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بررسی الکتریکی تأثیر لنز محدب بر روی پارامترهای اساسی سلول خورشیدی لایه نازک سیلیکونی

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چکیده- در این مقاله، عملکرد سلول خورشیدی همگون لایه نازک سیلیکونی در حضور لنز محدب که با چندین مرحله لایه‌نشانی و خوردگی شیمیایی ساخته شده، مورد بررسی و شبیه‌سازی قرار گرفته است. استفاده از لنز باعث متمرکز شدن نور تابشی در نزدیکی آند سلول خورشیدی شده و در نتیجه عملکرد سلول خورشیدی بهبود یافته است. پارامترهای اساسی سلول خورشیدی بر اساس تابعی از ضخامت لنز بررسی شده و شبیه سازی‌ها نشان می‌دهد که ضخامت لنز تأثیر قابل توجهی بر روی این پارامترها دارد. پارامترهای اساسی شامل چگالی جریان اتصال کوتاه، ولتاژ مدار باز و ضریب پرشوندگی به ترتیب تا مقادیر $۳۱/۵\ \mu A/cm^2$، $۰/۴۱۲V$ و ۰/۷۵۱۹ افزایش داشته اند.در ساختار پیشنهادی برای سلول خورشیدی در مقایسه باحالت بدون لنز، بازده تا ۳۰٪ افزایش داشته است. در بررسی‌های انجام شده مشاهده گردید که ضخامت $۸\mu m$ مقدار بهینه برای لنز می‌باشد و در این ضخامت، مشخصه‌های جریان-ولتاژ و بازده کوانتومی خارجی به ترتیب به بیش از ۵۰٪ و ۸۰٪ افزایش یافت.

کلید واژه- سلول خورشیدی سیلیکونی، سلول خورشیدی لایه نازک، لنز محدب، متمرکز کننده

Electrical Investigation of Plano-convex Lens Effect on Significant Parameters of Thin Film Silicon Solar cell

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Abstract- In this paper, the performance of a thin film silicon-based solar cell in presence of Plano-convex lens on its top is investigated and simulated by a TCAD tool. This structure consists of conventional thin-film silicon solar cell and a silicon dioxide Plano-convex lens which is constructed by deposition and chemical etching of silicon dioxide on top of solar cell. The lens concentrates the incident light closer to the solar cell's contacts; as a result, the performance of solar cell has been increased. Significant parameters of solar cells including short-circuit current, open-circuit voltage, Fill Factor and conversion efficiency are obtained as a function of lens thickness. Furthermore, the Dark/Illumination current ratio and External Quantum Efficiency (EQE) of a solar cell with and without lens are compared. Simulation results reveal that the lens thickness has a great impact on solar cell parameters and increases open-circuit voltage, short-circuit current and Fill Factor up to 0.412 V, 31.5 $\mu A/cm^2$ and 0.7519, respectively. In the proposed solar cell, efficiency is enhanced more than 30% from its original value. Considering different lens thicknesses, 8µm is the optimal thickness for the lens. I-V characteristics under illumination for two structures, with and without a lens, are also studied. According to the results, an incrementally current shift with an increase of 50% exists with respect to the second case. By applying a Plano-convex lens to the solar cell structure, EQE reaches the maximum value up to 80%.

Keywords: ***Plano-convex lens, thin film solar cell, silicon solar cell, concentrator***

1. Introduction

The menace of global warming and energy crisis necessitate searching for renewable and green energy resources. Of these alternative resources are geothermal, biomass, nuclear energy, wind power, the mechanical vibration energy in the end solar energy [1].

Since the sun is the most abundant renewable energy resource, solar photovoltaic (PV) systems are increasingly being used in many countries [2]. Among all the materials that have been used for solar cells, Silicon is well-known material which has evolved to be dominant raw material for photovoltaic devices. This is reflected by worldwide market share of solar cells based on multi or monocrystalline silicon wafer exceeding 80% [3].

Ultra-thin film (<5 μm) and thin film (<100 μm) crystalline Silicon solar cells are promising solutions for the issue of high production cost of solar cells [4]. Moreover, as solar cells approach their nominal efficiency and the high cost of PV modules, concentrating PV is used to concentrate sunlight to achieve a cost-effective solar energy.

Reduced total solar cell panel area, more efficiency at higher light concentration, increased and stable energy production throughout the day due to tracking, higher efficiency at direct-normal irradiance, very low energy payback time and less sensitivity to variations of semiconductor prices are some advantages of using concentrator photovoltaics(CPVs) modules [5-6].

