0.32	2.81	2.06
240	5.17	54.6	5.46	0.26	1.91	0.61	2.55	1.16	2.14	3.31	6.52	0.59	0.37	3.23	2.40
260	4.77	52.8	5.28	0.28	1.95	0.64	2.58	1.32	2.26	3.37	6.65	0.68	0.39	3.48	2.56
280	4.43	26.8	2.68	0.57	1.60	1.32	2.33	2.94	4.67	3.53	5.44	1.37	0.73	6.49	4.77
300	4.14	13.0	1.30	0.89	0.16	2.04	1.29	4.87	7.22	2.65	1.66	1.26	0.63	5.56	4.09
320	3.88	15.8	1.58	0.80	0.40	1.85	1.50	4.70	6.54	2.92	2.25	1.41	0.66	5.85	4.30
340	3.65	16.8	1.68	0.77	0.58	1.78	1.63	4.82	6.30	2.99	2.67	1.57	0.69	6.15	4.52
360	3.45	19.6	1.96	0.71	0.96	1.63	1.90	4.67	5.77	3.20	3.60	1.77	0.74	6.54	4.81
380	3.27	24.1	2.41	0.62	1.41	1.42	2.20	4.30	5.04	3.43	4.85	1.89	0.75	6.62	4.87
400	3.10	29.3	2.93	0.53	1.74	1.23	2.43	3.91	4.35	3.60	5.90	1.90	0.71	6.30	4.63
420	2.95	33.1	3.31	0.48	1.89	1.11	2.54	3.69	3.91	3.66	6.44	1.87	0.67	5.92	4.35
440	2.82	38.3	3.83	0.42	2.00	0.96	2.62	3.36	3.39	3.67	6.86	1.76	0.60	5.31	3.90
460	2.70	42.9	4.29	0.37	2.03	0.85	2.64	3.10	3.00	3.64	6.99	1.64	0.53	4.73	3.48
480	2.59	47.8	4.78	0.32	2.01	0.74	2.63	2.82	2.62	3.53	6.91	1.48	0.46	4.10	3.02
500	2.48	52.3	5.23	0.28	1.96	0.65	2.59	2.58	2.29	3.39	6.68	1.33	0.40	3.54	2.60
520	2.39	56.9	5.69	0.25	1.86	0.56	2.52	2.33	2.00	3.21	6.34	1.17	0.34	3.00	2.21
540	2.30	60.3	6.03	0.22	1.77	0.51	2.45	2.17	1.79	3.05	6.02	1.07	0.30	2.62	1.93
560	2.22	64.5	6.45	0.19	1.65	0.44	2.37	1.95	1.55	2.83	5.59	0.92	0.25	2.19	1.61
580	2.14	67.1	6.71	0.17	1.56	0.40	2.30	1.84	1.41	2.68	5.31	0.85	0.22	1.94	1.43
600	2.07	69.1	6.91	0.16	1.48	0.37	2.25	1.76	1.31	2.55	5.08	0.79	0.20	1.76	1.29
620	2.00	71.6	7.16	0.15	1.39	0.33	2.19	1.65	1.18	2.39	4.79	0.72	0.17	1.54	1.13
640	1.94	73.6	7.36	0.13	1.31	0.31	2.13	1.56	1.08	2.25	4.55	0.67	0.16	1.38	1.01
660	1.88	75.2	7.52	0.12	1.24	0.28	2.09	1.49	1.01	2.14	4.36	0.62	0.14	1.25	0.92
680	1.83	76.7	7.67	0.12	1.18	0.26	2.04	1.43	0.94	2.03	4.18	0.59	0.13	1.14	0.84
700	1.77	77.7	7.77	0.11	1.13	0.25	2.02	1.40	0.89	1.96	4.06	0.57	0.12	1.07	0.79
720	1.72	78.8	7.88	0.10	1.09	0.24	1.98	1.36	0.84	1.88	3.93	0.54	0.11	1.00	0.73
740	1.68	79.6	7.96	0.10	1.05	0.23	1.96	1.34	0.81	1.81	3.83	0.53	0.11	0.94	0.69
760	1.63	80.3	8.03	0.10	1.02	0.22	1.94	1.33	0.78	1.77	3.75	0.52	0.10	0.90	0.66
780	1.59	80.6	8.06	0.09	1.00	0.22	1.93	1.34	0.76	1.74	3.71	0.51	0.10	0.88	0.64
800	1.55	80.9	8.09	0.09	0.99	0.21	1.92	1.35	0.75	1.71	3.68	0.52	0.10	0.86	0.63

