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Potential of Graphene as TCO for Photovoltaic Application

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***Abstract*—**The main impediment faced by solar Photo-Voltaic Cell (PVC) is the excitation of charge carriers by high and low energy photons to make them reach the conduction band. The latter energy photons are the ones that contribute very small amount to the device current while the former transport more energy than required to excite an electron, this extra energy results in heating of cell. To enhance the device current use of Transparent Conducting Oxides (TCOs) is the best option as electrodes for optoelectronics application such as LEDs, LCDs, touch screens and solar cellsowing to its good electrical conductivity and optical transparency. Forthwith devices use indium tin oxide(ITO) as a TCO layer. However, its high toxicity and increase rarefication and high price demands alternative TCO. In This research paper Graphene is used as an ultrathin TCO layer as electrode as an alternative for the usual ITO electrode for amorphous silicon-based solar cells. The research determines that graphene, in a suitable multilayer structure with anti-reflecting properties, can enhance or at least compete with the absorption of an ITO electrode, for an amorphous silicon active layer with various thicknesses.

Keywords*-Graphene, Transparent Conducting Oxides, Indium Tin Oxide, SILVACO-Atlas*

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I. INTRODUCTION *(HEADING 1)*

Solar PVC is a solid-state (p-n junction) electrical device [1] that converts the energy of light (photons) directly into electricity (DC) using photovoltaic effect. This process requires materials having high absorption coefficient to excite electrons (exciton) to higher energy state leading to current generation. Solar PVC [2] structure is shown in Fig-1 encapsulating a number of layers from the light-facing Transparent Conducting Oxide(TCO) side to the dark back –reflector as given under.

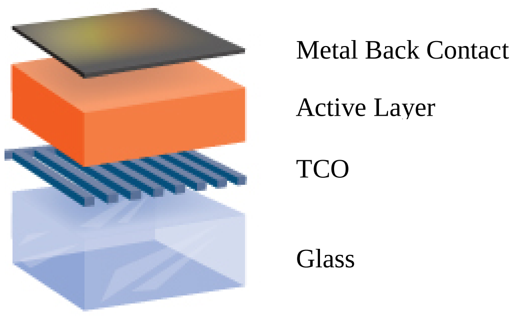

Figure 1. Solar PVC structure

For the better spectral response rate the front layer of solar PVC is stacked as aTransparent conducting Oxide (TCO) layer.The ideal TCO should be fully transparent (with transmittance>80%) forabsorbing wide range of wavelengths, as well as have metal-like conduction properties. Most common TCE used today are based on doped metal oxides, such as ITO. However, the relatively high cost, limited optoelectronic performance, and mechanical brittleness exclude ITO from many applications.

Recently, research progress in nanomaterials [4] has opened new areas for alternative TCO as Graphene. This single layer of atom of carbon hexagon called Graphene [5] is seeking a lot of attention of researches because of its uniqueness and nonpareil properties. These exceptional electronic qualities and the outstanding electron/hole-transport properties of individual graphene crystallites have successfully attracted photovoltaic researchers to replace the existing materials in numerous ways (as TCO/blocking layer/hole transport layer/ electron transport layer). Table-1 shows the comparative study between ITO and graphene CVD films.

TABLE I. COMPARISON OF GRAPHENE THIN FILM WITH ITO

	ITO	***Graphene CVD Film***
Sheet Resistance(Ω/sq)	10-350	200-2000
Transmittance(%)	88	>90
Flexibility	Inferior	Good
Cost	High($2-120 /m2)	Very High($10,000 /m2)
Commercial Process	High Volume	Lab Scale
Environmental Effects	Good	Good
colour	Slightly Yellow or Brown	Colorless
Key developers	American Elements,Diamond Coatings	Samsung ,Graphene Laboratories. Stanford,UT

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	ITO	*Graphene CVD Film*
		Austin
Drawbacks	Britttle and explosive	Extremely sensitive to defects and impurities

Graphene [6] withal to these properties exhibits high tensile strength due to which it can be successfully used with crystalline silicon (c-Si) based solar PVC [6-7].

In this research project, the electrical and optical potential of a graphene surface-covering oxide is investigated. This research examines its possibility as a transparent oxide for perovskite based solar cells. We determine that graphene [8] can enhance or at least compete with the absorption of an ITO electrode.

The paper is structured as follows. Section II reviews Graphene potential and its usefulness for solar PVC. In section III graphene as TCO layer is discussed by analysing various parameters. In Sec. IV, modelling and simulation of a-Si is done and comparative result in terms of absorbance of the active material with ITO/Graphene electrode is presented.

The next section gives an overview of literature survey and problem identification

II. LITERATURE SURVEY AND PROBLEM IDENTIFICATION

Wherever Times is specified, Times Roman or Times New Roman may be used. If neither is available on your word processor, please use the font closest in appearance to Times. Avoid using bit-mapped fonts if possible. True-Type 1 or Open Type fonts are preferred. Please embed symbol fonts, as well, for math, etc.