Concentrators such as curved mirrors and optical lenses are applied to concentrate the incident light to the small area. Although concentrators boost the overall efficiency of the solar cells, there are few studies on the compact factory lenses with higher efficiency [7]. Lower cost and simple fabrication process and low absorption coefficient make SiO_2 an impressive option to fabricate Plano-convex lens.

In this paper, thin film Silicon solar cell has been simulated by TCAD tool. Open-circuit voltage (V_{OC}), short-circuit current density (J_{SC}), Fill Factor (FF) and Efficiency (η) as a function of SiO_2 Plano-convex lens thickness are investigated. Furthermore, the Dark/Illumination current ratio and External Quantum Efficiency (EQE) of the simple solar cell and optimal lens thickness are compared.

2. Method

As shown in Fig.1, a Boron-doped Silicon wafer is considered and the emitter is doped with implanting Phosphorus. Aluminium is utilized for both the front and the back contacts. Concentration-dependent S.R.H recombination, Auger recombination and generation, and Concentration-Dependent are regarded for the simulations.

In all simulations, as illustrated in Fig. 2, SiO_2 is considered as the lens material in which the thickness of the lens is an important parameter in solar efficiency (Fig. 2b).

3. Results and discussion

As the lens has a serious effect on the solar cell performance, preeminent parameters for different thicknesses of the lens are investigated. Fig. 3 demonstrates the influence of the lens thickness on the open-circuit voltage and short-circuit current.

Table 1: parameters of the solar cell

Device dimension	50μm×20μm
Anode contact dimension	5μm×0.2μm
Substrate doping concentration	1×10^{14} cm^{-3}
Emitter doping concentration	1×10^{15} cm^{-3}
Junction depth	400nm
incident beam power	AM.1
radiation angle	90°

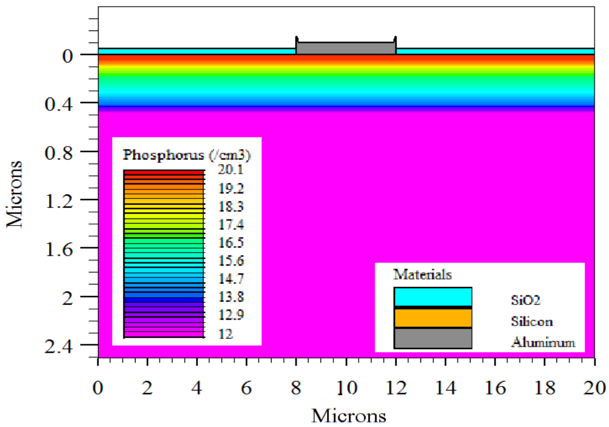
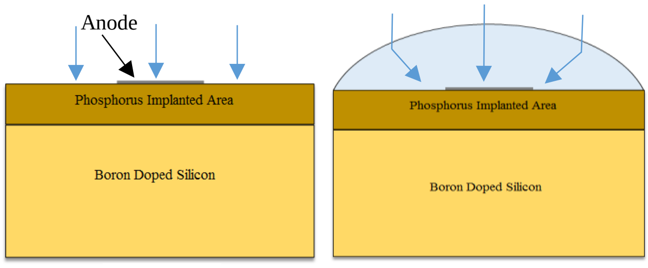
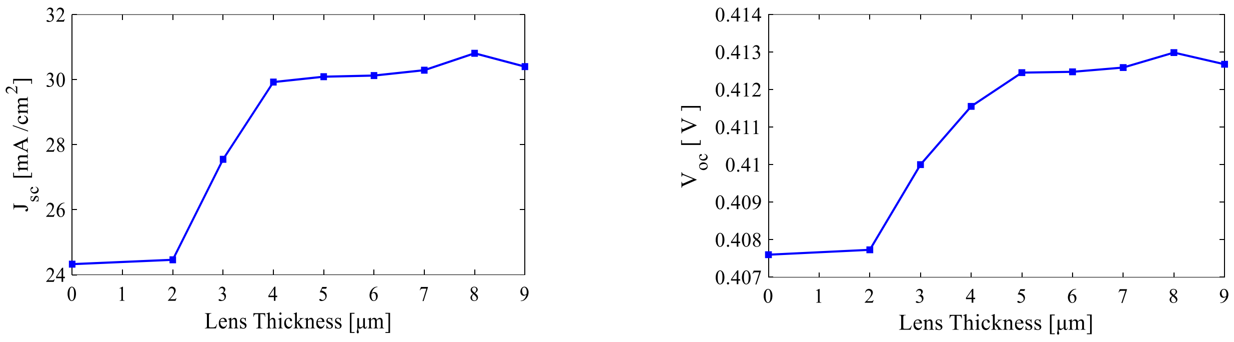


