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SOFT LITHOGRAPHY FOR CONCENTRATOR PHOTOVOLTAIC CPV-SYSTEM'S APPLICATION

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ABSTRACT
Soft lithography refers to a series of fabricating techniques for replicating structures using "elastomeric stamps, molds, and conformable photo masks. In this paper, we have fabricated an array of micro-scale PMMA/SiO$_2$ Fresnel lenses CPV-system for high efficiency crystalline silicon solar cells(Si-Solar cells). Fresnel rings units containing eleven concentric rings having maximum diameter of$45.24\mu m$ were created on PMMA layer. The resulting CPV-system when placed on the surface of Si-Solar cells increased the open circuit voltageV_{OC} by 17.9mV, short current I_{SC} by 31.22mA and the maximum power P_{max} by 11.42mW. Meanwhile, this system enhanced power conversion efficiency of Si-Solar cells by 3.54% and decreased the series resistance R_s of Si-Solar cells by 0.81Ω.
Keywords: Micro-Fresnel lens,Photovoltaic, Solar cells, PMMA, PDMS.

INTRODUCTION

The spectral response of Si-Solar cells is critically dependent on the number of incident photons absorbed especially from far infrared to the red-end region of visible light(N. L. Chiromawa & K. Ibrahim, 2015b; N. L. Chiromawa & Ibrahim, 2014; N. L. Chiromawa & K. Ibrahim, 2015;N. L. Chiromawa & Ibrahim, 2016b;N. L. Chiromawa & Ibrahim, 2016a; N. L. Chiromawa & K. Ibrahim, 2015a;Cheng et al., 2011;Hayashi et al., 2015 and J. Chen et al., 2011).Fresnel lenses find wider applications in modern actively developing photovoltaic systems and are becoming the backbone of the solar concentrators in different photovoltaic solar cells(Karp et al., 2010 and Nielson et al., 2011). Fresnel lenses used in CPV-system's application are almost universally Plano-convex in which solar radiations are focused by means of a series of concentric grooves (also referred to as point focus) or parallel grooves (known as line focus) (Davis, 2011).When parallel rays of light are passed through the aperture of the Fresnel lens, each ring of the prisms refracts the light at a slightly different angle and focused on a focal point(Ryu et al., 2006).Conventional Fresnel lenses used in CPV applications suffers from long focal distance, non-uniform illumination on the solar cells and it occupies a larger surface area compared to that of solar cells(Xing et al., 2015 and Lv et al., 2015).

To achieve a high magnitude light trapping system which can improve the internal quantum efficiency of Si-solar cells, micro array of Fresnel lenses MAFLs, CPV-system could be a better solution. MAFLs CPV-system can also suppress surface reflection, enhancing the absorption of light and could replace conventional CPV-systems in Si-solar cells, detectors and other photosensitive devices(Chan et al., 2015;Shih et al., 2006;Stöhr et al., 2015;Losic et al., 2007;Y. Chen et al., 2013 and Bhagat et al., 2007). In our previous paper, we have investigated the effects of oxygen addition in the sidewall profiles of micro-scale Fresnel rings by reactive ion etching RIE(N. L. Chiromawa & Ibrahim, 2017).

In this paper, PMMA/SiO$_2$MAFLs CPV-system by the series of the electron beam lithography EBL, the reactive ion etching RIE and the Polydimethylsiloxane PMDS, replica molding techniques for high efficiency Si-solar cells was fabricated. However, literature on the use of soft lithography for Si-solar cells could not be located. Unlike the other conventional CPV-systems in which the systems have large surface areas compared to that of solar cells these are placed far away from the surface of the solar cells.

This system have the same size as solar cells and hence, is placed on the surface of the solar cells without occupying any additional surface area in the space. However, the overall size of the cell is5 cm by 5 cm, and the array has the same size as that of the cell as illustrated in Fig. 1.