TABLE II. TABLE TYPE STYLES

S.No	*Authors name and Year*	*Proposal*	*Problem Identification*
1.	Towhid H.Chowdhary, Ashraful Islam et.al, 2016	This paper investigates the role of graphene in organic PVC and DSSC for transportation of carrier. The paper concludes Graphene as TCE alternative replacement of ITO/FTO layer for remarkableoptical transmittance.	•For large scale production, fabrication of single layer of graphene with controlled electrical and optical parameters is a challenge. •Absorption rate is not good •Efficiency can be enhanced
2.	Mohammad Mahdi Tavakoli, Rouhollah Tavakoli et. al., 2016	This paper uses Graphene in the form of scaffold as an interface layer between absorption layer and electron transfer layer in pervoskite solar cell. Reduced graphene scaffold (rGS) enhances the carrier transportation and shows 27% increase in the performance as compare to conventional solar cells.	•Use of ZnO and TiO2 shows only 10% improvement in the performance of the cell. •Better alternatives needed to increase overall cell efficiency
3.	Mn-Ning Lu, Chin-Yu Chang, Tzu-Chien Wei, Jeng-Yu Lin, 2016	In this paper Graphene is used as cathode material for Dye sensitized solar cell to provide high performance.	•The major disadvantage of graphene is its susceptibility to environment of oxidative as inferred in this paper.
4.	Yawei Kuang, Yushen Liu, Yulong Ma, 2015	The photovoltaic behaviour of graphene based GaAs junction solar cell on various parameters is studied in this paper. Graphene compatibility multi-junctions devices is also investigated.	•GaAs has high direct bandgap and is highly resistive to radiation so there is need to combine a material that is well suited with it for large scale applications. •The device incorporating is not able to provide high efficiency.
5.	Singh E., Nalwa H.S., 2015	Graphene in this paper is proposed in organic photovoltaic cell as counter electrode, ETL layer, HTL layer and electron blocking layer.	•Need to have environmental degradation and cost effective solution, graphene is being used in photovoltaic industry. •The performance of graphene largely depends on various parameters such as thickness, passivation and heteroatom doping.
6.	J.-Y. Lin, A.-L. Su, C.-Y. Chang, K.-C. Hung, and T.-W. Lin, 2015	With the help of electrophoretic deposition, a new hybrid material is being fabricated for dye sensitized solar cell by introducing MoS2/reduced graphene oxide (RGO) nanocomposites with carbon nanotubes (CNTs). The use of conductive network of CNT gives an extra access for transportation of electrons and increases the charge transfer rate.	•The structure with MoS2/RGO-CNTs achieves the efficiency of 7.46% as compared to costly PCE (7.23%). •The process of fabrication is complicated one.
7.	Santosh Kumar Ray, Rahul Kumar, Tapas Chakrabarti, 2015	The paper proposes a triple junction solar cell for better efficiency. This paper shows how to achieve higher efficiency 32.84% using Triple	•More exploration is required in selecting of materials and the modelled solar cell is to be fabricated in

S.No	Authors name and Year	Proposal	Problem Identification
		junction solar Cell.	physical lab and the efficiency of that physical lab should match with the simulated one.

III. GRAPHENE AS TCO LAYER

TCO's in solar PVC are highly transparent and conductive thin oxide layers. In consideration tostrong electrical conductivity and high transmittance of monolayer graphene sheet [9-10], theyareconsidered as potential candidates to replace TCOs. In today's scenario, graphene materials in transparent oxidesstill lack practical applications, especially in case of cryogenic-temperature substrates and thin film devices [11]. However, the research works by scientists have proposed future implementations of this materialas transparent oxides. The Fig.2 shows the schematic of proposed device[12].

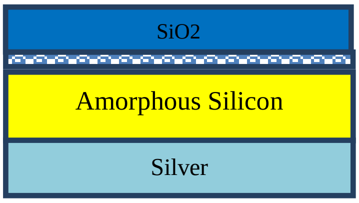


Figure 2. Graphene thin oxide layer with SiO2 anti reflective coating on a-Si absorptionlayer and silver as back reflector

IV. PREPARE YOUR PAPER BEFORE STYLING

The simulation parameters considered for modelling the device [13]are shown in following table.

TABLE III. SIMULATION PARAMETERS

Metal Oxide	a-Si	Graphene
Bandgap (eV)	1.7	0.026
Effective Density of States(Conduction band) (cm^{-3})	$3x10^{20}$	$3x10^{17}$
Effective Density of States(Valence band) (cm^{-3})	$3x10^{20}$	$3x10^{17}$
Electron mobility (cm^2/Vs)	1	10,000
Hole mobility (cm^2/Vs)	0.1	10,000

V. PERFORMANCE METRICS

The performance metrics of a Solar PVC [14-16]] can be well defined by parameters such as short circuit current density(Jsc),open circuit voltage(Voc), Fill Factor(FF) and power conversion efficiency(η)is done.

A. Short-Circuit Current

The short-circuit current (I_{SC}) is determined by the amount of photon flux is incident on the solar cell which in turn is estimated by the spectrum used.