Figure 1: p-n junction depth of thin film silicon solar cell and impurity amount in each area



(a) (b)

Figure 2: (a) Thin film Silicon solar cell and (b) Silicon solar cell with a SiO_2 Plano-convex lens



(a) (b)

Figure 3: (a) Short-circuit current and (b) open-circuit voltage of solar cell versus lens thickness

As shown in Fig. 3a, a significant increase in the short circuit current is occurred by increasing the lens thickness above 2 µm. Since Plano-convex lens deflects the radiant light closer to the anode contact, photo generation rate is increased. In addition, the generated carriers near the contact have a shorter route to be collected. Thus, Plano-convex lens-based solar cells have a lower recombination rate compared to the conventional solar cells assuming an equal carrier lifetime. Consequently, it is expected to have a rise in the short-circuit current by increasing the lens thickness. Note that, as demonstrated in Fig. 3a, the maximum J_{SC} happens in the thickness of 8µm and a slight decrease in the current is observed for thicknesses above 8µm.

On the other hand, the open circuit voltage has a logarithmic relation with the light generated current of the solar cells. A slight change in V_{OC} can be seen from Fig 2b. The minimum and maximum voltages of 0.407 V and 0.412 V are achieved as shown in Fig. 3b for the proposed solar cell, respectively.

Obviously, the more power a solar cell can provide for the load, the better power performance will have the solar cell. Although V_{OC} and J_{SC} are maximum available voltage and current of solar cells respectively, their multiplication, which is called nominal power, is not a representative of the maximum transferable power from solar cells. Indeed, the knee point in the I-V characteristics demonstrates the maximum power point. An appropriate figure of merit to assess the performance of the cells from this point of view is widely known as the Fill Factor.

FF is the ratio of the maximum power to the nominal power and as it is aforementioned, there is an increase in the nominal power of the proposed solar cell due to the increase in the lens thickness. Since FF is almost constant for all lens thicknesses in Fig.4, it can be concluded that the maximum transferable power is increased almost with the same proportion as nominal power.

As the efficiency of solar cells is the most important parameter for performance comparison, the convention efficiency has been calculated. Due to increase in the lens thickness of the solar cell, the maximum transferable power of solar cell had been raised. Thus, by assuming equal incident power for solar cells, the total convention efficiency has been increased. Fig. 4 illustrates that convention efficiency of Plano-convex solar cell reached 7.26%, which represents over 26.5% enhancement of convention efficiency in comparison with a simple solar cell with an efficiency of 5.6%.

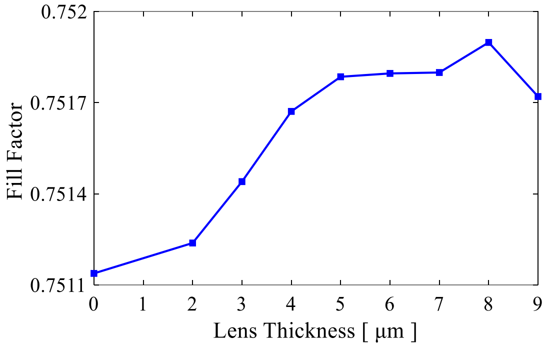


Figure 4: Fill Factor of thin film silicon based solar as a function of Plano-convex Lens thickness

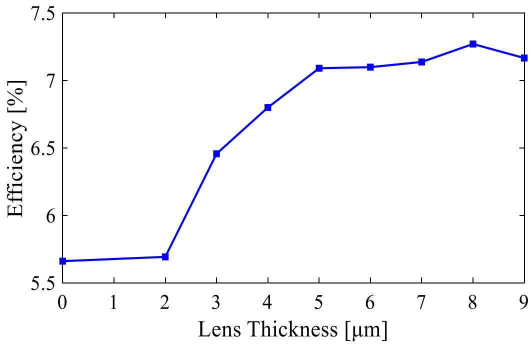


Figure 5: Efficiency of solar cell as a function of Plano-convex Lens thickness

Optimum thickness of Plano-convex lens for the maximum values of efficiency, short circuit current, and open circuit voltage is 8µm. These values are summarized and compared with the simple solar cell in Table 2. External Quantum efficiency is another crucial parameters that are defined as available current divided by I_{Source} which are the amount of photon absorbed by the device expressed by current density and the amount of current generated by the light source, respectively. [8]