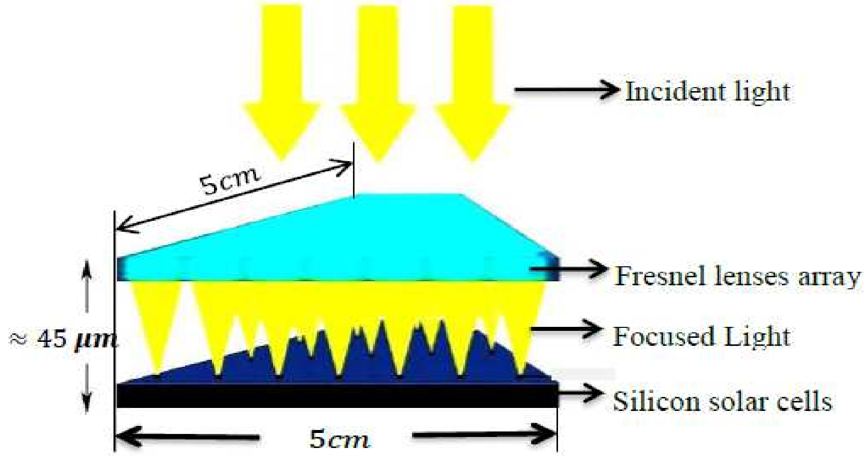

Figure 1: Schematic illustration of Micro array of PMMA/SiO_2 Fresnel lenses CPV-system on Si solar cells.

Materials and Method

The methodology adopted in this work comprises the Fabrication and Characterization Processes. *Fabrication Process*: The summary of fabrication steps adopted in this work is given in Fig. 2 below;

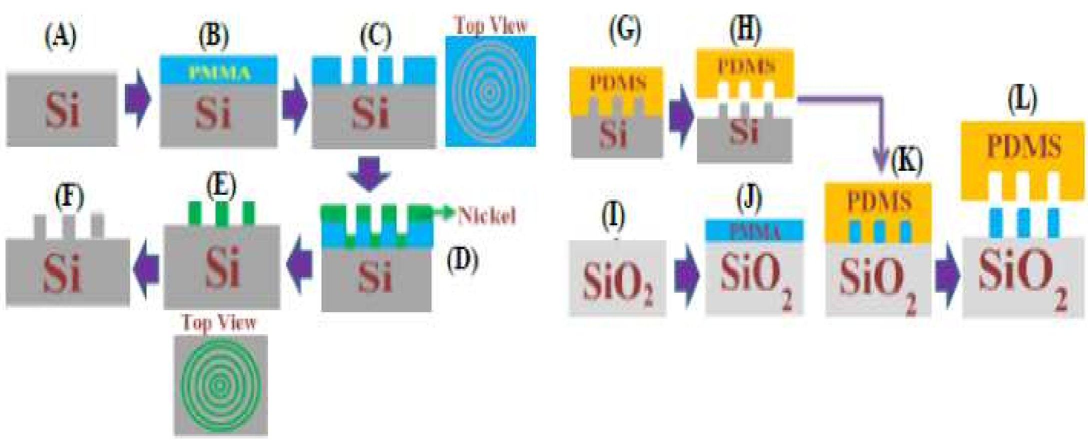

Fig.2: Schematic illustration of the fabrication process of Micro-array of Fresnel lenses CPV-System by soft lithography; (A) RCA cleaning process of Si substrate (B) Spin coating of PMMA photoresist on the Si substrate and baking (C) EBL process and Developing (D) Metal deposition (E) Lift off process (F) Reactive ion etching process (G) PDMS mixture preparation and Poured on Si-Mold (H) Tearing of PDMS from Si-Mold (I) Clean the fused silica (SiO_2) (J)Spin coating of PMMA on SiO_2 (K) Imprint PDMS-Mold on PMMA/SiO_2 (L) Tear the PDMS from PMMA/SiO_2 to obtain PMMA/SiO_2 Fresnel lens.

