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Flexible Solar Modules Using Polycarbonate for Templating and Encapsulation

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Abstract: Combining both approaches of fabricating photovoltaic cells and designing solar modules using polycarbonate in the form of nanospheres and panels is an innovate approach in solar cells technology. Polycarbonate nanospheres was employed to control the position of the growth of silicon nanowires using the technique of Nanoscale Chemical Templating. The grown silicon nanowires were catalyzed via Vapor-Liquid-Solid (VLS) technique at the Chemical Vapor Deposition (CVD) or UHVCVD reactor. The bottom-up grown nanowires were doped with aluminium (Al) throughout the growth process then the p-i-n junctions were formed material. The conventional silicon cells or the innovative ones can be incapsulated in a polycarbonate flexible-surfaces. The polycarbonate material will allow us to further increase the performance of the devices and decrease the overall costs. The study presents concepts along with their experimental proofs presented as Scanning Electron Microscopy (SEM) micrographs, and optical characterizations. The proposed method is also flexible, as it is amenable to both standard lithography techniques and self-assembled patterning techniques.

Keywords: Chemical Vapor Deposition (CVD), Silicon (Si), Nanowires (NWs), Nanosphere (NS), Polycarbonate (PC), Nanoscale Chemical Templating (NCT)

1. Introduction

Vertical nanowires made of silicon substrate solar cells are of great interest because they would allow for ultimate light trapping and distinguished charge carriers' separation. They could therefore achieve, in principal, good efficiency than thin film planar cells, with the added merits of minimal use of materials and much lower process cost [1]. Nanowire solar cells have some potential benefits over traditional wafer-based or thin-film devices related to optical, electrical, and strain relaxation effects; new charge separation mechanisms; and cost. Ordered arrays of vertical nanowires with radial junctions take advantage of all these effects, as explained in some details by Wacaser et al. [2]. Controlling the position of nanowires is another important topic for research. A promising recently emerged field for future low cost, decent efficiency solar cell devices is the use of vapor-liquid-solid (VLS) grown silicon nanowires (Si-NWs). Bottom-up approach of Si-NWs growth via VLS mechanism has a key advantage for device applications, since it is possible to template the position of the NWs by controlling the placement of the initial metal seed or catalyst particle. This templating then allows integration of NWs with other parts of the structure, as required for many of these applications [3-6]. It has been proposed by Khayyat et al. 2013 [5] that the technique of microsphere lithography to produce regular hexagonal arrays of Al-seeded nanowires, and the fabrication process continues to fabricate solar cells [5-8]. Templating the Si-NWs growth using polycarbonate micro- or nanospheres as explained by the research group of Khayyat [5] is as a direct application of the concept of Nanoscale Chemical Templating NCT [6-8]. There are several advantages of using polycarbonate at the level of templating the growth, as it is an economical approach reduces the number of the required steps of lithography. Moreover, using polycarbonate sheets in solar cells is of potential applications. The fact that 61% CO_2 footprint reduction for each footprint reduction for each Kg of polycarbonate based on certified renewable feedstock, according to SABIC report [9]. Polycarbonate plastic materials are transparent amorphous, although they are made commercially available in a variety of colours, the raw material allows for the internal transmission of light nearly in the same capacity as glass. Polycarbonate polymers are used to produce a variety of materials and are particularly useful when impact resistance and/or transparency are a product requirement. Polycarbonate is a relatively hard, lightweight material. These properties make polycarbonates suitable for products intended for long open-air operation, such as PV cells and modules.

One of the key goals of the current article is to create new application markets for acrylic such as applications for polycarbonates in solar cells fabrication and solar panels engineering and other alternate energy technologies [9, 10].

2. Materials and Methods

Using CVD reactor which includes a home-built Al evaporator [5]. Si-NWs were grown in a home-built (UHVCVD) tool operated under Ultra High Vacuum Chemical Vapor Deposition. Si-NWs, as previously observed [5], grow preferentially perpendicularly in the (111) direction so Si(111) substrates were primarily used. The detailed growth conditions along with the pre-growth steps were described in previous work [5-8].