Table 2: Variation Of Optical And Solid State Properties With Wavelength Of Radiation And Photon Energies For Bi_2S_3 Thin Film.

Radiation wavelength & photon energy		Radiation transmission parameters		Radiation extinction optical parameters							Solid state properties				
λ(nm)	$h\nu$ (eV)	T(%)	τ x10^8	A	R x10^8	α x10^6 (m^{-1})	n	k x10^{-2}	αt x10^{-1}	$\alpha\tau$ x10^{14} (m^{-1})	ε_r	ε_I x10^{-1}	σ_o x10^{14} (S^{-1})	σ_ex10^2 ($\Omega^{-1}m^{-1}$)	σ_t x10^{-1} ($Wm^{-1}k^{-1}$)
200	6.21	52.4	5.24	0.28	1.95	0.65	2.58	1.03	3.61	3.39	6.68	0.53	0.40	3.53	2.60
220	5.64	49.7	4.97	0.30	1.99	0.70	2.61	1.22	3.90	3.47	6.83	0.64	0.44	3.86	2.84
240	5.17	47.7	4.77	0.32	2.02	0.74	2.63	1.41	4.13	3.53	6.91	0.74	0.46	4.11	3.02
260	4.77	49.5	4.95	0.31	2.00	0.70	2.62	1.45	3.93	3.48	6.84	0.76	0.44	3.89	2.86
280	4.43	45.9	4.59	0.34	2.03	0.78	2.64	1.73	4.34	3.57	6.96	0.91	0.49	4.34	3.19
300	4.14	47.8	4.78	0.32	2.01	0.74	2.63	1.76	4.12	3.53	6.91	0.93	0.46	4.10	3.02
320	3.88	29.7	2.97	0.53	1.76	1.21	2.44	3.09	6.77	3.61	5.97	1.51	0.71	6.26	4.61
340	3.65	24.7	2.47	0.61	1.46	1.40	2.24	3.78	7.79	3.46	5.00	1.69	0.75	6.60	4.85
360	3.45	23.7	2.37	0.63	1.37	1.44	2.18	4.13	8.04	3.41	4.74	1.80	0.75	6.63	4.88
380	3.27	23.1	2.31	0.64	1.33	1.46	2.15	4.42	8.17	3.39	4.61	1.90	0.75	6.64	4.88
400	3.10	23.1	2.31	0.64	1.33	1.47	2.15	4.66	8.18	3.38	4.60	2.00	0.75	6.64	4.88
420	2.95	23.0	2.30	0.64	1.32	1.47	2.14	4.90	8.19	3.38	4.59	2.10	0.75	6.64	4.88
440	2.82	22.5	2.25	0.65	1.28	1.49	2.11	5.21	8.31	3.36	4.45	2.20	0.75	6.64	4.88
460	2.70	22.8	2.28	0.64	1.30	1.48	2.13	5.40	8.24	3.37	4.53	2.30	0.75	6.64	4.88
480	2.59	23.6	2.36	0.63	1.37	1.44	2.17	5.52	8.06	3.41	4.72	2.40	0.75	6.63	4.88
500	2.48	23.7	2.37	0.63	1.38	1.44	2.18	5.73	8.04	3.41	4.75	2.50	0.75	6.63	4.87
520	2.39	25.0	2.50	0.60	1.48	1.39	2.25	5.73	7.73	3.47	5.07	2.58	0.74	6.59	4.84
540	2.30	27.3	2.73	0.56	1.63	1.30	2.36	5.57	7.24	3.54	5.55	2.63	0.73	6.46	4.75
560	2.22	29.2	2.92	0.53	1.73	1.23	2.43	5.48	6.87	3.59	5.89	2.66	0.71	6.31	4.64
580	2.14	31.2	3.12	0.51	1.82	1.17	2.49	5.38	6.51	3.63	6.19	2.68	0.69	6.13	4.51
600	2.07	33.6	3.36	0.47	1.90	1.09	2.55	5.21	6.09	3.66	6.49	2.65	0.66	5.87	4.32
620	2.00	35.6	3.56	0.45	1.96	1.03	2.59	5.09	5.76	3.68	6.68	2.63	0.64	5.63	4.14
640	1.94	38.8	3.88	0.41	2.01	0.95	2.62	4.82	5.29	3.67	6.88	2.53	0.59	5.25	3.86
660	1.88	41.7	4.17	0.38	2.03	0.87	2.64	4.59	4.88	3.65	6.97	2.43	0.55	4.88	3.59
680	1.83	45.6	4.56	0.34	2.03	0.79	2.64	4.25	4.38	3.58	6.97	2.24	0.49	4.38	3.22
700	1.77	48.5	4.85	0.31	2.01	0.72	2.62	4.03	4.03	3.51	6.88	2.11	0.45	4.01	2.95
720	1.72	52.1	5.21	0.28	1.96	0.65	2.59	3.74	3.64	3.40	6.70	1.94	0.40	3.57	2.62
740	1.68	55.7	5.57	0.25	1.89	0.58	2.54	3.44	3.26	3.26	6.43	1.75	0.35	3.13	2.30
760	1.63	58.0	5.80	0.24	1.83	0.54	2.50	3.29	3.04	3.16	6.24	1.64	0.32	2.87	2.11
780	1.59	60.6	6.06	0.22	1.76	0.50	2.45	3.11	2.79	3.04	6.00	1.52	0.29	2.59	1.90
800	1.55	62.4	6.24	0.21	1.71	0.47	2.41	3.00	2.63	2.94	5.82	1.45	0.27	2.40	1.77