Characterization Process: After e-beam exposure and development (Fig. 2: C), the developed structures were characterized using Field Emission Scanning Electron Microscope FESEM and EDS/EBSD detector system (model: FEI Nova NanoSEM 450) and the Atomic force Microscope AFM, (Dimension EDGE, BRUNKER; Shimadzu) system. Meanwhile, the reactive ion etching (RIE) system (Oxford Instruments, Plasma Lab 80 RIE) was utilized in the fabrication of micro-array of Fresnel rings on Si using SF_6/O_2as the main etching gases.. Fig. 3: Shows the FESEM images and EDX spectrum of the developed structures on PMMA/Si surface, while Fig. 4: Shows the AFM images of surface topography and the etching profiles of Si-Fresnel rings

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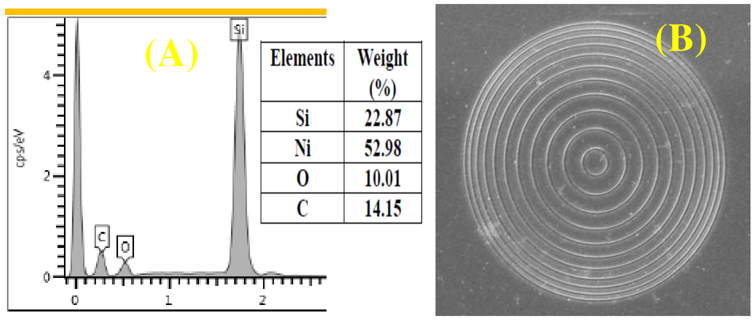

Figure3: FESEM images and EDX spectrum of the Fresnel rings on PMMA/Si surface (A) EDX spectrum showing the % weight of the elements detected (B) FESEM image of the Fresnel rings on PMMA/Si surface

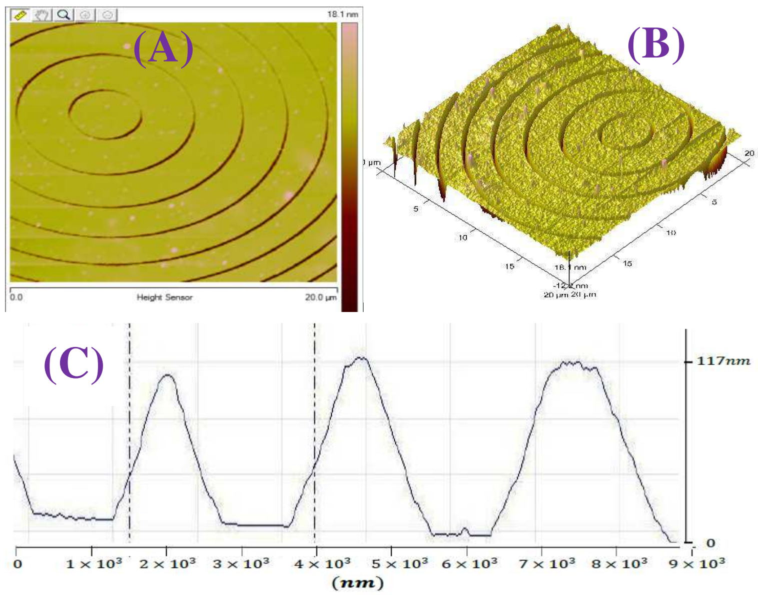

Figure 4: AFM images of surface topography and the etching profiles of Si-Fresnel rings (A) 2-D view $(20\ \mu m)^2$(B)3-D view of the developed structures $(20\ \mu m)^2$(C) Etching profiles.