It has been shown, according to Khayyat et al [5], that as the thickness of Al catalyst layer is increased (from 2 nm to 5 nm) the fidelity of the growth increases, then after reaching 5 nm Al thickness then the growth fidelity decreases quite significantly. Based on these measurements, it has been decided to choose 5 nm of Al thickness. The samples were then transferred into the hot growth chamber for a pre-growth anneal at 600°C, which is above the Al/Si bulk eutectic temperature of 577°C. This anneal was 20 min long under full pumping and was intended to allow the Al film to agglomerate into small islands on the surface and form liquid droplets. The furnace was then cooled to the desired growth temperature (usually 520°C) and pure silane (SiH_4) was introduced at a fixed flow, 20 sccm, using a mass flow controller (MFC). Examining the Si-NWs morphology were examined with an environmental scanning electron microscope (SEM) FEI Co., Eindhoven, The Netherlands, model XL 30.

The patent application (to be filed) allows us to grow NWs at the available CVD without oxidation of the catalysing materials as the catalysing layer has been covered in a separate evaporation tool to be transferred later in the CVD reactor for growing process. Covering the catalyst layer Al, a chemically active material, will prevent the oxidation, as it has been proven experimentally.

3. Results and Discussion

The study present conceptional and experimental work on templating the growth of Si-NWs using microsphere of polycarbonate. In addition to conceptional descriptions and some primitive measurements proofing the success of the growth as patents applications.

3.1. Templating Si-NWs Using Polycarbonate Microsphere Lithography

Nanoscale Chemical Templating (NCT) technique, proposed by Khayyat [5], proposed the concept of controlling the position of the grown NWs catalysed with chemically active elements such as Al. So, seed materials have to be evaporated on the substrate in a stand-alone evaporator as routinely practised with gold (Au) catalyst. However, when we catalyse the nanowires growth with chemically active element such as alluminum (Al) so we have to install it in the tool of the CVD.

The proposed concept has been evaluated applying the technique of microsphere lithography to produce regular hexagonal arrays of Al-catalysed Si-NWs. PC microspheres are commercially available with narrow size distributions, and when dispersed properly using a spinner on the Si substrate surface they form a close-packed array that forms gaps through which a material can be deposited. Si (111) of p-type substrates were cleaned using standard techniques [5-11] which leave a thin oxide on the Si surface. A drop of 1 µm diameter PC microspheres in solution taken directly from the commercially provided stock solution was dispersed onto the substrate. Then the growth procedure has been adopted as explained earlier [5]. Figure 1 illustrates schematically in four steps of NCT process using microspheres. After spinning in the microspheres (step 1), where it followed by step 2, where then layer of 5 nm Al deposited on the surface covering the top surfaces of the microspheres and bare Si surface. Step 3 describes regions of Al that will act as seeds form at the gaps between microspheres, while on top of the microspheres the Al layer reacts with the oxide and becomes inactive [5]. The final step of this process, step 4, shows the growth of Si-NWs after allowing SiH_4 to flow, providing the required medium of VLS system, to be followed by epitaxial perpendicular Si-NWs growth [12-14].

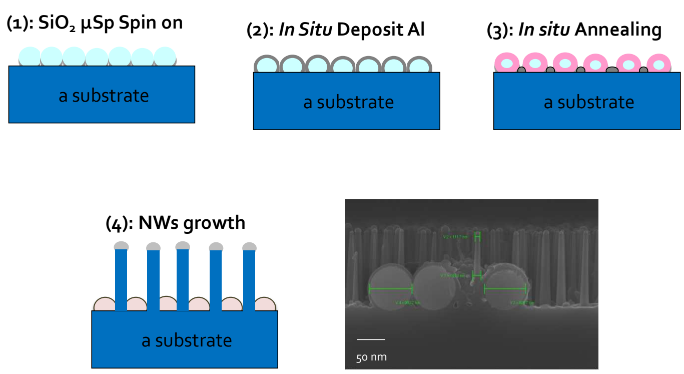


Figure 1. A schematic representation showing that microspheres (MS) can be used for templating in four main steps, along with cross-sectional SEM micrograph of grown Si-NWs between the MS.

