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RESEARCH ARTICLE

Temperature Dependent Structural and Optical Properties of Doped Cadmium Sulphide Thin Films

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Abstract

Cadmium sulphide thin films were prepared using the SILAR (successive ionic layer and reaction) method. The films were then doped with zinc and annealed at different annealing temperatures. The as-deposited and annealed films were structurally characterised using X-ray Diffractometry (XRD) studies. The optical characterisation was done using the UV spectrophotometer to investigate the transmittance and reflectance versus wavelength measurements. The structural characterisation reveals that the films were polycrystalline, crystallising mostly with the cubic structure. From the optical characterisation, the energy bandgap for the as-grown layers was found to be in the range 2.30 eV to 3.80 eV which is within the range suitable for use as window layers in solar cell devices.

Introduction

Cadmium Sulphide (CdS) has been successfully utilised as buffer layers in the most advanced thin film solar cells such as CdTe (cadmium telluride) and CIGS (copper indium gallium selenide) based devices. CdS thin films have also been used as window layers in the earth-abundant based solar cell devices such as SnS (tin sulphide) and the kesterites (CuZnSnS). This has been reported by various authors (Susane et al, 2012; Abu Sharma et al, 2004; Nwofe et al, 2013). Cadmium Sulphide belongs to the II-VI group of semiconductor compounds which has been used in making heterojunction thin film solar cells, (Nwofe et al, 2013; Ogah, et al 2011; Vigil-Galan et al 2006; Reddy et al, 2006), mostly because it is a wide band gap semiconductor. It has been reported that CdS exhibits good thermal stability and can be used as light dependent resistors sensitive to visible and near infrared light (Hossain et al, 2012). Cadmium sulphide thin films can be grown using different range of deposition techniques such as thermal evaporation (Kar and Choudri, 2006; Shen et al, 2005), chemical bath deposition technique (Vigil-Galan et al 2007), RF magnetron sputtering (Lee and Lee, 2007), SILAR (Lukaitis et al, 2001; Xie et al, 2005), metal-organic chemical vapour deposition (O/Brien et al, 1996: Halsall et al, 1988), reverse micro emulsion method (Iorgu et al, 2013) and spray pyrolysis (Vijaya, 2014). Some reports in the literature indicate that cadmium sulphide can be doped using different materials such as nickel (Elango et al 2012), lead (Nerle and Rabinal 2014), copper (Tadataka and Jun/ichiro, 1993; Patil, 1972; Tiwari et al, 2013), Zirconium (Thiyagarajan et al, 2009), manganese (Venkatesu and Ravichandran, 2013), cobalt, nickel, magnesuim, selenium and zinc (Moore and Klein, 1969), tellurium (Atten and Haanstra, 1964), cerium (Saravana et al, 2012), mercury (Vijaya, 2014), aluminuim (Hasnet and Poder, 2012), europium (Saravan et al, 2011), and silver, (Iorgu et al, 2013). Chemical spray pyrolysis method has been widely used recently because its simplicity and inexpensiveness has found to be a better chemical method for the preparation of thin films with larger area compared to other methods. Spray pyrolysis also provides an easy method of doping an element in the required proportion through the solution growth method. Another significant advantage of using spray pyrolysis over other deposition methods is the ease to modify/control the various deposition parameters such as; substrate temperature, rate of deposition, air pressure, source to substrate distance, and cooling

rate after deposition. This is very important since these parameters affect the physical, electrical and optical properties of the thin films. Also the equipments can be easily assembled locally, thus reducing the needs for more sophisticated and expensive equipments. Vijaya (2014) observed that doping of Cadmium sulphide thin films enhanced the use not only as windows in thin film solar cell devices but also on other electronic displays as well as absorber layers in lieu of the doping effect on the energy bandgap. Zinc-doped Cadmium sulphide thin films grown by the closed vapour transport technique has been reported by other research groups (Kim et al, 2007) but report on CdS thin films grown by the SILAR method are relatively rare. In this study, the CdS thin films grown by the SILAR technique and doped with zinc to improve the properties has been reported. The work reported herein is a fundamental step towards improving the properties of cadmium sulphide thin films for applications in different opto-electronic devices.

