Journal of Fundamental and Applied Sciences

ISSN 1112-9867

Available online at http://www.jfas.info

Research Article

LIGHT INTENSITY AND TEMPERATURE EFFECT ON THE DC PARAMETERS OF OPTIMIZED nc-3C-SiC:H BASED SOLAR CELL

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Received: 29 October 2020 / Accepted: 10 Febrery 2021 / Published online: 01 January 2022

ABSTRACT

The Hydrogenated nanocrystalline cubic silicon carbide (nc-3C-Si:H) based solar cell with interesting efficiency, find her place promoted in photovoltaic applications. To improve the sunlight absorption and its electrical performances, the structure of the solar cell can be optimized, combining new materials to form multi-layers solar cells. In this context, the nc-3C-SiC:H, having a wide band gap, excellent optical, electrical and structural properties is used as wide bandgap absorber layer. In this work, we report a theoretical study of new optimized nc-3C-SiC:H/ i-a-Si:H/ a-Si:H/ µc-Si solar cell using the SCAPS one dimension program. We investigate the temperature and incident light intensity effect on the DC parameters of the solar cell. For the proposed structure, optimal power conversion efficiency (PCE) of 16.89% is registered under AM1.5G spectrum at room temperature.

Keywords: Heterojunction solar cell, nc-3C-SiC: H, dc parameters, light intensity effect.

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doi: http://dx.doi.org/10.4314/jfas.v14i1.6

1. INTRODUCTION

The orientation towards new natural, durable, clean and renewable sources of energy has increased the demand on these sources and pushed the researchers and energy industrialists to improve the techniques of its exploitation. At the top of the pyramid of these sources, the solar energy is considered efficient and competitive to replace traditional sources. The solar cells are the devices capable to transform cleanly the light flux into electricity. The invention of the first solar cell (photocell) dating back to 1954 by Daryl Chapin and these colleagues Calvin Fuller and Gerald Pearson of the Bell laboratory. This photocell is based on silicon with a yield close to 6% [1]. Basing on this invention, the performance of solar cells keeps improving day to day. Nowadays, silicon solar cells technology remains the dominant type in the photovoltaic market above 90% [2]. The silicon technology brings together two main sectors: crystalline silicon (c-Si) and the thin-film (TF-Si) sector. In order to optimize the yield of this technology and minimize manufacturing costs, non-crystalline or amorphous hydrogenated silicon (a-Si: H) is incorporated to this technology either as an absorbent (photoactive) material [3] or as a passivation layer [4, 5].This technology is commonly called heterojunction with intrinsic thin layer (HIT). In general case, the silicon heterojunction (SHJ) solar cells use a c-Si absorber while the other components have a thin-film structure [6]. An intrinsic a-Si:H provides excellent passivation of c-Si surface [7] and then improve carrier selectivity [8]. Numerous research projects have been launched and funded to improve the power conversion efficiency of HIT solar cell. Recent work proves that the yield of the a-Si:H based cells reaches 25.91% under AM1.5G [9]. Other cells competing with HIT are the III-V semiconductors based multi-junction solar cells. In 2016, F. Dimroth et al. registered a record efficiency of 46,1%, under 312 times concentrated AM1.5d spectrum, for GaInP/GaAs//GaInAsP/GaInAs solar cell [10]. Despite the very encouraging conversion efficiency of HIT technology, it remains largely limited due to thinner absorbing layer and light degradation issue like the optical absorption loss in the infrared wavelength range [11]. Another practical limitation arises when operating cells in severe conditions and hostile environments under high temperatures and strong electromagnetic radiation. To overcome this limitation and build a large photon collection (absorption range), a good solution is to use wide bandgap semiconductors like silicon carbide (SiC). This material, with its multitude polytypes, has long been known for its potential properties and outstanding resistance to harsh environments, e.g., his thermal stability, good electron transport characteristics [12], radiation resistance, and dielectric strength.