The described concept at figure 1, has been examined and it showed encouraging results, however, further optimization of the Si-NWs growth has to be carried out. It can be shown the outer shell of the silica microspheres shows the oxidation of the evaporated Al on the top of the spheres forming Al_2O_3. We show the results of this process, where Si-NWs can be seen growing in the gaps between the microsphere array [15, 16]. The microsphere of PC exhibit two main contents of distinct colours, the core which represents more than 90% of the microsphere remains as it is, while the very outer exposed part of the shell of oxidized Al. The concept of controlling the growth positions of Si-NWs using PC microspheres has been approved [10, 11, 17].

3.2. PC Encapsulation of Solar Panels

This section describes a potential research project on technical feasibility on the application of PC, instead of glass, using the available C-Si PV module or the innovate Si-NWs cells [18-20].

The lamination process can be performed in a conventional laminator apparatus or the current available process in the KACST PV modules factory using low temperature curing (approx. 100°C). Ethylene-vinyl-acetate (EVA) can then be used as usual in the production line of the PV module of multi-crystalline silicon solar cells.

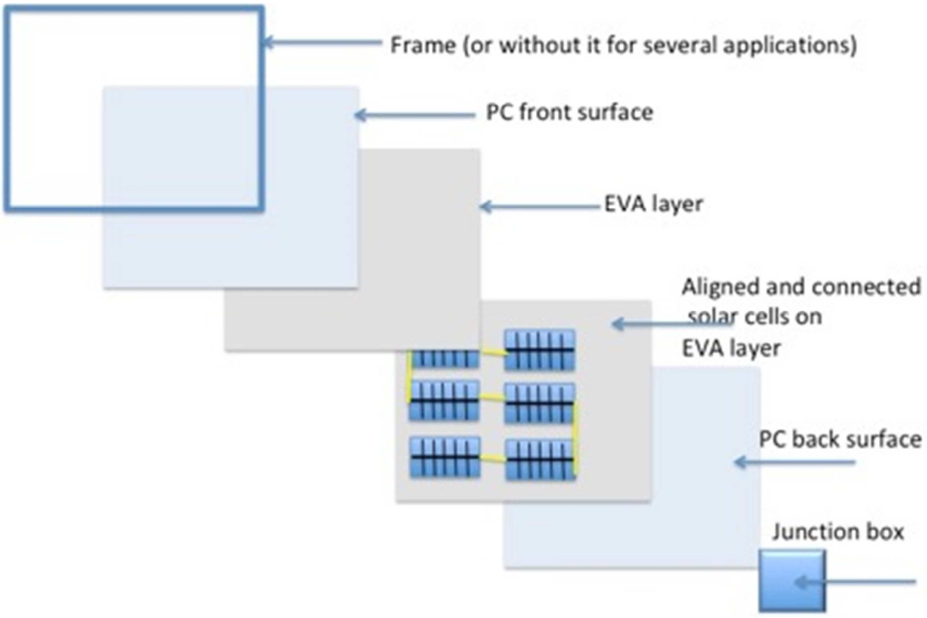
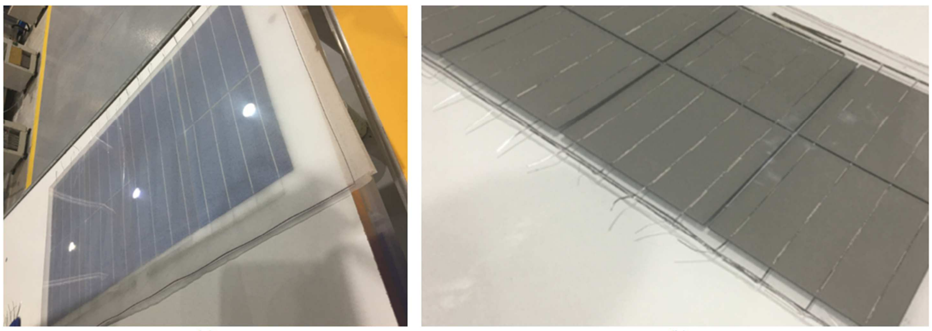


