Tuning band gap in tandem solar cells

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The basic drawback of single junction solar cells is their inability to absorb multiple wavelengths of light. Tandem solar cells are designed to extract maximum energy from the light by absorbing multiple wavelengths. A multilayer solar cell was fabricated using multiple coating techniques. The characterization of the cell was carried out to analyze its properties and behavior under different conditions. The effect of layers' thickness on the light absorption efficiency is discussed in this paper. The thickness of P-type material is varied to examine the effect of layer thickness on the band gap.

1. Introduction

Solar energy is one of the major renewable energy resources. There are three generations of solar cells. They differ in fabrication methods and materials used. First generation solar cells were fabricated by using silicon or germanium as a source material. They were relatively expensive besides their low efficiency. The efficiency of these cells depends on the purity of the source materials. Pure silicon is very expensive that make first generation solar cells less cost effective. Single crystal silicon cells are most efficient product of this generation. Their theoretical efficiency is 19 percent [2]. Polycrystalline silicon cells are commercially manufactured, their theoretical efficiency is 14 percent but their efficiency decreases with time as silicon degrades in the presence of intense light and other atmospheric remedies. Second generation solar cells also have low efficiency but they were cheaper to produce. Copper indium diselenide and cadmium telluride cells are examples of second generation solar cells. Their theoretical efficiency is 17 percent. [3]. Third generation solar cells are efficient and cost effective but they are not being manufactured on commercial scale. Lots of research is being done on third generation cells to make them cost effective and commercially available. Third generation solar cells are based on thin film technology and their theoretical efficiency is up to 66 percent.

The reason for their enhanced efficiency is the presence of multiple semiconductor materials in the structure. Third generation solar cells are divided into two categories, i.e. single layer solar cells and multilayer solar cells. Single layer solar cells are also called quantum dots solar cells. Semiconductor quantum dots are coated on a substrate to make a p-n junction. Their efficiency is high because of nano-structured quantum dots. Usually, one photon is able to create one electron-hole pair but due to nano-structure of quantum dots one photon can create 2-7 electron-hole pairs. This effect is justified by taking in account the increment in surface area and hence surface energy of the quantum dots at nano scale. Multilayers or Tandem solar cells are combination of more than one cell, i.e. multi-junction layers are deposited on one another to fabricate multiple cells on a single substrate.
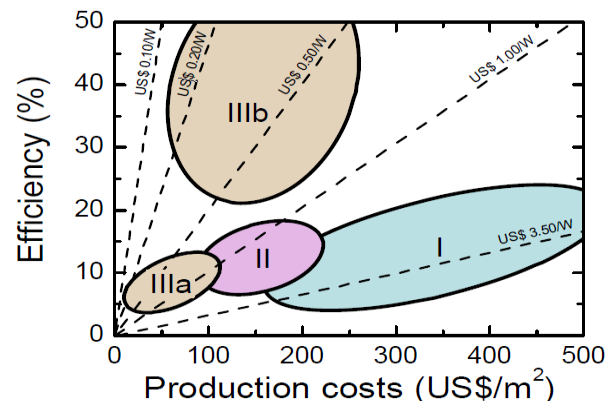

Fig. 1. Relationship between efficiencies of different solar cell generations as a function of cost [1].

There are various factors which affect the efficiency of Tandem solar cells, e.g. Fabrication method, type of materials used, layers thickness etc. The response of the cell by variation in layer thickness was studied by using different characterization techniques. A tandem solar cell having two sub-cells (two hetro-junctions) was fabricated using electron beam and thermal evaporation coating techniques. Indium tin oxide (ITO) coated glass substrate (2 cm x 2 cm) was selected for cell fabrication, ITO serves as cathode in the cell. Cuprous oxide (Cu_2O) and copper Pthalocyanine (CuPc) were used as p-type materials in both cells respectively and titanium dioxide (TiO_2) was used as N-type material in both sub-cells. Copper was used as interlayer between two cells, the purpose of interlayer was to facilitate recombination of excitons. The anode was

also a thin layer of copper. All of the materials were purchased from Sigma Aldrich outlet.