2. OVERVIEW ON THE SiC BASED SOLAR CELL

Several theoretical and experimental works have underlined the excellent efficiency of the SiC based solar cell and many structures have been investigated [13, 14, 15, 16]. One of these structures is based on cubic-SiC polytype, commonly known 3C-SiC or β –SiC. This last is a very attractive material for intermediate-band solar cells that having the lowest gap among all the polytypes (2.2~ 2.36eV) and a deep impurity given by the boron acceptor level at ~0.7 eV above the valence band [17]. M. Toure et al. studied a structure based on cubic silicon carbide. It’s a bilayer solar cell of 3C-SiC on a silicon substrate with optimal PCE of 19.98% [15]. The properties of SiC/Si_xC_{1-x} solar cell has been also investigated by controlling the silicon and carbon content (stoechiometric coefficient) of the SiC. Then his band gap can be controlled [18, 19, 20]. When the silicon and carbon content increase the band gap increases also. In addition, for the amorphous SiC alloys, the C-H bonds are much more stable than the Si-H bonds which should have consequences for the thermal stability of the films with respect to hydrogen effusion [21]. The crystallography structure and electronic properties of μc-SiC:H for photovoltaic applications is also drew attention by many authors [22]. The use of SiC in solar cells, it's not a new thing, it has been studied for decades. The work of yoshihisa and Masataka Kondo, in 1981, underlined the use of the amorphous hydrogenated silicon carbide: a-SiC:H as a favorable window material for high efficiency a-Si pin solar cell [23]. Ming and these collaborators are experimentally studied the Low-Temperature Growth of a-SiC:H based solar cell to boost the conversion efficiency in an indoor lighting of 500 lx [24].

The amorphous SiC can be transformed to nano-crystalline SiC thin films by HWCVD technique without hydrogen dilution [25]. For the hydrogenated nanocrystalline cubic silicon carbide (nc-3C-SiC:H) is widely used as n-type emitter or p-type absorber layers in heterojunction crystalline silicon solar for. Furthermore, using a-SiC:H makes the capturing of the short wavelength possible and hence increased the *Voc* [26]. More recently, solar cell based on a-SiC: H have been studied. In this structure, the a-SiC:H has been incorporated in a-Si:H based p–i–n solar cells to improve his efficiency [27]. Proceeding from the importance of the silicon carbide, we propose in the in this work to study a heterojunction solar cell based on nc-3C-SiC: H, materials. The different layer properties, the solar cell design and its dc parameters will be discussed in the next section.

3. DESIGN AND PARAMETERS OF THE PROPOSED SOLAR CELL

The proposal nc-SiC:H based solar cell has designed as shown in figure 1. It's a stack of five layers where a nanometer thick nc-3C-SiC: H is used as an active absorber material (window for incident light). The front contact (TCO) is based on thin conductive oxide Sn02: F to reduce the reflection losses. We take note that the choice of TCO and its electrical and optical properties is not only important for electrical contact but only for efficient light trapping trough the device. Therefore, to increase the PCE of the solar cell and for better long wavelength response, a non-doped a-Si:H (intrinsic) is inserted as intermediate absorber layer. The goal of insertion of this intrinsic layer is to ensure an excellent separation of the carriers into free charges due to the electric field at the p-n junction. This layer is incorporated between the P-type nanocrystalline-3C-SiC: H and N-type a-Si:H layers. As we know, the SCR region extends on the weakly doped side, thus it extends on the intrinsic region and enables a maximum electron-hole pairs to be deeply generated within the device. In addition, reducing the intrinsic layer thickness; provide an excellent improvement of the solar cell efficiency. The important physical parameters, associated for each layer, reported in literature are given in table1.