B. Open-Circuit Voltage

The open-circuit voltage (V_{OC}) is a voltage that can be attained through a solar cell when the current through the external circuit is zero. This is the maximum voltage of a solar cell.
The open-circuit voltage is given by eq(1):

$$V_{OC} = \frac{\eta kT}{q} \ln\left(\frac{I_{SC}}{I_O} + 1\right) \quad (1)$$

C. Fill Factor

Fill factor is the ratio of the maximum power to the product of short-circuit current (ISC) and open-circuit voltage (VOC) represented in eq(2).

$$FF = \frac{P_{MAX}}{I_{SC} * V_{OC}} \quad (2)$$

D. Efficiency

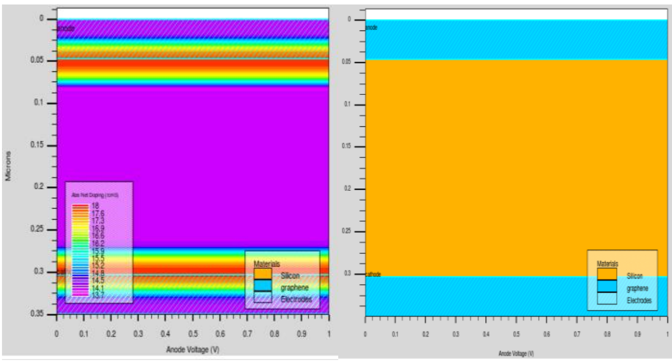
The efficiency determines the actual performance of a photovoltaic cell. The efficiency is the measure of the output power to the input power. Mathematically, efficiency is the ratio of maximum power delivered by the solar cell to the input power and is given by eq(3) and eq(4):

$$\eta = \frac{P_{MAX}}{P_{IN}} \quad (3)$$

$$\eta = \frac{V_{OC} I_{SC} FF}{P_{IN}} \quad (4)$$

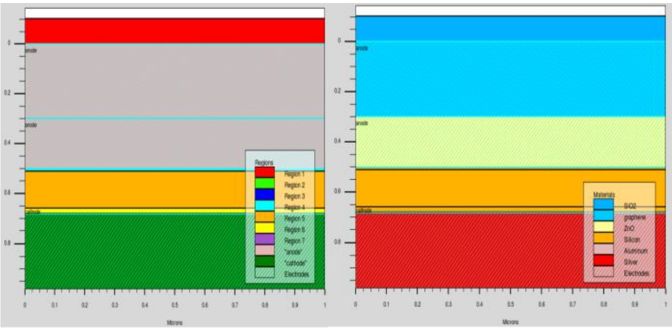
VI. RESULT AND SNAPSHOT

The snapshots represented from Fig.3-5 are the simulation result of device modelled on SILVACO-Atlas platform. The structural model and doping concentration of the device are illustrated in Fig.3.Fig.4 shows material wise and region wise specification of the device withI-V characteristics shown in Fig.5. The output parameters obtained by tonyplot are further extracted and enlisted in Table-IV. The srh and auger model are being used for simulation. This auger model is necessary at high current densities. It takes into account the direct transition of three carriers. SRH model used for simulation stands for Shockley-Read-Hall Model and is used for minority carrier lifetime and is used in most of the simulations[14-15].



(a) (b)

Figure 3. Doping concentration analysis of c-Si solar PVC (b)Structure showing graphene as electrode for c-Si solar PVC



(a) (b)

Figure 4. (a)Region wise specification a-Si thin film solarPVC (b)Materal wise specification of a-Si thin film solarPVC

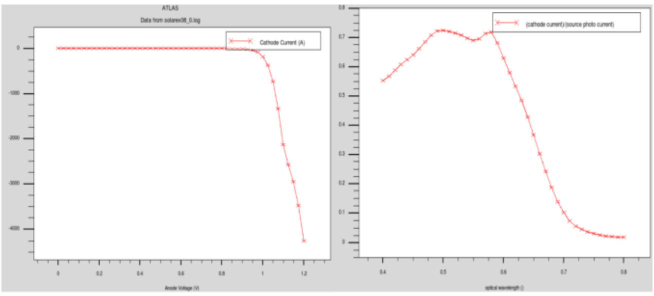


Figure 5. (a)Output characterization of a-Si thin film solarPVC (b)Optical characteristic of a-Si thin film solarPVC

TABLE IV. OUTPUT PARAMETERS OBTAINED BY THE SIMULATION

Performance Metrics	***Graphene(a-Si) thin film solar PVC***
Open circuit Voltage (Voc)	1.287
Short circuit current (mA/ cm^2)J_{sc}	10.19
Fill Factor FF	71.843
Efficiency(%)η	9.86

VII. CONCLUSION

With the increase in demand of energy the need of efficient and highly durable solar PVC stands as paramount fact. The advancement in solar industry and research work has come out with different proposal of improvement in cost and efficiency parameters. The thin film solar cells have found wide application in comparison to their counterpart conventional solar cells as they display high flexibility and low cost. This paper simulates graphene as TCO in a-Si solar cell and concludes that they competent to replace ITOin thin-film amorphous silicon photovoltaics.

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