Three Tandem solar cells were fabricated using above mentioned materials. The thickness of cuprous oxide (P-type material) layer was varied in all the cells to see the effects of thickness on the properties of the cell. The effect of variation in layer thickness on light absorption and band gap of the material was studied. The band gap of materials must be synchronized with energy of photons, i.e. more band gap synchronization more efficiency [4].

2. Experimental procedures

Electron Beam Coater and Thermal Evaporation apparatus were used for the fabrication of Tandem solar cells. Electron Beam coating is advanced technique with accurate thickness control while thermal evaporator used by us is a versatile technique but it lacks accurate thickness control. Nano powders of cuprous oxide (Cu2O), titanium dioxide (TiO2), copper Pthalocyanine (CuPc) and pure copper (Cu) were mixed with 5 % potassium bromide and pellets with 15 mm diameter and 16 mm depth were made by using hydraulic press. The pellet size was compatible with crucible used for source material in the Electron Beam coater. Three Indium Tin Oxide (ITO) coated glass substrates were used for the experimentation. The substrates were sonicated in the sonicator for 15 minutes, using acetone solvent, to remove impurities. The substrates were then dried and mounted on the substrate holder in the Electron Beam coater. The TiO2 pellet was put into the crucible and the chamber was closed.

Table 1. Parameters for electron beam coating.

Sr.No	Parameter	Status
1	Vacuum	1.8×10^{-8} Torr
2	Pumping rate of Turbo Pump	550 l/s
3	Time	2-4 min.
4	Crucible diameter, Depth	16 mm, 15 mm
5	Substrate Temperature	$25\ ^{0}C$
6	Chiller	2 l/min
7	Voltage Applied	2 kV
8	DC Power supply	3 kW
9	Compressed air pressure	12 psi
11	Chamber Dimensions	16" x 16" x 24"

A quartz crystal thickness monitor was installed in the chamber and the thickness of the layer was computer controlled. A thin N-type layer (40 nm) of TiO2 was deposited on ITO. The chamber was vented and TiO2 crucible was taken out of the chamber. Cu2O pellet was put into the crucible and the chamber was again closed. 60 nm thin P-type layer of Cu2O was deposited on all three samples then one sample was taken out, 80 nm layer was deposited on the remaining two samples, second substrate was also taken out and 100 nm layer was deposited on the

third sample. After depositing cuprous oxide films of various thicknesses on TiO2 film, pure copper pellet was put into the crucible and thin (10 nm) interlayer of copper was deposited on all Cu2O films. One sub-cell fabrication was completed till then. Another N-type layer (40 nm) of TiO2 was deposited on copper film. Copper Pthalocyanine is an organo-metallic complex, its pellet was not very hard to sustain high power electron beam; i.e. the pellet would be destroyed without deposition of film. Therefore, CuPc layer was deposited by the help of thermal evaporator. Tantalum boat was used as a resistant heater. CuPc powder was put onto the boat and samples were mounted on the substrate holder. Thickness control was not available in the thermal evaporation technique so the CuPc film was deposited on hit and trial basis.

Table 2. Parameters for resistive coating.

Sr.No	Parameter	Status
1	Vacuum	$3.1 \times 10{-4}$ Torr
2	Boat Temperature	$\sim 200\ ^{0}C$
3	Time	~5 mins
4	Water Cooling	1 l/min
5	Current Applied	30-70 A

Finally, the copper pellet was put into the Electron Beam crucible and a thin (20 nm) copper layer (anode) was deposited on CuPc film by Electron Beam coater.

3. Results and discussion

Band gap of cuprous oxide in the tandem solar cell was calculated through UV-Visible spectroscopy [5].

$$Eg=hc/\lambda$$

Wavelength is obtained from the plot by drawing tangent at the sharp sloe change I the curve until it touches the wave length axis and then taking the corresponding value of wavelength from the axis.

Following table shows the band gap calculated from the samples with the variation of cuprous oxide thickness.

Table 3. Band Gap association with absorbed wavelength.