It is reported that a compact cylindrical lens array utilizing Epoxy resin polymer (ERP) on multi-crystalline Silicon (mc-Si) with optimum lens thickness of 3.75 mm has an efficiency of 22.46% [7]. A summary and comparison with this work is presented in Table 2.

Tabel.2: Significant parameters of proposed structure with and without lens and comparing with mc-Si solar cell in [7]

	Simple solar cell	Solar cell with 8µm lens	mc-Si solar cell without ERP lens [7]	mc-Si solar cell with ERP lens [7]
J_{SC} [mA/cm^2]	24.33	31.5	42.41	45.27
V_{OC} [V]	0.407	0.412	0.615	0.615
FF	0.7751	0.7759	80.98	80.66
Efficiency (%)	5.6	7.26	21.12	22.46

Hence, the EQE is an excellent parameter to perceive a recombination rate in a device. Fig. 6 demonstrates an external quantum efficiency in simple solar cell and Solar cell with 8µm thickness lens. The EQE has a large increase in the amount by applying 8µm thickness lens. Therefore, it can be concluded that adding the lens to the structure causes a reduction of the recombining rate.

It can be obtained from Fig. 5 that there is an impressive growth in the external quantum efficiency between 300-900 nm wavelengths for 1 W/cm^2 intensity in a solar cell with the lens in comparison with the simple solar cell.

The dark and illumination currents of solar cells are illustrated in Fig. 7. As seen, the dark current of both considered solar cells has an equal amount at all cathode voltages because the internal structure of the solar cell would not change. However, the illumination current diagrams are considerably different as a result of decreasing in recombination ratio by adding lens on the solar cell structure. Illumination current of a solar cell with lens achieves up to 6.1 nA and it has an over 26.6% amplification of the amount comparing with simple solar cell.

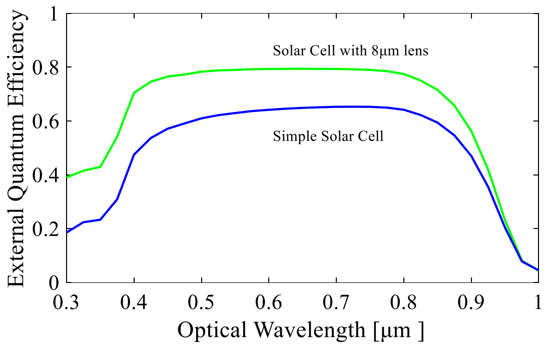


Figure 6: impact of the lens with a thickness of 8µm on solar cell's External Quantum Efficiency compared with simple solar cell

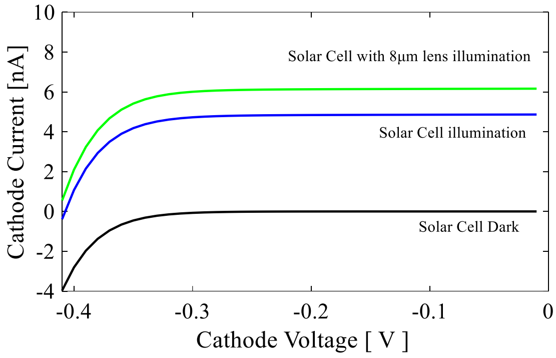


Figure 7: comparison of Dark and Illumination I-V curves for solar cell with 8µm thickness with simple solar cell

4. Conclusion

The effect of silicon oxide compact factory Plano-convex lens on thin film Silicon based solar cell is investigated. Different thicknesses of the lens on solar cell are studied and the results show optimum thickness is 8µm while open-circuit voltage, Short-circuit current, Fill Factor and efficiency are increased 0.412 V, 31.5µA/cm2, 0.7519 and 7.4% respectively.

Moreover, cathode current-cathode voltage diagram is investigated in CPV and compared with bare solar cell. Results reveal that the illumination current increases substantially while the SiO_2 lens is utilized on solar cell. Furthermore, External Quantum Efficiency is raised from 60% to 80%.

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