Material and Methods

Thin films of CdS were deposited on ultrasonically cleaned glass substrates using the SILAR method. The substrate temperature was varied in the range 303 K to 363 K, keeping other deposition variables constant. 169.0 g of $Cd(NO_3)_2.4H_2O$ (cadmium trioxonitrate (V) tetrahydrate) was dissolved in 100 ml of water while 270.6 g of $Zn(NO_3)_2.6H_2O$ (zinc trioxonitrate (V) hexaydrate) was dissolved in 100 ml of water separately. 12 g of $Cs(NH_3)_2$ was further dissolved in 100 ml of water in a separate container. Consequently, 20 ml of the prepared 2.7 mol Cd^{2+} solution were poured in a 60 ml beaker to which 20 ml of 0.01ml and 0.05ml Zn^{2+} were added respectively, and 20ml of 14mol ammonia solutions were then added successively. 60 ml of S^{2-} prepared from the 0.4 mol thiourea solution was poured in another beaker. The above procedure was repeated for each of the respective temperatures used.

A PANalytical (XPERT=PRO) D8 advance X-ray diffractometer with a Cu Kα radiation source (λ = 1.5406 Å) was used to determine the phases present and the structural properties of both the as-deposited and doped CdS films. A UV spectrophotometer was used to measure the transmittance (T) and reflectance (R) versus wavelength measurements.

Result and Discussion

The physical observations of the as-deposited and doped CdS films indicates that they are free from pinholes, had no cracks and adhered strongly to the substrate. The films exhibited a yellow colour which increased with an increase in the substrate temperature and the doping concentration. Figure 1 gives the XRD plots for the as-grown cadmium sulphide layers. The structural characterisation reveals that the films were polycrystalline and appeared to be consistent with JCPDS: 03-065-6212 for the as-deposited layers. Also from the XRD analysis, it was observed that

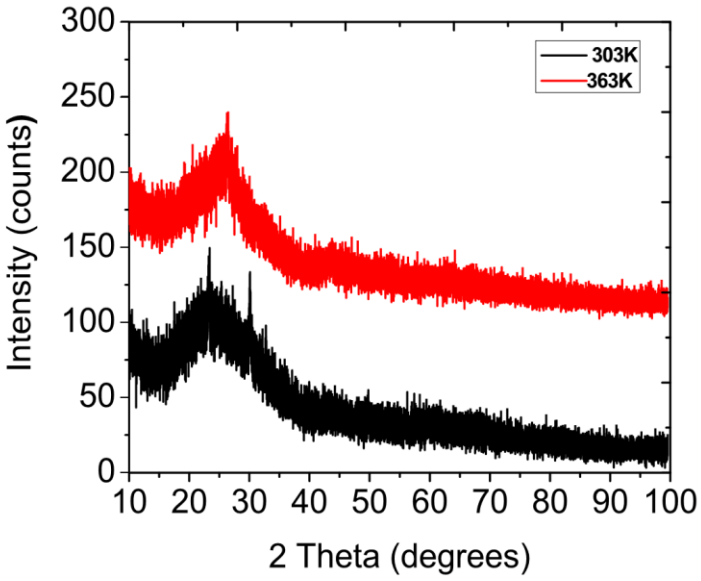

Figure 1. X-ray diffraction profiles of as-deposited CdS thin films grown at different substrate temperatures.

the as-deposited films crystallised in the cubic structure with Bragg peaks corresponding to the (111) and (220) planes (not shown). The doped layers also exhibits the cubic structure with the PDF: 01-075-0018 and the calculated lattice parameter was obtained as; a = b = c = 5.3900. Iorgu et al, (2013) has observed similar effects for cadmium sulphide thin films grown by the reverse microemulsion technique while other authors, (Iorgu et al, 2013; Elango et al, 2012; Saravana et al, 2012; Kim et al, 2007) reported a similar observation for doped CdS layers. From the optical transmittance and reflectance versus wavelength measurements, some important optical constants such as the optical absorption coefficient α, and energy bandgap E_g, were deduced. Figure 2 gives a typical $(\alpha h\nu)^2 \; versus \; h\nu$ plots for the as-grown CdS layers at different substrate temperatures.