Sample No.	λ1 nm	E1 eV	λ2 nm	E2 eV
1	450	2.77	780	1.6
2	520	2.39	750	1.66
3	500	2.49	720	1.72

This table shows that materials respond to different wavelength depending upon their band gaps.
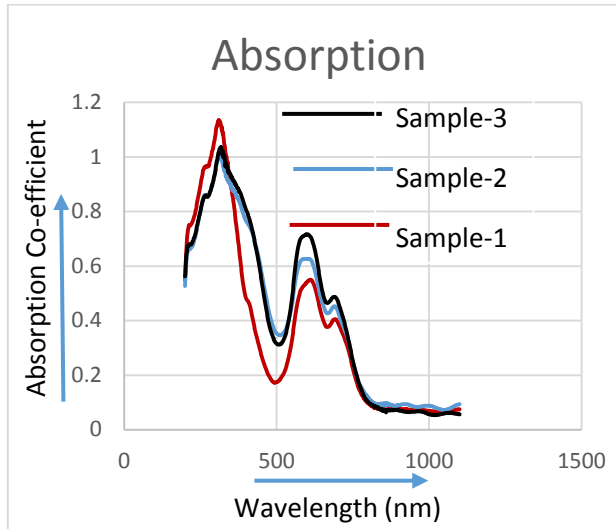
Absorption

Fig. 2. Graph showing relationship between wavelength and absorption coefficient.

Energy more than band gap is absorbed while energy less than band gap is transmitted. UV-visible graphs show two peaks in the result due to multilayer coatings of different materials. Cu_2O p-type material has direct band gap and operates in the range of 500-650 nm wavelength. TiO_2 is n-type material which operates usually in the UV region 250-400 nm wavelengths. It shows both absorption as well as scattering effect in this range. CuPc is an organic dye whose absorption is among all these materials. It is clear from the curve that absorption increases with increasing thickness of the Cu_2O. Higher band gap will absorb more light because it needs more energy for excitation.
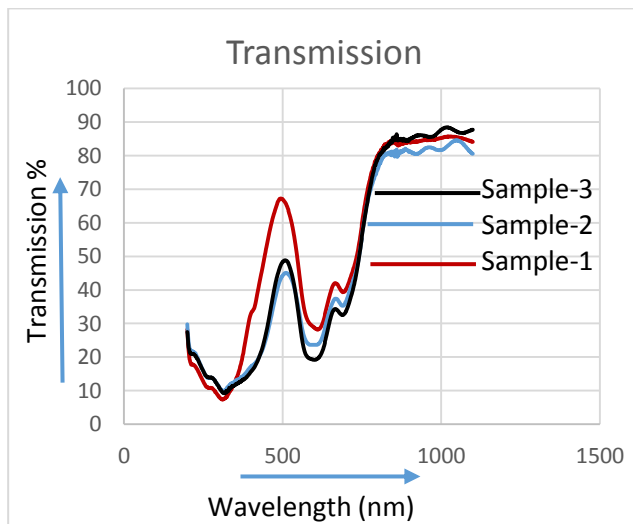
Transmission

Fig. 3. Graph showing relationship between wavelength and Transmission %.

It is clear from the transmission curve that maximum transmission in UV range is seen from 450-550 nm then transmission decreases up to 600 nm due to absorption by Cu_2O. After that transmission again increases because it has not sufficient energy for excitation. TiO_2 shows scattering effect in UV range which is responsible for less absorption and more transmission.

4. Conclusion

Multilayer structure was produced by Electron beam coater and thermal evaporator for the deposition of in organic and organic materials respectively. Variation in band gap of Cu2O 1.6-1.72 eV is observed due to change in coating thickness. Coating thickness responds differently according to their band gap in electromagnetic spectrum. Two peaks in absorption and transmission spectra are obtained due to materials with different band gaps operating in different ranges. Band gap of Cu_2O shows increase in absorption up to 600 nm wavelength and then decrease with increasing wavelength. With the variation of the coating thickness band gap of Cu2O can be tuned to increase absorption efficiency of solar cell.

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