Figure 2. *A schematic representation of the various parts arrangements of PC-PV module, ready for installation at the current PV production lines of industries.*

Figure 2 describes the various main steps of module lamination. Schematically; it begins with the placement of EVA film. Whereas, there are several technologies other than EVA such as silicone onto the first PC surface (back surface of the regular PV module could be opaque). Next, the solar cell matrix is placed onto the EVA or silicone. Another PC panel is coated with the encapsulant and is then turned upside down and placed onto the first panel containing the cell matrix. The whole sandwich is then introduced into a laminator, where a vacuum is drawn and the laminate is heated up. The structure of the module is shown in Figure 2. As in conventional modules, it consists of several layers laminated together, with the solar cell matrix (8 cells) in the center. Due to the possible differences in thermal expansion [18-21] between the materials of the various layers explained Figure 2, there was a certain degree of curvature in the produced module (see photos figure 3). This stress build-up can be diminished by application of innovate solutions.



(a) (b)

Figure 3. *Optical images of solar panels encapsulated by PC (a) the front (b) back.*

Nanowires have very high surface to volume ratio, making them ideal components for light absorption or any related to interface phenomena. The optical characteristics of the coated photovoltaic cell reveal that the nano-spheres with an average diameter size of 100 nm exhibits excellent light harvesting characteristics (see figure 4) if compared to the nanospheres of other sizes [8, 10, 21, 22]. The reflectance of light from Si substrate covered with NWs is almost zero, in comparison to the plain Si substrate, as it is shown on figure 4.

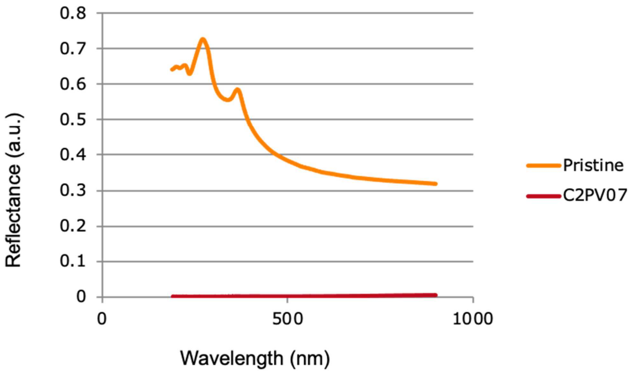


Figure 4. *NWs solar cells are excellent light absorber. The reflectance of Si-NWs is almost zero in comparisons to pristine Si.*

There are more innovate methods, under investigations, of growing Si-NWs and other semiconductors catalyzed with oxygen reactive element without or with air exposure. The patent application (to be filed) allows us to grow NWs at the available CVD without oxidation of the catalysing materials as the catalysing layer has been covered in a separate evaporation tool to be transferred later in the CVD reactor for growing process. Covering the catalyst layer (Al), a chemically active material, will prevent the oxidation, as it has been proven experimentally. The whole process from growing Si-NWs in the CVD reactor to building a solar panel is summarized in figure 5, as follows;