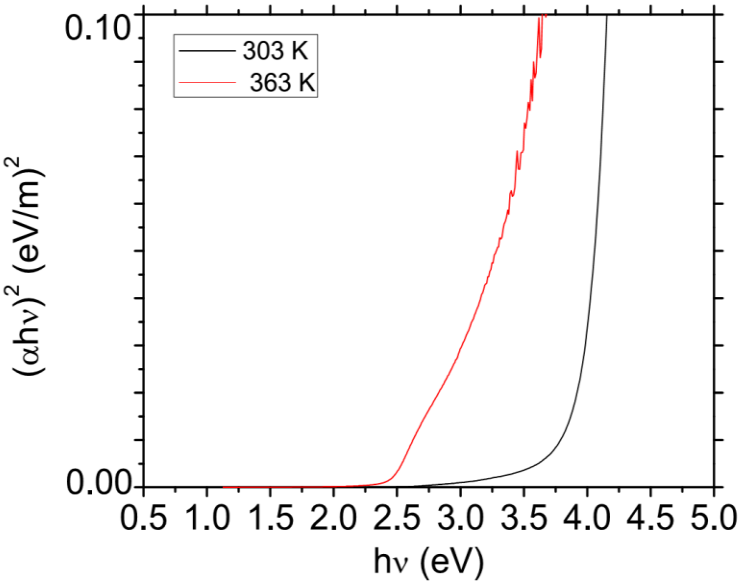

Figure 2. $(\alpha h\nu)^2 \; versus \; h\nu$ plots of as-deposited CdS thin films grown at different substrate temperatures.

The energy bandgap was deduced using the relation (Nwofe et al, 2012; Pankove, 2012) given as:

$$\alpha h\nu = B\left(h\nu - E_g\right)^n \qquad (1)$$

where B is an energy independent constant, α is the optical absorption coefficient, $h\nu$ is the photon energy, E_g is the energy bandgap and n equals 0.5 for direct allowed transitions.

The plot of $(\alpha h\nu)^2 \; versus \; h\nu$ is a straight line and its energy axis intercept at $(\alpha h\nu) = 0$ gives the energy band gap E_g of the material. The values of the energy band gap extrapolated from the $(\alpha h\nu)^2 \; versus \; h\nu$ plots were found to vary between 2.30 eV to 3.80 eV. As indicated in figure 2, the energy bandgap decreased with an increase in substrate temperature. This was attributed to the increase in molarity of the solution due to the addition of Zn^{2+} ions. It is possible that an increase in substrate temperature causes uniformity of the films due to the re-organisation of the atoms arising from the evaporation of the water molecule leading to the observed effects. Increase in substrate temperature could lead to an increase in grain size due to increased surface mobility. Other research groups (Hasnet et al, 2012; Tadataka and Jun/ichiro, 1993) have reported similar observation for doped CdS layers. However it has been argued in the literature for other semiconductor compounds (Devika et al, 2007; Nwofe et al, 2012; 2013), that a decrease/increase in the energy bandgap could also be due to the effect of other deposition parameters such as the source to substrate distance or annealing effects. Agbo (2011) and Agbo (2012) in their investigations on core-

shell thin films observed that the energy bandgap could be altered at different substrate temperatures/and or annealing effects and attributed it to quantum size effects. The energy bandgap of thin films can be modified through different approaches as highlighted in different reports in the literature (Nwofe et al, 2012; Nwofe et al, 2013; Luckert et al, 2011, Potter et al, 1988; Gao et al 2005; Tamborra et al, 2004; Du et al, 2002) irrespective of the deposition techniques. The values of the energy bandgap (2.30 eV to 3.80 eV) obtained in this work is within the range of the energy bandgap reported by other authors (Vigil-Galán et al, 2006; Kar and Chaudhuri, 2006; Patil, 1972) and is suitable for various opto-electronic applications and solar cell devices. Our future work will focus on the use of these layers to make solar cell devices with improved efficiency.

