Electrical Studies Of Silicon Based Hetero-Junction Solar Cells Prepared By Spray Pyrolysis Technique

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Abstract:

Titanium dioxide, Copper Oxide, Cadmium Telluride & Tin Sulfide thin films were deposited in a multi-cycle on cleaned Si (100) substrates maintained at a temperature of 350ºC, 300ºC, 350ºC & 270ºC by a simple low cost versatile spray pyrolysis technique under optimum conditions, for the application as a window / absorber layer for hetero-junction solar cells. The n-type conductivity of TiO_2 and p-type conductivity of CdTe, CuO, SnS semiconducting films were confirmed by Hot probe measurements. The dark-light I-V characteristics of Au/TiO_2/p-Si/Al, Au/CuO/n-Si/Al, Cu-Au/CdTe/n-Si/Al and Al/SnS/n-Si/Al hetero-junction solar cells under illumination of 206 mW/cm^2 have shown excellent rectifying behavior. The estimated lower saturation current, open circuit voltage, Fill Factors and shunt resistance confirm that as photo generated charge carriers pass through the multi-cycle deposited layers, they are blocked or trapped at the grains, defects, pin-holes which are rich in sprayed films. Au/CuO/n-Si/Al hetero-junction solar cells are found to possess higher value of efficiency compared to other cells, as a result of lower number of interface states, lower series resistance and considerably higher shunt resistance. The light response of Al/SnS/n-Si/Al solar cell is reasonably good however other cell parameters are negligible as a consequence of higher series and shunt resistance. Lower limit of interface states due to depletion and interface, as estimated from the capacitance measured at low (50Hz) and high frequency (1kHz) are found to vary from 5.7 - 26.95x10^{10} Fcm^{-2}eV^{-1} respectively. The diode factor of the cells are found to vary from 1.49-4.87, confirming the dominant interface recombination mechanism at the junctions.

Keywords: Spray pyrolysis; multi-cycle; hetero-junction solar cell: cell parameters: recombination

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1. Introduction

In the recent past, some of the most widely used investigated materials are Titanium dioxide (TiO_2), Cadmium Telluride (CdTe), Copper oxide (CuO) and Tin Sulfide (SnS) respectively. There has been increasing interest in the fabrication of semiconducting films because they exhibit useful structural, optical and electrical properties such as high refractive index [1], high dielectric constant [2], gas sensing applications [3, 4, 5] and remarkable solar energy conversion [6,7,8,9]. Several techniques have been used for

the preparation of these films, which include sputtering [10, 11, 12, 13], chemical vapor deposition [14], molecular beam epitaxy [15] and spray pyrolysis [16, 17, 18, 19]. Probably, the spray pyrolysis is an elegant and a cheapest technique towards preparation of semiconducting thin films. The films prepared by Spray pyrolysis are of better crystalline quality, clean, adherent, denser and porous, etc., which are favorable characters for solar cell and sensors applications [20]. It needs no vacuum, since the films are deposited in the atmospheric ambiance. Hetero-junction solar cells formed simply by depositing transparent semiconductor films such as ITO/TiO_2/CdTe/CuO/SnS on Si substrates. The metal oxide film (TiO_2) thickness plays a key role in the enhancement of power conversation efficiency of solar cells [21]. Reasonably good efficiency can be expected for TiO_2 films with optimum thickness and hence the control of the film thickness [22] is very much essential for application of film as a good window or absorber layer in a hetero-junction solar cell. Hetero-junctions have the ability to selectively block holes or electrons via barriers of valence or conduction band. Lattice mismatch is an important factor for selectively blocking carriers in heterojunctions. The problem of lattice mismatch between the silicon and wide band gap semiconductor is avoided in hetero-junctions. Sushobhan avasthi et.al., [23] have studied carrier blocking low-temperature processed hetero-junction formed by coating TiO_2 films on crystalline silicon with an expensive technique such as Atomic Layer Deposition (ALD) and junction application towards silicon photovoltaics. However, just a few people pay attention to wide bandgap semiconductor hetero-junctions on silicon processed by a low cost technique such as spray pyrolysis. In the present work, intrinsic TiO_2 film as a transparent window layer, CdTe / CuO / SnS film as a absorber layer was deposited by spray pyrolysis on p-type Si, n-type Si substrate to form a hetero-junction solar cell. The films of various materials were deposited on silicon to fabricate hetero-junction solar cells and their photovoltaic performance was investigated.