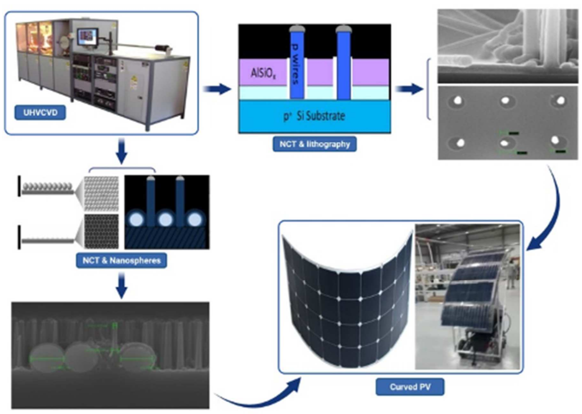


Figure 5. *Pictorial representation of building solar panel via Si-NWs growth using nanoscale templating with photolithography and with microspheres.*

Growing semiconductor nanowires can be catalyzed by chemical active materials using an efficient and an economic approach [20-22]. It has well established in the literature that nanowires can be catalyzed using gold. However, gold affects negatively the performance of the semiconductor devices, as it acts as a deep level energy level trapping charge carriers. On the other hand aluminum is a part of semiconductor's industry. Aluminum is used a p-type dopants of silicon [7, 23]. However aluminum is a chemically active element, as we evaporate aluminum of the semiconductor substrate, we should not expose the samples to air. The Chemical Vapor Deposition CVD does not include an aluminum evaporator, so we have to install it in the tool separately. These nanowires which includes aluminum can be used for applications such as solar cells and more. The other related patent application (to be filed) method, is also flexible, as it can be applied to both standard lithography [23, 24] techniques and self-assembled patterning techniques like microsphere lithography based of NCT technique. There are more innovate methods, under investigations, of growing Si-NWs and other semiconductors catalyzed with oxygen reactive element without or with air exposure.

4. Conclusions

The combination of the NCT technique along with PC microspheres is an economic approach, as it requires fewer steps compared to conventional patterning approaches, not requiring lift off of a metal layer or removal of the mask. Encapsulation of silicon solar panels with PC sheets reduces the weight of the solar panels and opens up for more applications of solar panels at harsh environment considering the mechanical properties of PC. The methodology used in achieving controlled placement of single NWs seeded with Al is an example of proving the concept of NCT technique, more oxygen-reactive materials such as Sn, Sb, In, Ga, and Ti templated by NCT will have more advanced applications in nanodevices fabrications.

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Data Availability Statement

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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References

[1] Jeehwan Kim, Augustin J. Hong, Jae-Woong Nah, Byungha Shin, Frances M. Ross, and Devendra K. Sadana, Three-Dimensional a-Si: H Solar Cells on Glass Nanocone Arrays Patterned by Self-Assembled Sn Nanospheres, ACS NANO, VOL. 6' NO. 1' 265–271' 2012.

[2] Wacaser, B.; Khayyat, M.; Reuter, M.; Sadana, D.; Ross, F. Technical advantages and challenges for core-shell micro/ nanowire large area PV devices, Photovoltaic Specialists Conference (PVSC), 35th IEEE, 2010.

[3] Huang, B. J.; Lin, T. H.; Hung, W. C.; Sun, F. S. Performance evaluation of solar photovoltaic/thermal systems, Solar Energy Volume 70, Issue 5, 2001, Pages 443-448.

[4] Gong, Li; Lu, J.; Ye, Z. Transparent and conductive Ga-doped ZnO films grown by RF magnetron sputtering on polycarbonate substrates, Solar Energy Materials and Solar Cells Volume 94, Issue 6, June 2010, Pages 937-941.

[5] Wacaser, B.; Reuter, M.; Khayyat, M.; Wen, C.; Haight, R.; Guha, S.; Ross, F. Growth Systems, Structure, and Doping of Aluminum Seeded Epitaxial Silicon Nanowires, Nano letters, Vol 9, 2009.

[6] Khayyat, M.; Wacaser B.; Reuter, M.; Ross, F.; Sadana D.; Chin, Tze. Nanoscale chemical templating of Si-NWs seeded with Al, Nanotechnology 24, 2013, 235301.