References

Siebentritt, S. and Schorr, S. (2012). Kesterites—a challenging material for solar cells. Progress in Photovoltaics: Research and Applications 20(5):512-519.

Abu Sharma, J. A., Johnston, S., Moriarty, T., Teeter, G., Ramanathan, K., and Noufi, R. (2004). Properties of ZnO/CdS/$CuInSe_2$ solar cells with improved performance. Progress in Photovoltaics: Research and Applications, 12(1):39-45.

Nwofe, P.A., Ramakrishna Reddy, K.T., and Miles, R.W. (2013). Determination of the minority carrier diffusion lengths of SnS using electro-optical measurements. Electronic Materials Letters 9(3):363-366.

Nwofe, P.A., Ramakrishna Reddy, K.T., and Miles, R.W. (2013). Effects of sulphur and air annealing on the properties of thermally evaporated SnS thin films for application in thin films solar cell devices. Journal of Renewable and Sustainable Energy 5:011204.

Ogah, O. E., Reddy, K. R., Zoppi, G., Forbes, I., and Miles, R. W. (2011). Annealing studies and electrical properties of SnS-based solar cells. Thin Solid Films 519(21):7425-7428.

Vigil-Galán, O., Arias-Carbajal, A., Mendoza-Pérez, R., Santana, G., Sastré-Hernández, J., Contreras-Puente, G., and Tufiño-Velázquez, M. (2006). Spectral response of CdS/CdTe solar cells obtained with different S/Cd ratios for the CdS chemical bath. Solar energy materials and solar cells, 90(15):2221-2227.

Ramakrishina Reddy, K.T., Reddy, N.K, and Miles, R.W. (2006). Photovoltaic properties of SnS based solar cells. Solar Energy Mat. & Solar Cells 90, 3041-3046.

Kar, S. and Chaudhuri, S. (2006). Shape selective growth of CdS one-dimensional nanostructures by a thermal evaporation process. The Journal of Physical Chemistry B 110(10):4542-4547.

Shen, G., Cho, J. H., Yoo, J. K., Yi, G. C., and Lee, C. J. (2005). Synthesis of single-crystal CdS microbelts using a modified thermal evaporation method and their photoluminescence. The Journal of Physical Chemistry B, 109(19): 9294-9298.

Vigil-Galán, O., Morales-Acevedo, A., Cruz-Gandarilla, F., Jiménez-Escamilla, M. G., Aguilar-Hernández, J., Contreras-Puente, G., and Ramón-Garcia, M. L. (2007). Characterization of CBD–CdS layers with different S/Cd ratios in the chemical bath and their relation with the efficiency of CdS/CdTe solar cells. Thin Solid Films, 515(15):6085-6088.

Lee, J. H. and Lee, D. J. (2007). Effects of $CdCl_2$ treatment on the properties of CdS films prepared by rf magnetron sputtering. Thin Solid Films 515(15):6055-6059.

Laukaitis, G., Lindroos, S., Tamulevičius, S., and Leskelä, M. (2001). Stress and morphological development of CdS and ZnS thin films during the SILAR growth on (1 0 0) GaAs. Applied surface science, 185(1):134-139.

Xie, R., Kolb, U., Li, J., Basché, T., and Mews, A. (2005). Synthesis and characterization of highly luminescent CdSe-core CdS/Zn0.5Cd0. 5S/ZnS multishell nanocrystals. Journal of the American Chemical Society, 127(20): 7480-7488.