Table 1. The important physical parameters of the layers

Layers/parameters	**P-type nc-3C-SiC:H**	**Undoped a-Si:H**	**N-Type a-Si:H**	**N-μc-Si**
Eg (eV)	2.2	1.8	1.8	1.2
Electron Affinity	3.51	3.9	3.9	4.5
ε_r	9.7	11.9	11.9	10
CB effective density of states (1/cm^3	4.0E+20	1.0E+20	1.0E+20	1.0E+19

VB effective density of states (1/cm^{3})	4.0E+20	1.0E+20	1.0E+20	1.0E+19
Electron thermal velocity (cm/s)	2.0E+7	1.0E+6	1.0E+6	1.0E+7
Hole thermal velocity (cm/s)	1.5E+7	1.0E+6	1.0E+6	1.0E+7
Electron mobility (cm²/Vs)	3.0E-1	20	20	50
Hole mobility (cm²/Vs)	3.0E-3	5.0	5.0	50
N_D (cm^{-3})	1.0E+19	1.0E+10	1.0E+17	1.0E+18
N_A (cm^{-3})	10	1.0E+10	1.0E+6	10

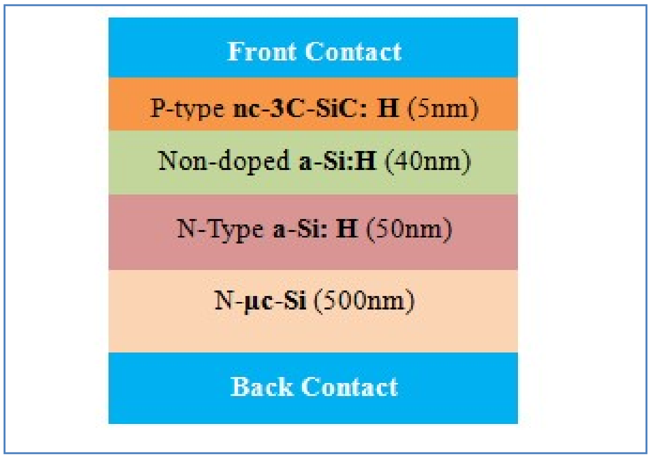

Fig.1. The solar cell designs

4. RESULTS AND DISCUSSION

The impact of temperature and incident light intensity on the dc parameters of the solar cells has been studied using SCAPS-1D program. Under three different temperatures: 273K, 300K and 318K, the main dc parameters Vco, Jsc, FF and PCE, are extracted for incident light intensities ranging from 1 to 100% for two spectra AM1.5G (1000W/m^2) and AM1.5D (1000W/m^2). The curves below give the evolution of these parameters under the considered conditions. According to these curves, for low incident spectra, the J_{sc} curves are almost identical. When intensity increases more electron-hole pairs are generated and Jsc about 31.441 mA/cm^2 is obtained for AM1.5G spectra and temperature of 318K.

On the other hand, the open circuit voltage is largely affected by the temperature variation and is more important for low temperature. Under AM1.5G spectra, the Vco increases from 0.7259 to 0.8399 V. For the same considered temperature, its characteristics present a little difference about 2mV between the two spectra. In another side, the effect of light intensity remains more important on V_{co}, FF and PCE than for J_{sc}.

