

Simulation of HIT solar cells with $\mu\text{c-3C-SiC:H}$ emitter

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To obtain higher conversion efficiency for HIT (Heterojunction with Intrinsic Thin film) solar cells, an effective way is to use $\mu\text{c-3C-SiC:H}$ with a wide bandgap as the cell emitter. In this paper, a simulation study is carried out for the HIT solar cells with $\mu\text{c-3C-SiC:H}$ emitter. The performance of solar cells with $\mu\text{c-3C-SiC:H}$ emitter is compared with that of solar cells with a-Si:H emitter. For a 10 nm-thickness emitter, the cell efficiency can realize an increase of above 1.0% for the use of $\mu\text{c-3C-SiC:H}$. The main cause for the improvement is the reduction of optical loss in short-wavelength region.

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1. Introduction

Heterojunction crystalline silicon (c-Si) solar cells have been intensively investigated as a new alternative to conventional c-Si solar cells. Recently, SANYO company has developed the so-called HIT solar cells where the conventionally used silicon emitter has been replaced by a a-Si:H emitter fabricated at a temperature less than 300 °C and a very thin intrinsic a-Si:H film has been introduced between the doped a-Si:H film and the c-Si substrate with the purpose of passivating the c-Si surface [1-7]. The low-temperature fabrication process prevents the property degradation of the c-Si substrate that is usually observed in high-temperature process, and make it possible using low-quality c-Si substrates to reduce the device cost efficiently [3,6]. In addition, HIT solar cells exhibit a better temperature coefficient than that of conventional c-Si solar cells, which means higher performance under outdoor conditions for the same conversion efficiency [3,5,6]. In the HIT cells, some approaches, such as surface texturing, c-Si surface cleaning, finer width of grid electrode, and high quality intrinsic a-Si:H deposition, etc., have been performed to maximize the cell efficiency [6-10].

One of challenges to the development of higher-efficiency HIT solar cells is the optical loss in short-wavelength region caused by the absorption of a-Si:H due to its high absorption coefficient [6]. SANYO also reported that the internal quantum efficiency (IQE) of the HIT solar cell deteriorated in wavelength regions lower than 700 nm because of the absorption loss in the a-Si:H emitter layer [3]. In the past years, the optical absorption loss in the a-Si:H emitter layer has been certainly improved by SANYO. So, the short-circuit current (J_{sc}) increased from 38.93 mA/cm² in 2007 to 39.52 mA/cm² in 2009, and their record for the world's highest energy conversion efficiency (η) increased from 22.3% to 23.0%

for a practical size of 100.4 cm² [7,11]. Although some reductions of the optical loss in short-wavelength region are implemented, there may be a room for higher J_{sc} by further improving the emitter of the HIT cell. Thus, a new candidate material can be proposed to replace a-Si:H as an emitter in the HIT solar cell. Hydrogenated microcrystalline cubic silicon carbide ($\mu\text{c-3C-SiC:H}$) thin film is a promising one as an emitter of the HIT solar cell. The advantage of using $\mu\text{c-3C-SiC:H}$ as the emitter is its low absorption coefficient and wide bandgap (2.2 eV) while retaining its high conductivity [12,13]. In addition, $\mu\text{c-3C-SiC:H}$ thin films can be deposited at a low substrate temperature (about 300 °C), which indicated that $\mu\text{c-3C-SiC:H}$ and a-Si:H thin films can be conveniently fabricated in one deposition system with different chambers [13,14]. However, there have been few reports on its application in heterojunction c-Si solar cells.

In this paper, we present a simulation study on HIT solar cells with $\mu\text{c-3C-SiC:H}$ emitter. The cell performance influence of using $\mu\text{c-3C-SiC:H}$ emitter in comparison with a-Si:H one is discussed. The cause of enhancing the cell performance utilizing $\mu\text{c-3C-SiC:H}$ emitter is analyzed.

2. Methodologies

The computer simulation software, One-Dimensional Device Simulation Program for the Analysis of Microelectronic and Photonic Structures (AMPS-1D) [15], is used for the solar cell simulation. AMPS-1D can provide a convenient way to evaluate the role of the various materials and parameters presented in the solar cells. The simulation method of the program is based on Poisson equation, the hole and electron continuity equations. Fig. 1 illustrates a schematic structure of the HIT solar cell in this study.