2.Experimental

Titanium Oxide (TiO_2) thin films were prepared at 350p C by using the precursors of 0.1 M Titanium Tetra Iso Propoxide AR (TTIP) ($C_{12}H_{28}O_4Ti$) and 0.2 M Acetyl Acetone AR (AcAc) (CH_3-CO-CH_2-CO-CH3) (Sigma Aldrich) dissolved in absolute ethanol (C_2H_5OH). Cadmium Telluride (CdTe) thin films were prepared at 350p C by using the precursors of 0.01 M solution of Cadmium chloride and Tellurium oxide dissolved in a mixture of 1 part of ammonia solution and 4 parts of de-ionized water. In above prepared solution 1.5 ml of Hydrazine (mono) Hydrate and 1ml of HCl were added to get comprehensive solubility of precursors. Copper Oxide (CuO) thin films were prepared at 300p C by spraying a 0.01 M of Cupric acetate (monohydrate) dissolved in double distilled water. Tin sulfide (SnS) thin films were prepared at 270p C by spraying 0.01 M solution of Stannous chloride and Thiourea dissolved in de-ionized water. To achieve complete solubility of precursors, few drops of HCl were mixed in the above prepared solution. The TiO_2, CuO, CdTe and SnS films of thickness of around 100 nm were deposited in a multi cycle (5 s spray and 1 min pause) at a spray time of 20 s respectively on RCA cleaned polished p-silicon, n-silicon substrates of thickness 350 ìm, possessing a resistivity of 1-3 Ùcm which are maintained at a substrate temperature of 350ºC, 300ºC, 350ºC and 270ºC under optimum conditions [24]. Au-TiO_2, Au-Cu-CdTe, Au-CuO, Al-SnS contacts were made over films by coating desired metal through a mask with an area of 1.963 x $10^{-3}cm^2$ using Anelva SPF-332H make sputtering unit. Aluminum films of thickness 150 nm were coated on the back surface of each silicon substrate using Hindhivac 15F6 make thermal evaporation unit. Film thickness was investigated using DekTak3 Profilometer and was found to vary from 55 - 125 nm. Fig. 1 shows the cross section of TiO_2/p-Si, CdTe/n-Si, CuO/n-Si, SnS/n-Si solar cell. Hetero-junction solar cells were fabricated using the configuration of Au (150nm,150^{0}C)/TiO_2(95nm)/p-Si/Al(150nm,150^{0}C), Au-Cu(130nm-8nm,150^{0}C)/CdTe(95nm)/nSi/Al(150nm,150^{0}C),

Au(150nm,150^{0}C)/CuO(125nm)/n-Si/Al(150nm,150^{0}C)and Al (150nm, 150^{0}C) /SnS (63 nm)/n-Si/Al(150nm,150^{0}C)

were prepared by spray pyrolysis technique and their cell properties have been studied.



Fig 1. Cross-section of Au/TiO_2/p-Si/Al, Au/CuO/n-Si/Al, Cu-Au/CdTe/n-Si/Al and Al/SnS/n-Si/Al hetero-junction solar cell.

3.Results and discussion

TiO_2, CdTe, CuO, SnS semiconducting films prepared by spray pyrolysis technique were characterized through SEM (Scanning Electron Microscope) and EDX (Energy Dispersive X-Ray). SEM imaging and chemical composition study was performed by using Raith –e- line. The nature of semiconducting property was studied by hot probe technique. Structural and electrical characterizations of the films were performed using XRD, AFM, Raman, PL, four probe techniques and reported elsewhere [25, 26, 27, 28, 29]

The cells having effective area of 0.176 cm^2 were illuminated with 150 W halogen lamp. The I-V characteristics were measured and plotted in fig. 2. The dark-light I-V characteristics of cells have shown excellent rectifying behavior of hetero junction solar cells. Fig.3 shows the I-V characteristics of the heterojunction solar cells under illumination of 206 mW/cm^2. The values of capacitance namely, C_{LF} and C_{HF} have been measured by 4155C semiconductor parametric analyzer. From these values of capacitance, interface states (N_{is}) has been calculated for all the samples and the values of N_{is} are given in Table-1.The total number of interface states due to depletion and interface can be calculated from the capacitance measured at low frequency while the capacitance at high frequency is associated with depletion only. A lower limit of interface states (N_{is}) can be calculated from the relation

$$N_{is} = \left(\frac{C_{LF} - C_{HF}}{e}\right) \quad (1)$$

Where C_{LF} and C_{HF} are the frequencies at low (50 Hz) and high (1KHz) frequencies respectively [30].