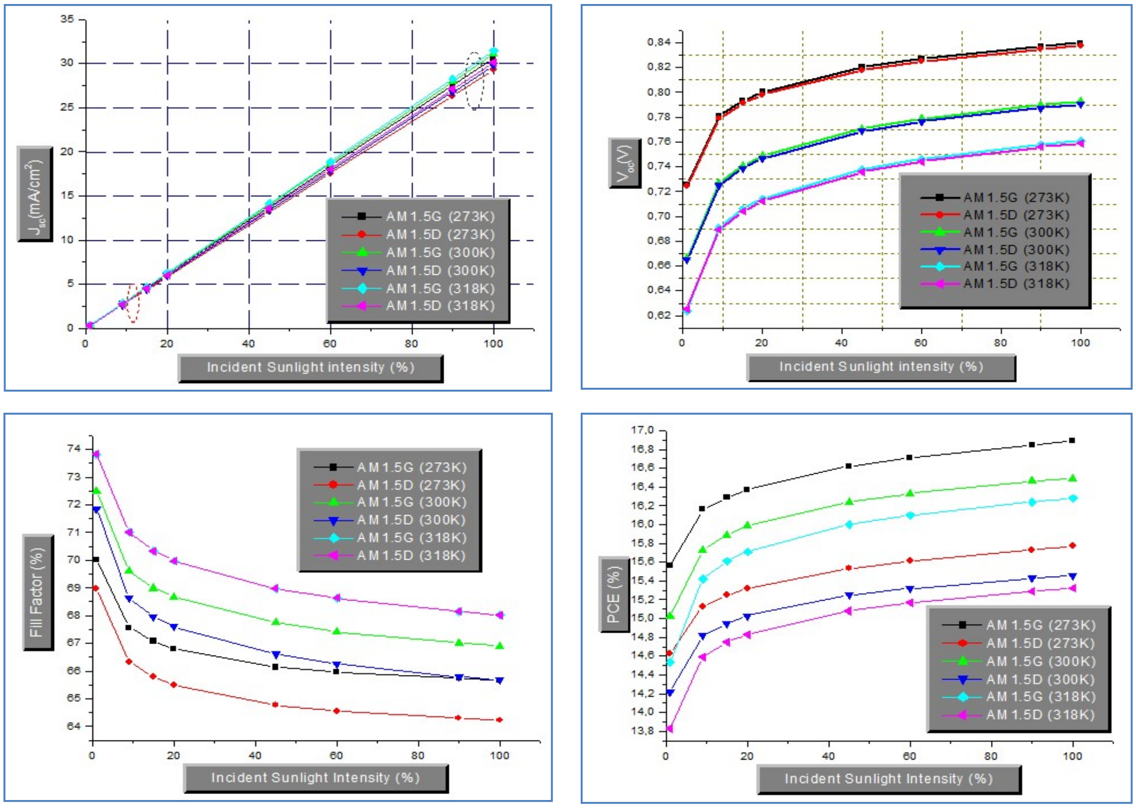

Fig.2. The dc parameters evolution under different incident sunlight intensity and temperature: a) open circuit voltage Vco, b) short circuit current Jsc, c) fill factor FF and d) power conversion efficiency PCE.

The temperature increases promote also the thermal agitation which induces the fall of the PCE of the solar cell. An optimal PCE equal to 16.89% is achieved under the standard sunlight AM 1.5G spectra and temperature equal to 273K. Compared to other studies on the a-SiC:H solar cell [14, 19, 28, 29, 30], the obtained dc parameter are judged encouraging. Also, optimizing the physical and structural properties of the solar cell like: the type of front and back TCO, the doping concentration, the defect density in a-3C-SiC:H, the layers thickness and others, the PCE can be improved.

5. CONCLUSION

Regarding the many recent works available in the literature, the SiC material attracts more attention for photovoltaic application. In this paper we carried out a theoretical study of the dc parameters of a new optimized solar cell structure based on the amorphous 3C-SiC:H. This study has been performed using SCAPS-1D program. The dc parameters of the solar cell are investigated considering two variable factors: temperature and light intensity of two spectrums AM1.5G and AM1.5D. According to the obtained results, it has been demonstrated that an enhancement of the Vco and Jsc is registered under the light intensity increase. At the same time, the temperature effect remains noticeable. The optimal achieved PCE is equal to 16.89%. The PCE of SiC based multilayer solar cells remains fundamentally linked to the quality of the SiC material and interface deposition. For more understanding of SiC-based solar cells, the presented results herein could be a useful adding to the previous studies. Nevertheless, the optimization of all dc parameters of the studied solar cell is proposed in other future studies.

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How to cite this article:
Belhadji Y. Light intensity and temperature effect on the dc parameters of optimized nc-3c-sic:h based solar cell. J. Fundam. Appl. Sci., 2022, *14(1), 107-115.*