physical properties of CdS / CdTe / CIGS thin films for solar cell application

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Abstract. Thin films of CdS, CIGS and CdTe were prepared on the glass substrate by vacuum thermal evaporation technique in the thickness 200, 500, 500 respectively at room temperature. From the study Structural properties of the thin films by the X-ray diffraction, we found polycrystalline nature for all thin films with a preferred orientation along [111] cubic for CdS and [211], [112] hexagonal for CIGS and [111], [202], [311] cubic for CdTe. The Transmittance spectrum was recorded as a function of wavelength range (500-1100) nm. The energy gap measurements record 2.35, 1.75, 1.5 eV respectively, we have found one activation energy for CIGS and two for both of CdS and CdTe that with explored from measure electrical conductivity with temperature. The Hall Effect measurements show that CIGS and CdTe were p-types carrier concentration and CdS thin films were n-type carrier. The current-voltage test in dark and light condition show all types of thin films have photoconductivity properties.

1. Introduction
In the last years from 1990 solar cells based on Cd- II-VI semiconductor materials like CdS, CdTe with CIGS are one of the most attractive and promising in thin film photovoltaic’s. Solar cells have developed and updated by introducing these semiconductors thin films which provide lower energy devices with high production capacity and consuming minimum material [1]. Attracted considerable attention was focused on Cd-semiconductor compounds due to their applications in photovoltaic devices [2]. All these materials are direct-gap semiconductors that can absorb incoming solar radiation at a thickness much thinner than the required thickness for the silicon wafers in crystalline silicon (Si) solar cells [3].

CdTe with a band gap of 1.45 eV is the material well suited to match the Air Mass (AM) equal 1.5 solar spectrum. Furthermore, its high absorption coefficient causes that only a few microns absorber film is required for solar cell operation and (Cupper Indium Gallium Selcinde) CIS/ CIGS materials are significantly different. The highest value of solar radiation absorption belongs to CIS/CIGS that can absorb almost complete incoming radiation at first 3–4 μm of the material thickness and 95% of the radiation in its first 0.4–0.5 μm [4].

Cu(In,Ga)Se₂ solar cells are very interesting because of their high efficiencies, with low cost and many important application possibilities. (CIGS) is one of the most promising semiconductor for use as absorber layer for thin-films solar cells. It is a member of an I-III-VI2 group of chakopyrite semiconductors, It is used as light absorber material in solar cells. These thin films deposited on different substrates with a variety of growth methods. CIGS deposition yield lower efficiencies, but offer other advantages.

CdS is a II-VI compound, n-type semiconductor with energy gap of 2.45 eV. It is used to fabricate heterojunction with CIGS, the carrier density of CdS is higher than in CIGS, the depletion field is completely in the CIGS layer where it generates electron-hole pairs. So that, it reduces...
recombination of minority carriers at the metallurgical interface. It is used in photovoltaics, photonics and optoelectronics [5]. In optoelectronics, Cds is used to manufacture lasers. It works also as a window layer which allows the light to pass through it with relatively low absorption. Cadmium telluride (CdTe) is a stable crystalline compound formed form cadmium and tellurium. It is mainly used as the semiconducting material in cadmium telluride photovoltaics and an infrared optical window. It is usually sandwiched with cadmium sulfide to form a p-n junction solar PV cell. Typically, CdTe PV cells use a n-i-p structure. The important advantage in this type of solar cells is the ability to quickly and easily manufacture these cells at much lower costs than crystalline silicon photovoltaic but typically have efficiencies that are lower than crystalline silicon [6-7].

The aim of this research is to study the properties of thin films to search for the suitability of these films for the manufacture of solar cells based on Cu(In,Ga)Se2 semiconductor material for better utilization of the solar spectrum to yield higher efficiency and performance stability [8-9].