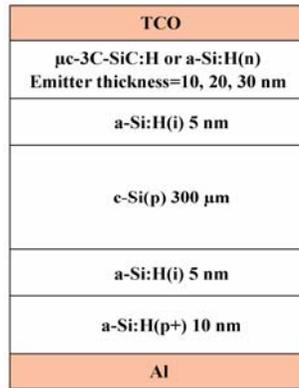


Fig. 1. Schematic structure of the HIT solar cell in the simulation.

In this simulation, the material parameters employed as the inputs are taken from the references [14,16-18]. The basic semiconductor properties of a-Si:H, $\mu\text{c-3C-SiC:H}$ and c-Si layers for the simulation are shown in Table 1. The surface recombination velocities of electrons and holes at the front and back contact interface are both set at 10^7cm/s . The simulated illumination is AM 1.5, 100mW/cm^2 . The light absorption coefficients of a-Si:H and $\mu\text{c-3C-SiC:H}$ are shown in Fig. 2. The absorption coefficient of $\mu\text{c-3C-SiC:H}$ was measured by our team. Our measured result is in good agreement with that in literature [19]. The absorption coefficient of a-Si:H is obtained from AMPS-1D and AFORS-HET program [20].

Table 1. Parameter sets for the simulation of HIT solar cells.

Parameters and units	$\mu\text{c-3C-SiC:H(n)}$	a-Si:H(n)	a-Si:H(i)	a-Si:H(p ⁺)	c-Si(p)
Thickness (nm)	10, 20, 30	10, 20, 30	5	10	3×10^5
Electron affinity (eV)	4.00	3.80	3.80	3.80	4.05
Band gap (eV)	2.20	1.72	1.72	1.72	1.12
Relative dielectric constant	9.72	11.90	11.90	11.90	11.90
Effective conduction band density (cm^{-3})	1.5×10^{19}	2.50×10^{20}	2.50×10^{20}	2.50×10^{20}	2.80×10^{19}
Effective valence band density (cm^{-3})	1.2×10^{19}	2.50×10^{20}	2.50×10^{20}	2.50×10^{20}	1.04×10^{19}
Electron mobility ($\text{cm}^2\text{V}^{-1}\text{s}^{-1}$)	20	10	20	10	1350
Hole mobility ($\text{cm}^2\text{V}^{-1}\text{s}^{-1}$)	2	1	2	1	450
Donor concentration (cm^{-3})	3×10^{18}	1×10^{19}	0	0	0
Acceptor concentration (cm^{-3})	0	0	0	1×10^{19}	1×10^{16}
Band tail density of states ($\text{cm}^{-3}\text{eV}^{-1}$)	9×10^{19}	2×10^{21}	2×10^{21}	2×10^{21}	1×10^{14}
Characteristic energy for donors, acceptors (eV)	0.15, 0.15	0.05, 0.03	0.05, 0.03	0.05, 0.03	0.01, 0.01
Capture cross-section for donor states, e, h^a (cm^2)-Band tails	1×10^{-15} , 1×10^{-17}	1×10^{-15} , 1×10^{-17}	1×10^{-15} , 1×10^{-17}	1×10^{-15} , 1×10^{-17}	1×10^{-15} , 1×10^{-17}
Capture cross-section for acceptor states, e, h (cm^2)-Band tails	1×10^{-17} , 1×10^{-15}	1×10^{-17} , 1×10^{-15}	1×10^{-17} , 1×10^{-15}	1×10^{-17} , 1×10^{-15}	1×10^{-17} , 1×10^{-15}
Gaussian density of states (cm^{-3})	1×10^{18} , 1×10^{18}	9.5×10^{18} , 9.5×10^{18}	5×10^{16} , 5×10^{16}	3×10^{18} , 3×10^{18}	
Gaussian peak energy for donors, acceptor (eV)	1.5, 1.5	1.12, 1.02	1.12, 1.12	1.24, 1.24	
Standard deviation (eV)	0.45	0.15	0.15	0.15	
Capture cross-section for donor states, e, h (cm^2)-Midgap	1×10^{-14} , 1×10^{-15}	1×10^{-14} , 1×10^{-15}	1×10^{-14} , 1×10^{-15}	1×10^{-14} , 1×10^{-15}	
Capture cross-section for acceptor states, e, h (cm^2)-Midgap	1×10^{-15} , 1×10^{-14}	1×10^{-15} , 1×10^{-14}	1×10^{-15} , 1×10^{-14}	1×10^{-15} , 1×10^{-14}	
Midgap density of states in c-Si ($\text{cm}^{-3}\text{eV}^{-1}$)					1×10^{12}
Switch-over energy (eV)					0.56
Capture cross-section for donor states, e, h (cm^2)					1×10^{-14} , 1×10^{-15}
Capture cross-section for acceptor states, e, h (cm^2)					1×10^{-15} , 1×10^{-14}