capable of exciting electron into the conduction band and therefore could serve as useful solar cell films.

Tables 1 – 2 show the electrical parameters for different wavelength for PdS and Bi_2S_3 thin films. The tables show that all the parameters are very high and decrease with increasing wavelength. This indicates that the materials are good electrical conductors, and in addition, have improved solar absorption.

These absorption levels would allow excitation of electrons into the conduction band, hence creating enough electron – hole pairs which are needed for the generation of electric current in solar cells. Since the films have good absorption in the UV – VIS – NIR regions they would be good generators of electron – hole pairs and as well good solar cells materials on the basis absorption alone. Also ε_r and ε_i values are very high, thereby showing that all of the films are good electrical conductors, hence they are capable of allowing the flow of electron – hole pairs through the films after they are generated. This confirms as well the fact that these films could be good solar cell materials.

Figure 3 shows the variation of the square of absorption coefficient α^2 against photon energy $h\nu$ for the films.

The band gap for PdS are determined to reside at 2.50eV while that for the Bi_2S_3 thin films are in the range of between 1.58 and 1.70eV. There is good correlation between the thickness of the films and band gap. However, at 600 nm (Table 3) as the thickness increase values for τ, α, and n increase while k decreases for the Bi_2S_3 thin films.

CONCLUSIONS

PdS and Bi_2S_3 thin films, which can be utilized in photovoltaic applications, were investigated and identified in this work as solar cell materials. They showed very high visible absorption levels, which are capable of causing electronic excitation and hence creating electron – hole pairs. The films show high-energy radiation absorption that would yield high electron – hole pairs. Additionally they have high electrical conductivities. The films would enhance transportation of electron – hole pairs as soon as they are created before recombination can take place. These properties of the films combine to make power generation possible in the films and hence make the both types of films good materials for solar cell fabrication

Table 3: Variation Of Spectral, Optical And Electrical Properties With Thickness For PdS and Bi_2S_3Thin Films.