RESULTS AND DISCUSSION

Commercially available mono-crystalline silicon solar cells (rated 0.25W) was used to study the increase in the output power and the efficiency when the CPV-system was brought in contact to the surface of Si-solar cells. Solar simulator system-IV (Model: KEITHLEY-2400 SOURCE METER) was utilized to study the increase in other characteristics parameters of the Si-solar Cells such as: maximum and open circuit voltages (V_m and V_{oc}), maximum and short circuit currents (I_m and V_{sc}), series and shunt resistances (R_s and R_{sh}), as well as the fill factor (FF) when the CPV-system was in use. The results obtained were then analyzed and compared to that obtained when the CPV-system was not in used. The experiment was taken in two different stages; in the first stage of the experiment, IV-characteristics of Si-Solar Cells were measured and recorded. While in the second stage of this experiment, CPV-system was brought to a distance of $\approx 45\ \mu m$ to the surface of Si-solar cells to study the improvements in the output power and the efficiency of the Si-solar cells. The results obtained were summarized in table 1.

Solar simulators' analysis on Si-solar cells without CPV-system shows that, the Si-solar cells has efficiency of 25.85% while the analysis on Si-solar cells with CPV-system placed on Si-Solar Cells, show that the efficiency increased to 29.39%. Fig. 5 shows the solar simulator analysis for IV-characteristics of Si-Solar Cells of the experimental stages observed in this work.

Table 1: Effects of MAFLs CPV-system on characteristics parameters of Si-Solar Cells

S/N	Parameter	Unit of measurement	Si-Solar Cells (Si-SC)	CPV-systemon Si-SC
1	I_{SC}	mA	68.73	99.95
2	J_{SC}	mA/cm^2	11.46	16.66
3	V_{OC}	mV	538.83	556.73
4	I_{max}	mA	56.94	86.99
5	J_{max}	mA/cm^2	9.49	14.50
6	V_{max}	mV	380	380
7	P_{max}	mW	21.64	33.06
8	FF	-	0.58	0.59
9	R_S	Ω	1.95	1.41
10	R_{Sh}	Ω	203.89	808.73

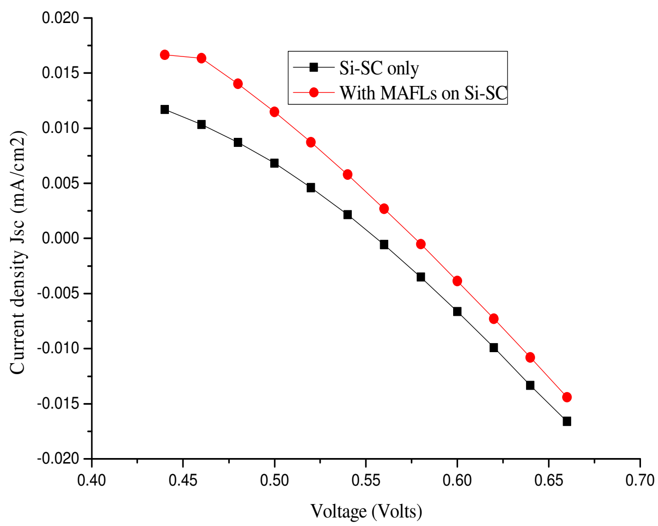

Figure 5: IV-characteristics of Si-Solar cells showing the effects of PMMA/SiO_2 Fresnel lenses array CPV-system in the improvement of the output characteristics of Si-Solar Cells.

CONCLUSION

In this work, we have successfully fabricated a micro-scaled array of PMMA/SiO_2 Fresnel lenses CPV-system by soft lithography technique. The resulting CPV-system when placed at a location ≈ 45 μmfrom the surface of Si-solar cells (i. e. approximately on the focal point of the CPV-system);an open circuit voltageV_{OC} increases from 538.83 mV to 556.73mV, the short circuit current $I_{SC}$from 68.75 mA to 99.95mA and the maximum power $P_{max}$from 21.64to 33.06mW. Finally, the electrical power conversion efficiency of the Si-solar cells was increased by 3.54 %.In general, these results clearly indicate the advantage of using small size CPV-system in investigating the improvement in the output characteristic parameters of silicon solar cells. It can be concluded that the system has a great potential in solar cells materials.

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