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بهبود جذب نور در سلول‌های خورشیدی آرایه‌ای نانوسیم سیلیکون کریستالی/سیلیکون بی‌شکل هسته-پوشش

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چکیده- در این مقاله، ویژگی های نوری سلول‌های خورشیدی نانوسیم هسته-پوشش با چینش افقی بهینه‌سازی شده است. ساختار بهینه از آرایه‌ای از نانوسیم‌های شش‌ضلعی غیریکنواخت تشکیل شده است. هر نانوسیم از یک لایه سیلیکون بی‌شکل تشکیل شده که بین لایه‌های سیلیکون کریستالی محصور می‌باشد. به منظور بهبود جذب نور و افزایش چگالی جریان اتصال کوتاه سلول خورشیدی، الگوریتم بهینه‌سازی ازدحام ذرات مورد استفاده قرار گرفته تا ابعاد هندسی نانوذرات بهینه گردد. در این مقاله نشان می‌دهیم که ساختار بهینه‌شده، کارآیی بهتری در زمینه جذب نور و چگالی جریان اتصال کوتاه دارد.

کلید واژه- جذب، سیلیکون بی شکل، سیلیکون کریستالی، نانوسیم‌های هسته-پوشش،

Absorption Improvement in Core-Shell c-Si/a-Si Nanowire Array Solar Cells

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Abstract- In this paper, the optical properties of laterally oriented core-shell nanowire silicon solar cells (NWSCs) are optimized. The optimum structure consists of an array with non-uniform hexagonal nanowires (NWs). Each NW is constructed from an amorphous silicon layer sandwiched between two crystalline silicon layers. In order to improve the light absorption and short circuit current density (*Jsc*) of NWSC, particle swarm optimization (PSO) algorithm is used to optimize the geometrical parameters of NWs. It is shown that the optimized structure has advantageous performance in terms of light absorption and *Jsc*.

Keywords: Absorption; Amorphous Silicon; Crystalline silicon; Core-Shell Nanowires;

1. Introduction

Semi-conducting Nanowires (NWs) have received growing interest in solar cells (SCs) applications, because of their unique optical properties including, high absorption [1]. NW is practically a low cost structure to design SCs; however, the primary challenge is to enhance the absorption and short circuit current density (J_{sc}) of nanowire solar cells (NWSCs). Crystalline silicon (c-Si) is the prominent material to design SCs [2]. However, amorphous silicon (a-Si) is considered as an effective material to increase the NWSCs absorption, due to its high absorption coefficient [3]. One of the amorphous silicon imperfections is low diffusion length (~100 nm) [1], which degrades the electrical properties of a-Si NWSCs. In order to overcome this limitation, the amorphous-crystalline silicon core/shell structures are simultaneously used to take the advantages of the a-Si high absorption and the high diffusion length (>200 µm) of c-Si [1]. In most studies based on the laterally oriented NWSCs, the attention was more paid to the single NWSCs [4]. In this paper, simulations are based on the NW arrays, considering the fact that the real NWSCs are more in compliance with the NW arrays [5].

One way to improve the absorption inside NWs is to design unusual cross-sectional geometries including, crescent-deformed [6], irregular [7] and gear-shaped NWs [8]. These nanostructures can achieve special modes that are not supported in usual NWs. As a result, the absorption and J_{sc} of the SC can be improved greatly. In the basis of the unusual structures, we show that non-uniform core-shell hexagonal NWs can accomplish broadband absorption with the proper design of different layers. Also, it is found that changing the cross-sectional geometry of NWs from a uniform shape to non-uniform, can adjust the absorption spectra and J_{sc} of the NWSC. In this paper, we have utilized this method for increasing the J_{sc} of core-shell c-Si/a-Si hexagonal NWs, as well.