Film Sample	Spectral properties						Optical properties at 600nm				Electrical properties at 500nm			t
	λ_A (nm)	λ_o (nm)	λ_a (nm)	λ_g (nm)	λ_t (nm)	λ_r (nm)	$\tau x10^{8}$	α x10^6 (m^{-1})	n	Kx10^{-2}	E_g (eV)	ε_r	$\sigma_e x10^2$ ($\Omega^{-1}m^{-1}$)	(μm)
ps13	200	300	800	496	800	460	6.91	0.34	2.25	1.76	2.5	6.68	3.54	0.35
bs21	200	420	800	730	800	700	2.34	1.45	2.17	6.92	1.7	2.55	8.85	0.77
bs20	200	500	800	776	800	760	1.64	1.81	1.58	8.62	1.6	3.1	8.31	0.81
bs2	200	440	800	785	800	660	3.36	1.09	2.55	0.21	1.58	4.75	6.63	0.56

REFERENCES

1. Green, M.A, *Solar Cells: Operating Principles, Technology and Systems Applications*, Prentice-Hall Inc. Eaglewood Cliffs N.J. (1982).

2. Starr, M.R. and W. Patz, *Photovoltaic for Europe: An Assessment Study*. D, Reindal Publishing Company, Dordrecht, Holland, (1983).

3. Chopra, K.L. and S.R. Das, *Thin Film Solar Cells*, Plenium Press, New York, (1983).

4. Eze, F.C. and C.E. Okeke , Chemical Bath Deposited Cobalt Sulphide Films; Preparation Effects, *Materials Chemistry and Physics* 47(1997) 31- 36.

5. Choi J.Y., K.J. Kim, J.B. Yoo and D. Kim, Properties of Cadmium Sulphide Films Deposited by Chemical Bath Deposition with ultrasonication, *Solar Energy* 64 (1-3) (1998) 41- 47.

6. Sabestian, P.J. and H. Hu, "Identification of the Impurity Phase in Chemically Deposited CdS Thin Films", *Adv. Mater. Opt. Electron*. 4, (1994),407 – 412.

7. Ezema, F.I. and C.E. Okeke, "Chemical Bath Deposition Of Bismuth Oxide (Bi2O3) Thin Film And Its Applications" *Greenwich Journal of Science and Technology*. 3(2) (2002).

8. Ndukwe, I.C., "Solution Growth, Characterization and Applications of Zinc Sulphide Thin Films", *Sol. Ener. Mater. Sol. Cells* 40(1996) 123 - 131.

9. Ezema, F.I. and C.E. Okeke "Preparation and Characterization Of Bismuth Broride Oxide Thin Films Prepared by Solution Growth Technique" *Nig. Journ. Phys*.14 (2) (2002) 48 -54.

10. Ezema, F.I. and C.E. Okeke "Characterization Of Bismuth Fluoride (BiF3) Thin Films Prepared by Solution Growth Technique And Its Applications" *Nig. Journ. Phys*.14 (2) (2002) 77 -85.

11. Pankove, J.I. (1971), *Optical processes in semiconductors*, Prentice-Hall, New York.

ABOUT THE AUTHOR

Dr. F.I. Ezema, B.Sc., M.Sc., Ph.D. serves as a lecturer in the School of General Studies, Natural Sciences Unit and Department of Physics/Astronomy at the University of Nigeria, Nsukka. His research interests are in the areas of thin film deposition, solar energy/solar radiation, and meteorology.

SUGGESTED CITATION

Ezema, F.I. 2003. A Critical Analysis of the Photovoltaic Potentials of Some Chemical Bath Deposited PdS and Bi_2S_3 Thin Films. *Greenwich Journal of Science and Technology*. 4(1):31-36.

Greenwich Journal of Science and Technology