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Electrical and optical properties of Si microwire solar cells

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ABSTRACT

A record-high efficiency of 16.92% was realized by using microscale-patterned Si solar cells. Si microwire (SiMW) solar cells were designed to compare their performances with the standard flat-Si solar cell. The diameter and period of SiMWs were tuned to investigate the effects on the operation and the electrical properties of the solar cells. The highest efficiency SiMW solar cell has a width of 1.57 µm to provide the significantly enhanced efficiency of 16.92% from 10.15% of the flat-Si solar cell, due to the improved values of open circuit voltage (608 mV), short circuit current density (36.47 mA/cm^2) and fill factor (76.29%). Impedance spectroscopy and capacitance-voltage studies were carried out to obtain series and shunt resistances, built-in potential, acceptor carrier density, depletion width and flat band potential. Optical properties of SiMW solar cells were analyzed by external and internal quantum efficiencies. The carrier lifetime was measured by using open circuit voltage decay technique. Systematic analyses were performed to reveal the optical and electrical features of SiMW solar cells. These findings may provide efficient design schemes for high-performing solar cells using structured platforms.

1. Introduction

Over the years, many materials have been tried for their efficient utilization in solar photovoltaics. There exists a tradeoff between the efficiency and the final cost of the device. Hence, only few materials like Silicon (Si), CdTe, CZTS, and CIGS are of the most interest [1–5] to achieve optimized solar cell performances. Si is an earth abundant material with nearly ideal properties as an absorber layer of solar cell which till date ruled the photovoltaics industry. However, the final cost of highly efficient wafer based Si solar cells is still much higher compared to the fossil fuels. Hence, researchers are motivated to cut down the cost of Si solar cells either by efficient design or use of low-cost manufacturing techniques for the solar cells [6,7]. Si microwire-array solar cells have gained tremendous attraction due to their ability to offer higher efficiencies [8,9]. Nowadays, research is progressing in many aspects which include patterning of the absorber layer [10], passivated emitter and rear cell (PERC) [11], back surface field (BSF) [12] and utilization of different interlayers [13]. Amongst all these possibilities, texturing of Si absorber layer is of the great interest [14–16]. The textured Si layers offer improved photon absorption and hence light utilization [17–19]. Vertically aligned wires reduce reflection due to the surface structure and hence improve the optical path length of guided mode coupling. Si wire arrays with radical p-n junctions are of particular interest amongst the possible surface structures [20]. Such core-shell structures allow the light absorption and carrier collection in orthogonal directions which reduce the collection length for photo-generated minority carriers. Initially Si microwire solar cells struggled with lower efficiencies but currently a considerable amount of literature is available on the high-efficiency silicon microwire (SiMW) solar cells. The study on electrical, optical and interfacial properties of any photovoltaic device is of much importance as it suggests plausible improvements in the existing devices.

We have recently shown an efficient designing for positioning the space charge region in SiMW solar cells [21]. The solar cells were designed in such a way that a strong electric field exists in the space charge region (SCR) and improves the probability of collection of photogenerated carriers. The spatial distribution of the SCR directly controls the collection length of the photogenerated carriers in SiMW solar cells. In this manuscript, we have made efforts to closely examine all the electrical, optical and interfacial parameters of SiMW solar cells. A rational design induced the record-high efficient SiMW solar cell (16.92%) among the microscale-patterned solar cells. This study may provide the design schemes for structured solar cells in terms of optical and electrical aspects.

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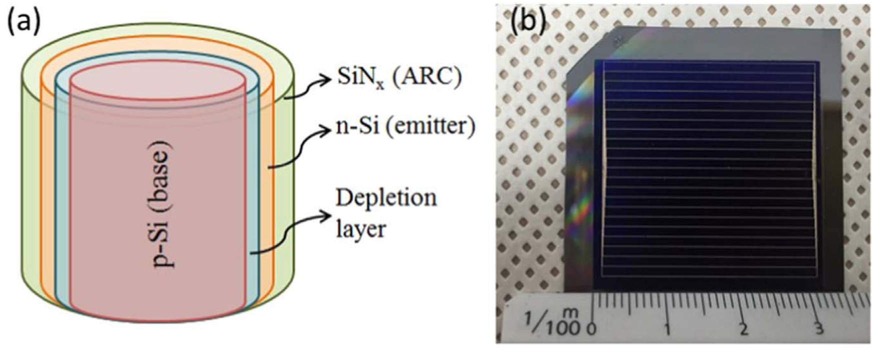

Fig. 1. (a) Schematics of the SiMW solar cell. (b) A photograph of the SiMW solar cell.

