High efficiency Si-nanowires/Poly (3,4-ethylene-dioxythiophene): Poly(styrenesulfonate) hybrid solar cells

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Introduction

To address the problem of low power conversion efficiency (PCE) of organic materials based solar cells, Si nanowires (SiNWs) have been embedded in a polymer matrix to form hybrid cells [1, 2]. Improvement in PCE is expected owing to the fast carrier transport and excellent light trapping characteristics of SiNWs [3]. In contrast to SiNWs based fully inorganic solar cells [3, 4] which require high temperature and expensive fabrication processes such as diffusion, thermal annealing and chemical vapor deposition, the SiNWs/organic hybrid cells involve lower temperature and simpler solution based fabrication processes. Therefore, they have great potential towards realizing low-cost, high efficiency and scalable solar cells. Recently, SiNWs on Si wafer have been incorporated with a hole conducting polymer, poly (3,4-ethylene-dioxythiophene): polystyrenesulfonate (PEDOT: PSS), to form a hybrid cell with a structure of Al/c-SiNWs/PEDOT/ITO, achieving a maximum PCE of 5.08% [2]. In this work, we present a SiNWs/PEDOT cell with a structure of Al/c-SiNWs/PEDOT/Ag. Our hybrid cells show much better performance and achieve a maximum PCE of 9%.

Experiments

The architecture of the cell consisting of Al/Si/SiNWs/PH500/Ag-grid is shown in Figure 1. Vertically aligned SiNWs arrays were fabricated on 2-4 Ω.cm N-type Si wafers (100) by electroless chemical etching in an aqueous solution of $AgNO_3$ and HF acid at room temperature. The solution concentrations of $AgNO_3$ and HF were 0.02 M and 0.46 M, respectively. Aluminum was deposited by e-beam evaporation onto the backside of the Si wafer to form the rear contact. Conductive PEDOT:PSS (Baytron PH500) was directly spin coated onto the SiNWs arrays. It was then annealed at 110°C for 10 mins in atmosphere. Finally, silver metal grids were directly deposited on the PH500 layer by e-beam evaporation. The active size of the cell was 1cm × 1cm. For comparison, planar Si/PEDOT hybrid cells were also fabricated using the same process.

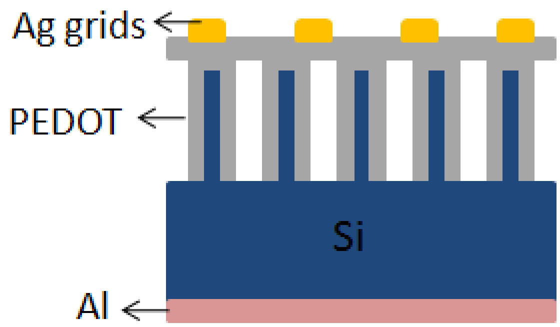
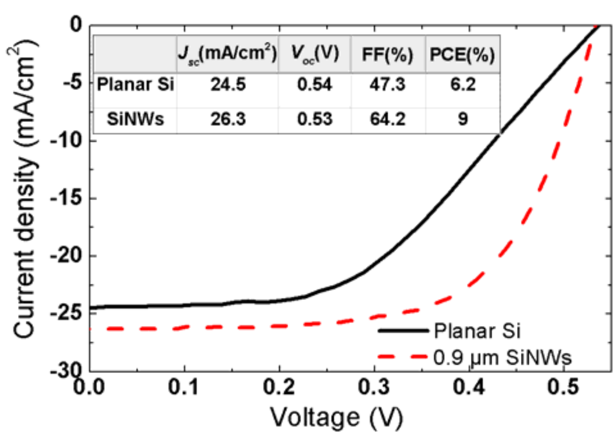


Figure 1: Device structure of the SiNWs/PEDOT heterojunction hybrid cell.