O'Brien, P., Walsh, J. R., Watson, I. M., Hart, L., and Silva, S. R. P. (1996). Properties of cadmium sulphide films grown by single-source metalorganic chemical vapour deposition with dithiocarbamate precursors. Journal of crystal growth, 167(1):133-142.

Halsall, M. P., Davies, J. J., Nicholls, J. E., Cockayne, B., Wright, P. J., and Russell, G. J. (1988). Growth and assessment of CdS and CdSe layers produced on GaAs by metalorganic chemical vapour deposition. Journal of crystal growth, 91(1):135-140.

Hossain, M. A., Koh, Z. Y., and Wang, Q. (2012). PbS/CdS-sensitized mesoscopic SnO_2 solar cells for enhanced infrared light harnessing. Physical Chemistry Chemical Physics, 14(20):7367-7374.

Elango, M., Natarj, D., Prem Nazeer, K., and Thamilselvan, M. (2012). Synthesis and Characterisation of nickel doped cadmium sulphide. Mater Res Bull. 47(6):1533-1538.

Nerle, U. and Rabinal, M.K. (2014). Solution Based Cation-Exchange Proces to Control Optoelectronic Properties of Cadmium Sulphide Thin Films. American Chemical Science Journal 4(2):151-165.

Saravanan, L., Pandarungan, A., and Jayavel, R. (2012). Synthesis and luminescence enhancement of cerium doped CdS nanoparticles. Mater Letts. 66(1):343-345.

Vijaya, M. G. (2014). Structural, Optical and Electrical Studies on Spray Deposited Mercury Doped Cadmium Sulphide Thin Films. International Journal of recent advances in Physics 3(1):17-22.

Hasnet, A. and Podder, J. (2012). Structural and electrical transport properties of CdS and Al-doped CdS thin films deposited by spray pyrolysis. Journal of Sci. Res. 4:11-19.

Saravan, L., Jayavel, R. Aldeyab, S.S., Jaidi, J.S., Ariga, K., and Vinu, A. (2011). Synthesis and morphological control of europium doped cadmium sulphide nanocrystals. J. Nanoscience Technol. 11(9):7783-7788.

Iorgu, A.I., Berger, D., Alexandrescu, L., Vasile, B.S., and Matei, C. (2013). Synthesis Of Photoluminescent Pure And Doped Cadmium Sulfide By Reverse Microemulsion Method. Chacogenides Letters 10(12):525-531.

Tadataka, E. and Jun′ichiro, M. (1993). Electrodeposistion and properties of copper-doped cadmium sulphide. Thin Solid Films 235(1&2):198-201.

Patil, S.G. (1972). Optoelectronic properties of copper-doped cadmium sulphide. J. Phys D: Appl Phys. 5(9):1692.

Tiwari, R., Dubey, V., and Tamrakhar, V.R. (2013). Copper Doped Cadmium Sulphide (Cds: Cu) Quantum Particles: Topological, Morphology And Photoluminescence Studies. International Journal of Engineering and technology. 3(3):67-74.

Thiyagarajan, R., Anusuya, M. and Mahaboob Beevi, M. (2009). Study of Structural and Mechanical properties of Zirconium Doped Cadmium Sulphide Thin Films. Journal of American Science 5(3):26-30.

Venkatesu, P. and Ravichandran, K. (2013). Manganese doped cadmium sulphide (CdS: Mn) quantum particles: Topological, photoluminescence and magnetic studies. Adv. Mater. Letts. 4(3); 202-206.

Moore, G.E. and Klein, M.V. (1969). Thermal conductivity of doped and pure cadmium sulphide. Physical Review Letters. 179:722.

Aten, A. C. and Haanstra, J. H. (1964). Electroluminescence in tellurium-doped cadmium sulphide. Physics Letters, 11(2): 97-98.

Kim, D. S., Cho, Y. J., Park, J., Yoon, J., Jo, Y., and Jung, M. H. (2007). (Mn, Zn) co-doped CdS nanowires. The Journal of Physical Chemistry C 111(29):10861-10868.