2. Fabrication and characterization of solar cells

The fabrication processes are similar to the previous reports [21], however, the height of SiMWs was tuned to be 5 µm. In brief, four different microscale Si structures were obtained on a single p-Si (100) wafer. The doping in flat and microwire Si was done by using phosphorous oxychloride ($POCl_3$) in a furnace at 800 °C for 40 min. The passivation was done by SiN_x layer coating by using plasma enhanced chemical vapor deposition. Ag front and Al rear contacts were screen printed followed by the co-firing process. The schematics of the SiMW solar cell and the photograph of the SiMW solar cell are presented in Fig. 1(a) and (b), respectively. The SEM images of SiMW pillars are shown in Fig. 2. The designed and fabricated SiMW solar cell parameters with nomenclature are presented in Table 1.

A simulator system (McScience-K3000, Korea) was employed to measure the solar cell performances. A photovoltaic power meter (McScience-K101) was used to monitor the I–V characteristics under one sun (100 mW/cm^2) illumination. Light intensity was calibrated with standard Si photodiode at room temperature. Complementarily. Light intensity was verified using a power meter (KUSAM-MECO, KM-SPM-11). After the calibration of spectral power density, quantum efficiency of the prepared samples were measured. Carrier collection

Table 1
Geometric dimensions and an effective area of microscale Si pillars.

Structure	Width µm	Period µm	Depth µm	Total pillars on the device #	Total pillar area mm^2	Total device area mm^2	Relative surface area %
Pillar-1	1.58	4.03	5.2	3.25×10^7	840	1864	182
Pillar-2	1.26	7.13	5.43	1.45×10^7	313	1337	131
Pillar-3	5.11	7.1	5.71	6.87×10^6	630	1654	161
Pillar-4	4.12	9.97	6.2	5.16×10^6	414	1438	140
Flat-Si	N/A	N/A	N/A	N/A	N/A	1024	100

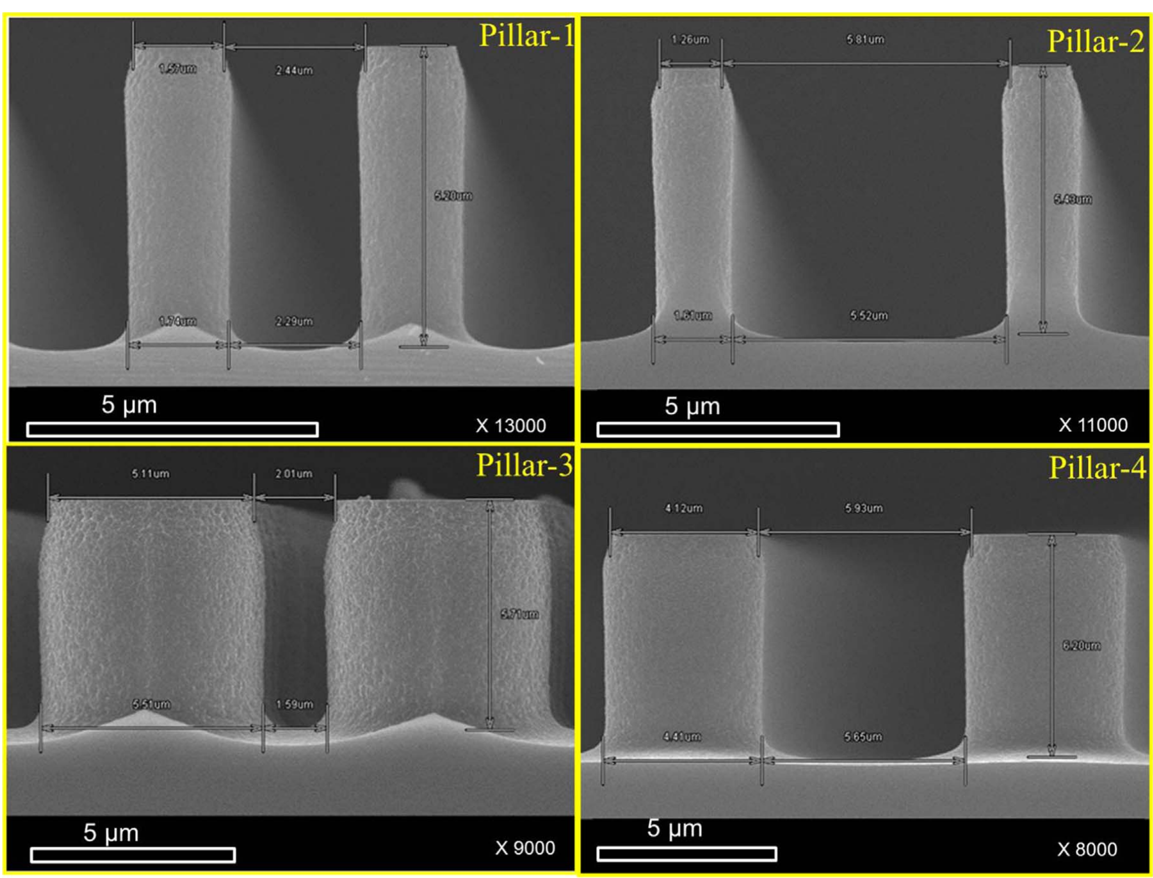

Fig. 2. SEM images of the SiMW pillars.