2. Theoretical Model

The uniform three-layer hexagonal NW structure is shown in Fig. 1(a), where the middle layer of a-Si is utilized to enhance the absorption inside the NWSC. To avoid the low diffusion length of a-Si, the thickness of this layer is fixed to 20 nm [5]. In this case, the detrimental effects of a-Si on the electrical properties of NWSC are negligible. Since the position and the amplitude of the resonance modes in the NWs absorption spectra are highly dependent on the NW geometry and dimension [9], a non-uniform hexagonal structure is proposed. The effects of these changes on the absorption spectra and the J_{sc} of the NWSC are investigated and an optimization procedure is conducted to optimize the J_{sc} of NWSC. To compare the proposed scheme with thin film SCs, the total thicknesses of the all NWs are assumed to be 200 nm. In addition, the thickness of a-Si layer is set to 20 nm to mitigate the negative impacts of a-Si on the electrical properties of NWSC [5]. In order to simulate a practical case of the SC, arrays of these hexagonal NWs are placed on top of a sufficient thick layer of quartz [10]. The refractive index of c-Si and a-Si are taken from Ref [3] and the simulations are based on finite element method (FEM). In order to evaluate the proposed structure, the absorption spectrum is calculated for both TE and TM polarizations in uniform and non-uniform NWs. Then, assuming the unity of the internal quantum efficiency, the J_{sc} is calculated based on the following equation [11]:

$$J_{sc} = \int_{\lambda_1}^{\lambda_2} \frac{q\lambda}{hc} I(\lambda)A(\lambda)d\lambda \qquad (1)$$

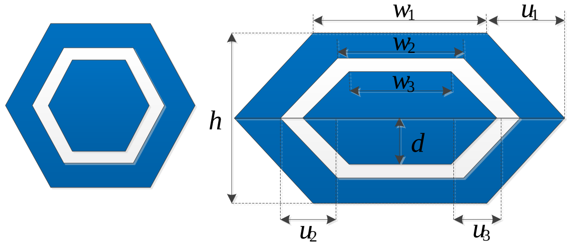

Fig. 1: Cross-sectional view of (a) uniform, (b) non-uniform NW.

where, q is the electron charge, λ is the radiation photon wavelength, h is the plank constant, and c is the light velocity. λ_1 and λ_2 are the minimum (280 nm) and the maximum wavelengths (1000 nm), respectively. $I(\lambda)$ is the standard radiation intensity of the sunlight spectrum on the earth that is equal to AM 1.5 and $A(\lambda)$ is the SCs absorption.

3. PSO Algorithm

PSO is a metaheuristic evolutionary algorithm that optimizes a problem by iteratively upgrading a candidate solution regarding to a certain measure of quality. This algorithm starts by initializing a population of random solutions called particles and changes these particles in the search space according to the determined processes. In Our simulations J_{SC} is used as the objective function and the structural dimensions are the particles to be optimized. More details on this method can be found in Ref. [12].

4. Results

J_{sc} of the uniform NWs is plotted in Fig. 2 as a function of a-Si layer position (d). The best value of the J_{sc} is obtained as 8.43 mA/cm^2, for d=35nm. However, when the a-Si layer is in the center of structure, the lowest value of the J_{sc} is obtained. There is 9.76% difference between maximum and minimum of J_{sc}. Therefore, optimization is very important. In order to improve the light absorption and J_{sc} of NWSC, particle swarm optimization (PSO) algorithm is applied to find the best geometrical parameters of non-uniform NWs. In this case, the variables are chosen to be d, w_1, w_2 and w_3. The absorption spectra of the optimized non-uniform structure is shown in Fig. 3 for both TE and TM polarizations and compared to the uniform NWSC with the same thickness of c-Si and a-Si layers. To have a justly comparison of proposed structure with thin film SCs, this film has the same thickness of a-Si, while the position of a-Si layer is optimized as well. The non-uniform NW arrays have the higher absorption for the most wavelengths, except for some lower wavelengths.

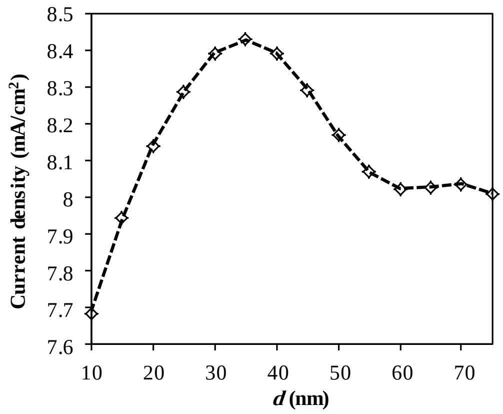

Fig. 2: J_{sc} of a uniform NWSC as a function of a-Si layer distance from the center.