2. Experimental procedure

This research includes the practical steps to depositing (CIGS, CdS and CdTe) thin films. The deposition of Cu(In1-xGax)Se2, CdS, CdTe layers with thicknesses of (500 nm) and deposited Aluminum metal electrode (Al) ohmic contacts with (200 nm) thickness were done using thermal evaporation on glass substrates using thermionic model (VE.90, USA) Vacuum system for deposition which reach to 10^{-6} Torr. The boat of molybdenum (Mo) was used to evaporate the materials while using Tungsten(W) boat to evaporate the Al contact electrodes. To examine the crystal structure, orientation, grain size and position of atoms can be calculated by using X-ray diffraction technique. X-ray diffraction (XRD) measurements using (SHIMADZU diffractometer system (XRD-6000)), having the following features: The source of x-ray is Cu with wavelength λ=1.54060Å, Current was 30 mA , Voltage was 40 KV and the scanning range was between angles (2θ) of (20 – 80) degrees with scanning speed 5 (degree/minute).

The Atomic force microscopy type AA3000 from Angstrom advanced Inc , used to study roughness and surface morphology for the CdS , CIGS and CdTe thin films. The optical properties of the CdS , CIGS and CdTe thin films were studied, the absorption and transmittance spectra for samples are recorded using UV-Visible spectrometer model UV-2610 product by Biotech engineering management company (UK ) in the wavelength range (200-1100) nm and V-670 UV-Vis/NIR spectrophotometer . The electrical properties measurements of semiconductor thin films which included DC conductivity and Hall Effect were determined to investigate the activation energies and the concentration of charge carriers, as well as mobility and use these measurements to distinguish whether the semiconductor n-type or p-type using system type HSM-300 made by ECOPIA Co. (Korea).

3. Results and discussion

3-1 Structural properties of thin films:
3-1-1 XRD measurements

All thin films have shown the polycrystalline structure in nature as shown in the figure 1 at RT.
Figure 1. shows the X-ray diffraction at 500 nm thickness for temperatures (300) K, (a) CdS,(b) CIGS, (c) CdTe thin films

3-1-2 Atomic Force Microscopy
We have test the AFM of CIGS,CdS and CdTe thin films respectively and showed in figure 2. that topography of surface polycrystalline with defect according to deposition process.

Figure 2. AFM picture of CIGS, CdS and CdTe thin films respectively.

3-2 Optical Properties of thin films
In the figure 3. the absorbance and transmittance curve show all thin films lay in the visible spectrum with different transparency curve

Figure 3. The transmittance curve for CdS, CIGS and CdTe thin films at thickness 200, 500, 500 nm deposited on glass at RT

3-2-1 Energy Gap:
The energy gap measurements record 2.35, 1.75, 1.5eV respectively from transmittance curve for CdS, CIGS and CdTe thin films at thickness 200 500, 500 nm deposited on glass at RT. The best thickness of CdS thin film for give high transmittance and high carrier mobility for solar cell measurements was 200nm (Bakkaier 2010). The results of energy gaps of all thin films shows that the
CdS layer, the first window face light permit the visible spectrum to next layer of CdTe and CIGS to absorbed of photons to generated electron holes inside and separated to electrodes by internal built-in voltage in P_N junction of solar cell as shown in the figure 4.

Figure 4. The optical energy gap for CdS, CIGS and CdTe thin films.

3-3 Electrical Properties of Thin Films:
3-3.1 DC conductivity
The DC conductivity have found one activation energy for CIGS and two for both of CdS and CdTe that with explored from measure electrical conductivity with temperature where one activation energy for CIGS and two activation energy for both CdTe and CdS in two range of temperature and conductivity measurements from graph as shown in the figure 5. and the data records in the table 1.