^a e, h represents the electron and hole, respectively.

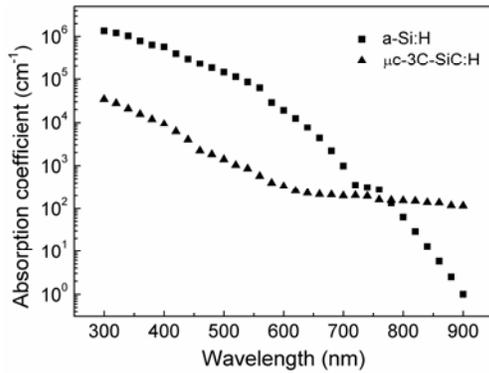


Fig. 2. Light absorption coefficients of $\mu\text{c-3C-SiC:H}$ and a-Si:H .

3. Results and discussion

It can be seen in Table 2 that J_{sc} is 40.13 mA/cm^2 and η is 25.95% when the thickness of $\mu\text{c-3C-SiC:H}$ emitter is 10 nm. While its thickness increases to be 20 nm or 30 nm, little influence is found for the cell performance. If a-Si:H is acted as the cell emitter, J_{sc} decreases to be 38.57 mA/cm^2 and η is reduced to be 24.85% by keeping 10 nm-thickness emitter. If the thickness of a-Si:H emitter is 30 nm, J_{sc} and η varies to be 36.04 mA/cm^2 and 23.07%, respectively. In other words, η will reduce by about 0.9% if the thickness of a-Si:H emitter increases by 10 nm.

Table 2. I - V parameters of HIT solar cells with $\mu\text{c-3C-SiC:H}$ and a-Si:H emitters, respectively.

Emitter materials	Emitter thicknesses (nm)	η (%)	J_{sc} (mA/cm^2)	V_{oc} (V)	FF
$\mu\text{c-3C-SiC:H}$	10	25.95	40.13	0.820	0.789
$\mu\text{c-3C-SiC:H}$	20	25.93	40.11	0.820	0.789
$\mu\text{c-3C-SiC:H}$	30	25.90	40.08	0.820	0.789
a-Si:H	10	24.85	38.57	0.818	0.788
a-Si:H	20	23.97	37.32	0.817	0.786
a-Si:H	30	23.07	36.04	0.816	0.786

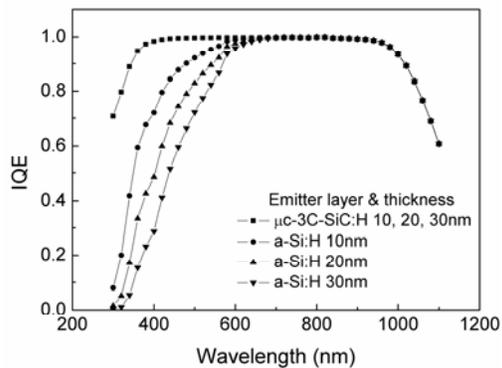


Fig. 3. Internal quantum efficiency (IQE) spectra of HIT solar cells with $\mu\text{c-3C-SiC:H}$ and a-Si:H emitters, respectively.