Results and Discussion

Figure 2 shows the comparison of current density-voltage (*J-V*) characteristics of planar Si cell and 0.9µm length SiNWs cells under simulated AM 1.5G at 100 mW/cm^2 illumination. Their photovoltaic parameters of short circuit current density (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF) and PCE, calculated from the *J-V* data, are also summarized in Figure 2. As compared to the planar Si hybrid cell, the PCE of the SiNWs cell increases greatly from 6.2% to 9%, as a result of improvement in J_{sc} from 24.5 to 26.3 mA/cm^2 and FF from 47.3% to 64.2%. The enhanced performance of the SiNWs cell is attributed to enhanced carriers separation owing to increased junction area, as well as the excellent light trapping of SiNWs arrays.



	J_{sc}(mA/cm^2)	V_{oc}(V)	FF(%)	PCE(%)
Planar Si	24.5	0.54	47.3	6.2
SiNWs	26.3	0.53	64.2	9

Figure 2: Comparison of current density-voltage *(J-V)* characteristics between a planar Si cell and SiNWs cell under simulated AM 1.5G at 100 mW/cm^2 illumination.

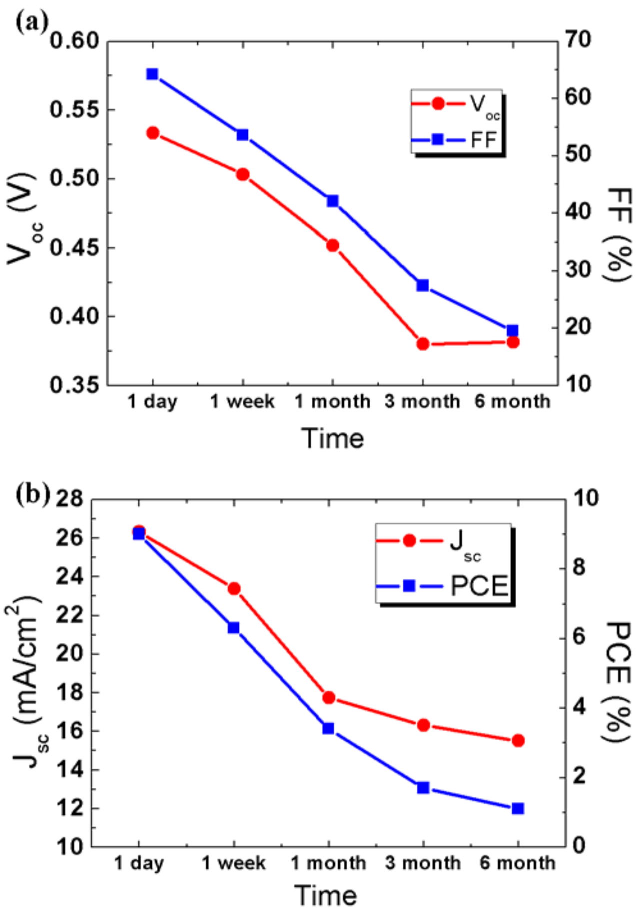


Figure 3: Stability of (a) V_{oc} and FF, and (b) J_{sc} and PCE of the SiNWs/PEDOT hybrid cell exposed in the air over time.

Figure 3 shows the stability of V_{oc}, FF, J_{sc} and PCE of the SiNWs/PEDOT cell exposed in the air over time. It is seen that there is a significant drop of PCE from 9% to 1.1% after 6 months, as a result of degradation in V_{oc} from 0.53 to 0.38 V, FF from 64.2% to 19.5%, and J_{sc} from 26.3 to 15.5 mA/cm^2. The primary cause for the instability of our hybrid cell is the sensitivity of PEDOT to the water in the air, especially in Singapore where the humidity is around 70%. This leads to tremendous increase in sheet resistance of the PEDOT film under Ag grids and hence degradation of cell performance.

Conclusion

We have demonstrated a high performance SiNWs/PEDOT heterojunction solar cell by spin coating method. As compared to planar hybrid cell, the PCE of SiNWs cell improves from 6.2% to 9%, benefitted from the geometrical feature of the SiNWs array structure. It is noted that the efficiency would be 10.2% if the top silver grid covered area (12% of active area) is subtracted. The performance of the hybrid cells degrades over time due to deterioration of PEDOT in the air. Therefore, good encapsulation of the cells is required to improve their stability.

References

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