Figure 5. ln conductivity variation versus (1000/T) for the CIGS ,CdS, and CdTe thin

Table 1. Electrical DC conductivity of CIGS,CdS and CdTe thin Films.

| Thin Film | σR,T (Ω.cm)⁻¹ | Ea₁ (eV) | Temp. Range (K) | Ea₂ (eV) | Temp.Range (K) |
|-----------|---------------|----------|-----------------|----------|----------------|
| CIGS      | 6.07x10⁻⁴     | 0.8844   | 403-293         |          |                |
| CdS       | 4.52x10⁻⁴     | 0.6923   | 293-353         | 0.2439   | 353-403        |
| CdTe      | 2.15x10⁻⁴     | 0.2776   | 293-313         | 0.0640   | 313-403        |

3-3.2 Hall Effect
The hall measurements show that CIGS and CdTe were p-tyes carrier and CdS thin films was n-type carrier. All data about Hall carrier mobility, conductivity and carrier concentration as shown in the table 2.
Table 2. Hall Effect measurements for CIGS, CdS and CdTe thin films.

| Thin Film | \( R_H \) \((\text{cm}^3/\text{c})\) | \( \mu_H \) \((\text{cm}^2/\text{V} \cdot \text{sec})\) | \( \sigma_{dc \text{ at R.T}} \) \((\Omega \cdot \text{cm})^{-1}\) | \( n_H \) \((\text{cm}^{-3})\) | Type |
|-----------|------------------|------------------|------------------|------------------|------|
| CIGS      | +2.6*10^8       | 5.2*10^7         | 1.79             | 3.5*10^16        | p-type |
| CdS       | -2.3*10^8       | 4.6*10^7         | 6.8*10^13        | 4.1*10^19        | n-type |
| CdTe      | +4.5*10^7       | 2.4*10^7         | 3.2*10^16        | 3.4*10^19        | p-type |

4. Conclusions

All results data as structural, optical and electrical properties showed that energy gap are suitable range in the optical visible range of wavelength that good matching like solar radiation spectrum and have good photoconductivity properties for solar cell application.

References

[1] Su-Huai Weia, S. B. Zhang, and Alex Zunger, 2000 "First-principles calculation of band offsets, optical bowings, and defects in CdS, CdSe, CdTe, and their alloys", journal of applied physics, vol. 87, no. 3.

[2] David Julien Louis Brémaud, 2009 "Investigation and Development of CIGS Solar Cells on Flexible Substrates and with Alternative Electrical Back Contacts", Doctoral Thesis, ETH Zurich university.

[3] Mushtak A. Jabbar, 2015 "Manufacturing and Evaluating of Flexible Nano Solar Cell", Doctoral Thesis, College of Education, University of Al-Mustansiriyah.

[4] E.R. Shaaban, N. Afify, and A. El-Taher, 2009 "Effect of film thickness on microstructure parameters and optical constants of CdTe thin films", Journal of Alloys and Compounds Vol. 482, pp.(400-404).

[5] Zhou Fang, Xiao Chen Wang, Hong Cai Wu, and Ce Zhou Zhao, 2011 “Achievements and Challenges of CdS/CdTe Solar Cells”, International Journal of Photoenergy, Volume 2011, Article ID 297350, p 8.

[6] M. Dharmadasa, P. A. Bingham, O. K. Echendu, H.I. Salim, T. Druffel, R. Dharmadasa, G. U. Sumanasekera, R. R. Dharmasena, M. B. Dergacheva, K. A. Mit, K. A. Urazov, L. Bowen, M. Walls and A. Abbas 2014 “Fabrication of CdS/CdTe-Based Thin Film Solar Cells Using an Electrochemical Technique ” Coatings Journal, Vol. 4, PP. 380-415.

[7] M. Dharmadasa, 2014 “ Review of the CdCl₂ Treatment Used in CdS/CdTe Thin Film Solar Cell Development and New Evidence towards Improved Understanding, Coatings Journal,Vol.4, PP. 282-307.

[8] S.D. Gunjali, Y. B. Khollam, M. T. Sarode, S. A.Arote, P. N. Shelke, K. C.Mohite, 2014 “Solar Cell Properties CdS/CdTe Heterojunctions Prepared by using Spray Pyrolysis Technique”, International Journal of Chemical and Physical Sciences, Vol.3, PP.102-108.

[9] S.S. Babkair, 2010 “Charge Transport Mechanisms and Device Parameters of CdS/CdTe Solar Cells Fabricated by Thermal Evaporation”, JKAU:Sci., Vol.22, No.1, pp.21-33.