There are some differences for the efficiency with different emitters. When the thickness of the emitter is 10 nm, the efficiency with $\mu\text{c-3C-SiC:H}$ emitter is 1.10% higher than that with a-Si:H emitter. While the emitter thickness is 30 nm, there is an increase in efficiency of 2.83% in the case of that the $\mu\text{c-3C-SiC:H}$ emitter replaced a-Si:H one. This result indicates that the use of $\mu\text{c-3C-SiC:H}$ as an emitter can achieve a better performance for the HIT cell.

The effects of different emitters are attributed to their different optical absorption coefficients and band gaps which can determine the IQE of the cell. Fig. 3 shows the IQE spectra of HIT solar cells with $\mu\text{c-3C-SiC:H}$ or a-Si:H emitter for the different thicknesses. We can note that little absorption loss is found in short-wavelength region for the cell with $\mu\text{c-3C-SiC:H}$ emitter. While the large absorption loss in short-wavelength region is clearly observed for the cell with a-Si:H emitter. These results suggest that blue light response of the solar cells is significantly improved by using $\mu\text{c-3C-SiC:H}$ instead of a-Si:H , and $\mu\text{c-3C-SiC:H}$ is suitable for an emitter layer of heterojunction c-Si solar cells.

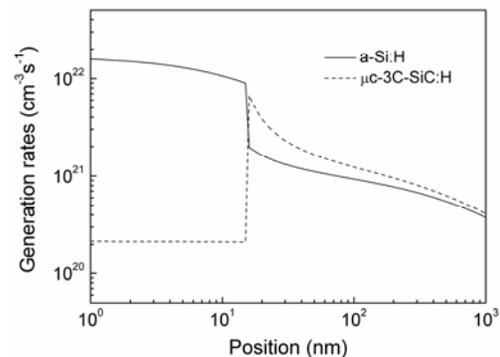


Fig. 4. Generation rates of photocarriers in the emitter region versus emitter position.

To further investigate above-mentioned phenomenon, we calculated the generation rates and recombination rates of photocarriers for the HIT cell as shown in Fig. 4 and Fig. 5. In Fig. 4, the generation rates of photocarriers in the $\mu\text{c-3C-SiC:H}$ emitter region are $2.1 \times 10^{20} \text{ cm}^{-3}\text{s}^{-1}$, while those in the a-Si:H emitter region reach $10^{22} \text{ cm}^{-3}\text{s}^{-1}$ orders of magnitude. As we know, the mobility of a-Si:H is very low and the doping concentration in the emitter is quite high, so it results in the fact that the collection efficiency of photocarriers in the emitter is very low. In fact, it can be seen in Fig. 5 that a lot of photocarriers in a-Si:H emitter region recombined. In contrast, due to the wide bandgap and low absorption of $\mu\text{c-3C-SiC:H}$, the generation rates in the $\mu\text{c-3C-SiC:H}$ emitter region are so little that it paves the way for the c-Si layer in the cell to absorb the incident photons most as depicted in Fig. 4.

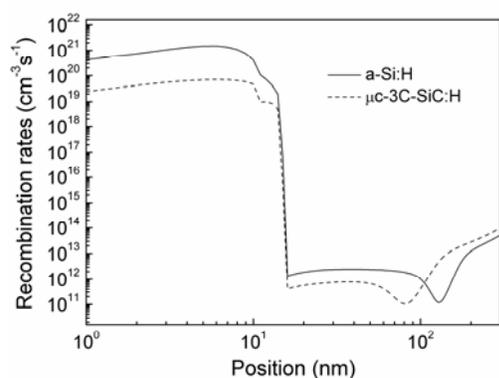


Fig. 5. Recombination rates of photocarriers in the emitter region versus emitter position.

4. Conclusions

The AMPS-1D simulation program has been used to simulate the HIT solar cells with $\mu\text{c-3C-SiC:H}$ emitter and to compare with that with a-Si:H emitter. The simulation results show that the cell efficiency is improved using a $\mu\text{c-3C-SiC:H}$ emitter. The origin of this improvement is the low absorption loss of the $\mu\text{c-3C-SiC:H}$ emitter in short-wavelength region. This indicates that $\mu\text{c-3C-SiC:H}$ is a promising material for the emitter of the HIT solar cells.

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