Nwofe, P. A., Reddy, K. R., Sreedevi, G., Tan, J. K., and Miles, R. W. (2012). Structural, optical, and electro-optical properties of thermally evaporated tin sulphide layers. Japanese Journal of Applied Physics, 51:10NC36.

Pankove, J. I. (2012). Optical processes in semiconductors. Courier Dover Publications.

Devika, M., Reddy, N.K., Reddy, S.D., Reddy, S.V., Ramesh, K., Gopal, E.S.R., Gunasekhar, K.R., Ganesan, V., and Hahn, Y.B. (2007). Optimization of the distance between source and substrate for device-grade SnS films grown by the thermal evaporation technique. Semicond. Sci. Technol. 19:306003.

Nwofe, P.A., **Ramakrishna Reddy, K.T., Tan, J. K., Forbes, I., Leach, M., Jang, D.Y., and Miles, R.W. (2012).** "Investigating the Potential of SnS for Use in Photovoltaic Solar Cell Applications". Proceeding of the Photovoltaic Science, Applications and Technology (PVSAT-8), p. 89 -92, Northumbria University, UK, (2^{nd} – 4^{th} April).

Nwofe, P.A., Ramakrishna Reddy, K.T., and Miles, R.W. (2013). Type Conversion of p-SnS to n-SnS using a $SnCl_4/CH_3OH$ heat treatment. IEEE Xplore, 2518-2523. doi: 10.1109/PVSC.2013.6744988.

Agbo, P. E. (2012). Effect of Thermal Annealing on Optical and Band gap of chemically deposited TiO_2/Fe_2O_3 Core/shell Oxide Thin Films. Adv. Appl. Sci. Res, 3(1):599-604.

Agbo, P. E. (2011). Temperature effect on the thickness and optical properties of Core-Shell TiO_2/ZnO crystalline thin films. Adv. Appl. Sci. Res, 2(6):399-399.

Nwofe, P. A., Reddy, K. T., Tan, J. K., Forbes, I., and Miles, R. W. (2012). Thickness dependent optical properties of thermally evaporated SnS thin films. Physics Procedia, 25, 150-157.

Nwofe, P. A., Reddy, K. R., Tan, J. K., Forbes, I., and Miles, R. W. (2013). On the Structural and Optical Properties of SnS Films Grown by Thermal Evaporation Method. Journal of Physics: Conference Series 417(1): 012039.

Nwofe, P. A., Reddy, K. T., and Miles, R. W. (2013). Influence of Deposition Time on the Properties of Highly-oriented SnS Thin Films Prepared Using the Thermal Evaporation Method. Advanced Materials Research, 602:1409-1412.

Luckert, F., Hamilton, D. I., Yakushev, M. V., Beattie, N. S., Zoppi, G., Moynihan, M., and Martin, R. W. (2011). Optical properties of high quality $Cu_2ZnSnSe_4$ thin films. Applied Physics Letters, 99(6):062104.

Potter Jr, B. G., and Simmons, J. H. (1988). Quantum size effects in optical properties of CdS-glass composites. Physical Review B, 37(18):10838.

Gao, T., Li, Q., and Wang, T. (2005). Sonochemical synthesis, optical properties, and electrical properties of core/shell-type ZnO nanorod/CdS nanoparticle composites. Chemistry of materials, 17(4):887-892.

Tamborra, M., Striccoli, M., Comparelli, R., Curri, M. L., Petrella, A., and Agostiano, A. (2004). Optical properties of hybrid composites based on highly luminescent CdS nanocrystals in polymer. Nanotechnology, 15(4):S240-S244.

Du, H., Xu, G. Q., Chin, W. S., Huang, L., and Ji, W. (2002). Synthesis, characterization, and nonlinear optical properties of hybridized CdS-polystyrene nanocomposites. Chemistry of materials, 14(10):4473-4479.