In order to have a more detailed discussion on this feature, the sunlight intensity (AM 1.5) alongside the absorption spectra of the uniform and non-uniform arrays for TM polarization is shown in Fig. 4. The radiation intensity of the sun is dropped abruptly for the lower wavelengths. So, the absorption intensity for these wavelengths do not have considerable influence on the J_{sc} of the SC.

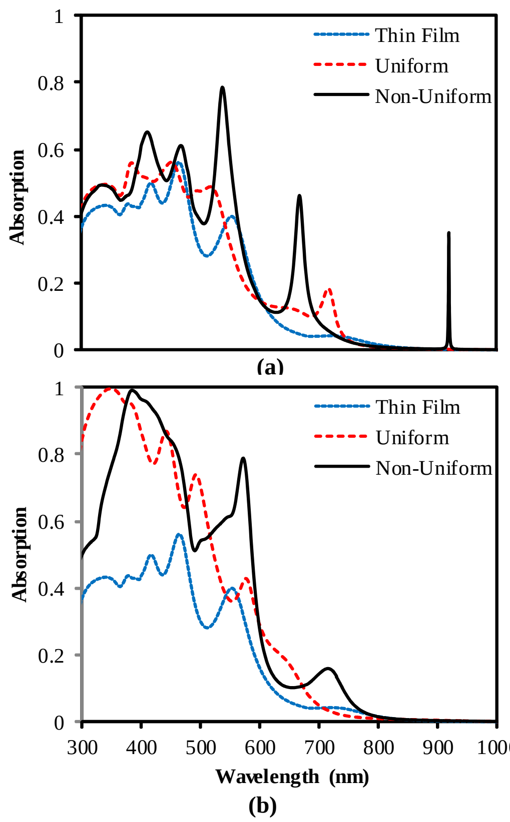

Fig. 3: Absorption spectra of uniform and non-uniform NWs as well as thin film SCs for (a) TE and (b) TM polarizations.

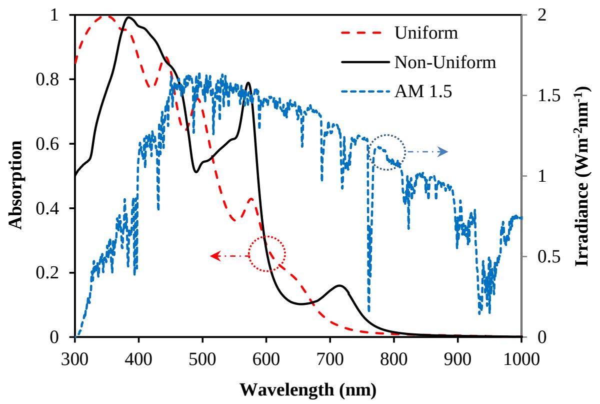

Fig. 4: Overlap figure of the absorption intensity and the radiation intensity of the sun spectrum (AM1.5).

Along the broadband absorption, a new resonance is generated in the wavelength of 919 nm, which shows the effect of the optimized design. The optimized parameters are displayed in Table I.

Table I. The optimized parameters.

Structure	Uniform	Nom-Uniform
d	35	55.08
w_1	141.42	144.12
w_2	77.78	123.20
w_3	49.50	95.52
u_1	70.71	72.06
u_2	38.89	61.60
u_3	24.75	47.76
J_{SC} (mA/cm^2)	8.32	9.278
Enhancement (%)	40.59	59.60

There is 19% increase in the *Jsc* compared to the optimized uniform Core-Shell c-Si/a-Si NWs. Also, for the non-uniform C-Si NWs and crescent-deformed solar cells, the optimized J_{SC} is 7.32 [7] and 7.94 mA/cm^2 [7], which are 27% and 17% lower than our proposed structure, respectively.

5. Conclusion

The light absorption of the non-uniform three-layer NWSCs is studied. Results shown that the proper design of non-uniform NW structures increases the absorption for the wide range of wavelengths and generates new resonance modes, as well. These effects can increase J_{sc} of the SCs, effectively. Using the optimal non-uniform NW structures resulted in 19% increase in the J_{sc} compared to the uniform structure with the same thickness.

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