The estimated cell parameters using fig. 2 and 3 are shown in Table-2. In general, the cells have low short circuit currents (I_{sc}), low open circuit voltages (V_{OC}), small Fill Factors (FF) and consequently low efficiencies (eff). The diode factor 'n' of the cell was found to vary from 1.49 - 4.87, confirming that interface recombination is the dominant mechanism in these junctions. Another important factor which causes reduction in both V_{oc} and the fill factor is the low shunt resistance. The shunt resistance is small due perhaps to the recombination along the grains and the defects which are in large number in sprayed films [8]. The low values of V_{oc-} and FF thus result in low efficiencies of the cells. Au/CuO/n-Si/Al heterojunction solar cells were found to have slightly higher value of efficiency compared to other cells, which may be attributed to lower number of interface states, lower series resistance and considerably higher shunt resistance. The light response of Al/SnS/n-Si/Al solar cell is reasonably good however other cell parameters

Table1: Calculated values of interfacial states for hetero-junction solar cells.

Hetero junction solar cell	C_{LF}nF	C_{HF}nF	$N_{is}10^{10}$Fcm^{-2}eV^{-1}
TiO_2/ p-Si	15.5	7.91	26.95
CdTe / n-Si	7.74	5.84.	6.747
CuO / n-Si	7.43	5.81	5.752
SnS / n-Si	-	-	-

are negligible as a consequence of higher series and shunt resistance. The heat treatment process of the semiconductor film coated Si substrate seriously influences the photovoltaic properties due to the change of the surface state of Si substrate by oxidation and contamination [31]. It is also observed that the cell parameters such as V_{OC}, I_{sc}, values found to be lower and series resistance is higher in case of silicon based TiO_2, CdTe, SnS solar cells as compared to CuO cells as a result of higher sheet resistance.

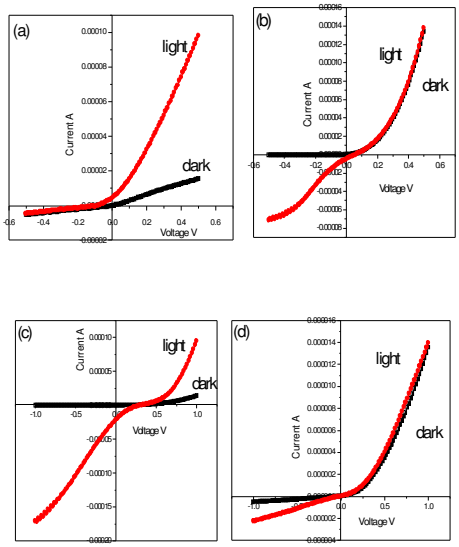


Fig. 2. Dark- light I-V characteristics showing rectifying behavior of hetero-junction solar cells namelyAu/TiO_2/pSi/Al, (b) Au-Cu/CdTe/ nSi/Al, (c) Au/CuO/nSi/Al and (d)Al/SnS/nSi/Al.

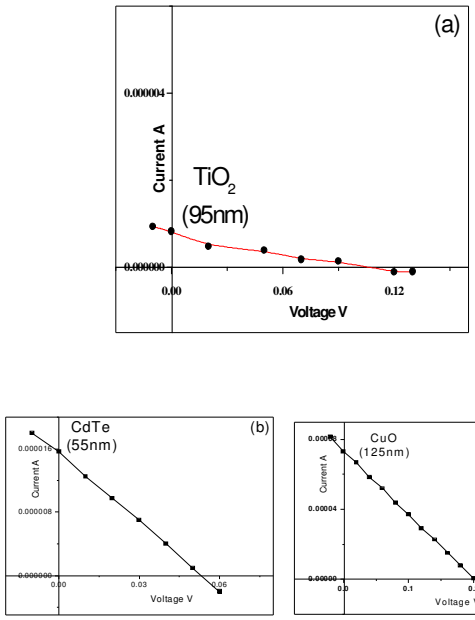


Fig. 3. I-V characteristics of the heterojunction solar cells [(a),(b) & (c) with active area of (1.085-1.985 cm^{-2}) under 206 mW/cm^2 illumination]

resistivity in sprayed films. Better cell parameters may be further obtained by improving the quality of sprayed films, varying the window or absorber thickness, reducing the resistivity of films either by annealing in air or vacuum, N_2, H_2, doping and also by adjusting spray parameters.

Table 2 Performance results of solar cells prepared by spray-deposition.

Hetero-junction solar cell	R_{Series} (Dark) K&Ω	R_{Series} (Light) K&Ω	R_{Shunt} KΩ	V_m mV	I_m 10^{-7} A/cm^2	V_{oc} mV	I_{sc} 10^{-7} A/cm^2	FF%	Eff 10^{-3}%
TiO_2 (95nm) p-Si	45.806	12.10	80.676	48.4	2.62	105.9	5.030	23.84	0.0616
CdTe (55nm) / n-Si	0.420	0.4156	3.4	27	51.6	53	101	26.12	0.676
CuO(125nm) /n-Si	0.341	0.3359	3.67	100	323	200	673	23.97	15.6
SnS (63nm) /n-Si	62.12	16.66	-	-	-	-	-	-	-

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