[7] Khayyat, M.; Wacaser, B.; Sadana, D. Nanoscale chemical templating with oxygen reactive materials, USPTO Patent number 8349715.

[8] Fan, H.; Werner P.; Zacharias, M. Semiconductor nanowires: from self-organization to patterned growth, *Small* 2, 2006, 700–17.

[9] CERTIFIED RENEWABLE POLYCARBONATE, FROM SABIC'S TRUCIRCLETM PORTFOLIO OF CIRCULAR SOLUTIONS.

[10] Brabec, C.; Sariciftci N.; Hummelen J. Plastic solar cells. Advanced Functional Materials, 11 (1), 2001, 15-26.

[11] Zeng, W.; Li, S.; Chow, W. Preliminary Studies on Burning Behavior of Polymethylmethacrylate (PMMA), Journal of Fire Sciences. 20 (4), 2002, 297–317.

[12] Wacaser, B.; Reuter, M.; Khayyat, M.; Haight, R.; Guha S. and Ross F. The Role of Microanalysis in Micro/Nanowire-Based Future Generation Photovoltaic Devices, Microscopy and Microanalysis, Volume 16, Supplement S2, 2010.

[13] Khayyat, M.; Wacaser, B.; Reuter, M.; Sadana, D. Templating silicon nanowires seeded with oxygen reactive materials, Saudi International Electronics, Communications and Photonics Conference (SIECPC), 2011.

[14] Huang Y. and Lieber, C. Integrated nanoscale electronics and optoelectronics: exploring nanoscale science and technology through semiconductor nanowires *Pure Appl. Chem.* 76, 2004 2051–68.

[15] Kayes, B.; Atwater H.; Lewis, N. Comparison of the device physics principles of planar and radial p–n junction nanorod solar cells *J. Appl. Phys.* 97, 2005, 114302.

[16] Law, M.; Goldberger J; Yang, P. Semiconductor nanowires and nanotubes *Annu. Rev. Mater. Res.* 34, 2004, 83–122.

[17] Samuelson L. Semiconductor nanowires for 0D and 1D physics and applications, *Physica* E 25, 2004, 313–8.

[18] Givargizov, E. Fundamental VLS growth *J. Cryst. Growth* 31, 1975, 20–30.

[19] Wacaser, B.; Dick, K.; Johansson, J.; Borgstrom, M.; Deppert K.; Samuelson, L. Preferential interface nucleation: an expansion of the VLS growth mechanism for nanowires *Adv. Mater.* 21, 2009, 153–65.

[20] Wagner R.; Ellis, W. Vapor–liquid–solid mechanism of single crystal growth, *Appl. Phys. Lett.* 4, 1964, 89–90.

[21] Kayes, B.; Filler, M.; Putnam, M. Kelzenberg, M.; Lewis N.; Atwater, H. Growth of vertically aligned Si wire arrays over large areas (>1 cm^2) with Au and Cu catalysts *Appl. Phys. Lett.* 91, 2007, 103110.

[22] Westwater, J.; Gosain, D.; Pand, S.; Control of the size and position of silicon nanowires grown via the vapor–liquid–solid technique, *Japan. J. Appl. Phys.,* 136, 1997, 6204–9.

[23] Harper, Charles A., Handbook of Plastic Processes, John Wiley & Sons, 2005 2. Harper, Charles A., Edward M. Petrie. Plastics Materials and Processes John Wiley & Sons, 2003 3. Stevens, Malcolm P. Polymer Chemistry: An Introduction. Oxford University Press, USA, 1998.

[24] Lee, Chee-Leong; Goh, Wee-Sheng; Chee, Swee-Yong; et al., Enhancement of light harvesting efficiency of silicon solar cell utilizing arrays of poly(methyl methacrylate-co-acrylic acid) nano-spheres and nano-spheres with embedded silver nano-particles, PHOTONICS AND NANOSTRUCTURES-FUNDAMENTALS AND APPLICATIONS Volume: 23 Pages: 36-44, 2017.