

Core-shell Silicon Nan wires Decorated Solar Cells

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Abstract. In this paper we report the design and fabrication process of core-shell SiNW solar cell based on Si wafers. The SiNWs significantly decrease light reflection in a wide range of solar spectra. The electrical characteristic of SiNW device is experimentally demonstrated. An efficiency of 2.95% and a short-circuit current density of 14.2 mA/cm² were obtained, significantly higher than values achieved for planar device. The performance can be further improved by optimizing the metal contact on SiNWs.

Keywords: Si nanowire (SiNW), radial junction, solar cell.

1. Introduction

Solar energy harvest and conversion has attracted much attention in the previous decades. Conventional single junction planar silicon solar cells have limited absorption efficiency near the junction and require high purified Si wafer [1]. SiNW was constructed with the potential to overcome the limitation of conventional flat silicon cells. Excellent light absorption can be achieved especially in the high energy region. Moreover, low-quality Si wafer can be used for these structures[2]. SiNW arrays with core-shell structures provide maximum p-n junction interface and direct transport pass attributing to efficient charge separation and collection [3-4]. In this paper, core-shell SiNW array based solar cells are designed and fabricate. DUV lithography patterned plasma etch is used to produce the SiNWs from cheap starting Si wafer. An efficiency of 2.95% and a short-circuit current density of 14.2 mA/cm² were obtained, significantly higher than values achieved for planar device.

2. Experimental

Fig. 1 represents a schematic of the SiNW solar cell design in a cross-sectional view. The The p-type Si(100) test wafer was used as the starting material. BF₂ was implanted to form the back surface field (BSF) [5] to produce a highly doped p⁺ layer. Standard KrF deep ultraviolet (DUV) lithography is employed to create nano-hemispheres with diameter of 200 nm in the forward surface. The arrays of SiNWs with length of 1.6 μm were created by etching the surface in SF₆ based plasma. Formations of core and shell were conducted by two different ion implantation processes. The four-rotation BF₂ implant was applied to the etched SiNW arrays. For the implant, the dose was 2.5 × 10¹³ cm⁻², the energy was 80 keV and the vertical tilt angle for each rotation was 7°. A more uniform distribution of p-type dopant in the wires was realized through a furnace annealing at 1000 °C for 1 hour which was called the drive-in process. Then, an almost same four-rotational phosphorous implant was conducted which a dose of 10¹⁵ cm⁻² and energy of 7 keV. After that, to convert the outer shell of the wires to n-type, a 5 second rapid thermal annealing process at 1000 °C was conducted. To make sure the formation of a uniform and shallow radial junction, the implant

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and annealing conditions were cautiously simulated by software T-SUPREM4. Bottom electrode was made by ejecting a consecutive film of Ti/Cu with thickness of 100 nm/500 nm onto the rear surface of the cell. The functions of Ti and Cu are to provide better adhesion between Cu and Si surface, and to ensure high electrical conductance in the metal electrode, respectively. Then, to finish the fabrication process of the SiNW based solar cell, an analogous Ti/Cu layer was ejected through a shadow mask to produce metal grids on the forward surface. At the same time, planar control device was produced with analogous starting wafer and under same process conditions as said before. To perform the I-V measurement, a top conductive rod and a back silver paste is introduced to the device.

The Scanning Electron Microscope (SEM) top view (tilt 45°) of SiNW device and Transmission Electron Microscope (TEM) cross-section view of SiNW device near the top surface are shown in Fig. 1(b) and Fig. 1(c) respectively.

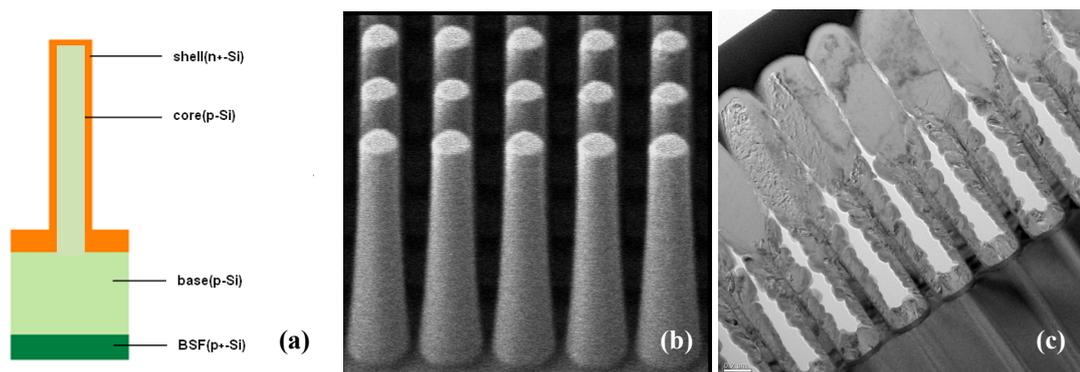


Fig. 1: (a) Cross section schematic structure of the SiNW solar. (b) 45° tilt SEM image of SiNW array formed by plasma etch. (c) Transmission Electron Microscope (TEM) image of SiNW device cross-section near the top surface where. Dark scale bars in (b) and (c) represent 1 μm .

3. Results and discussion

Optical reflectance was measured using integrating sphere on a Shimadzu UV 3600 UV-VIS-NIR Spectrometer. Fig. 2(a) illustrates measured reflection spectra of SiNW compared with planar silicon surface. It is seen that SiNW surface can significantly decrease light reflection in the overall solar spectra. With SiNW textured surface, the reflection is suppressed to less than 12%, while the reflectance is above 27% for a planar surface.

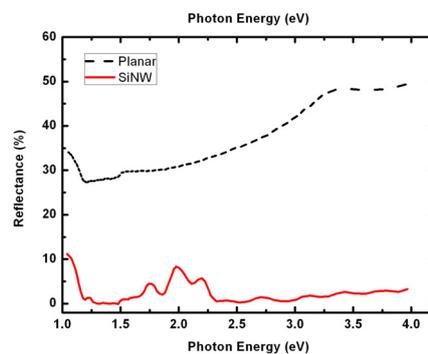


Fig. 2: Reflectance spectra of SiNW solar cell samples and planar Si surface

Fig. 3 shows the output characteristics of core-shell SiNW based and Si planar control solar cell under a solar simulator and dark I-V characteristic in reverse bias region. The short circuit current density (J_{sc}) and open circuit voltage (V_{oc}) of the planar solar cell is 9.34 mA/cm^2 and 548 mV respectively. While the J_{sc} and V_{oc} are found to be 14.2 mA/cm^2 and 485 mV for the SiNW solar cell. The higher J_{sc} of SiNW device is mainly attributed to the reduced light reflection and increased radial p-n junction area resulting from core-shell SiNW. The fill factor (FF) of 42.9% and PCE of 2.95% is obtained for core-shell SiNW device.

Meanwhile, the recombination caused by ion implantation-induced defects should be responsible for the low J_{sc} in planar device. The dark I-V characteristic analysis shows that the leakage current for SiNW based and planar devices are 65 μA and 21 μA at -1 V respectively. The larger leakage current is due to increased p-n junction area in SiNW based device. The series resistance R_s of solar cells is calculated using Multiple illumination intensity method. The obtained R_s is 12.9 Ω and 0.95 Ω for SiNW and planar devices respectively. The high R_s is caused by the imperfectly deposited metal layers on the sidewalls of SiNW and leads to voltage drop across the cell. This gives a reasonable explanation for low FF.

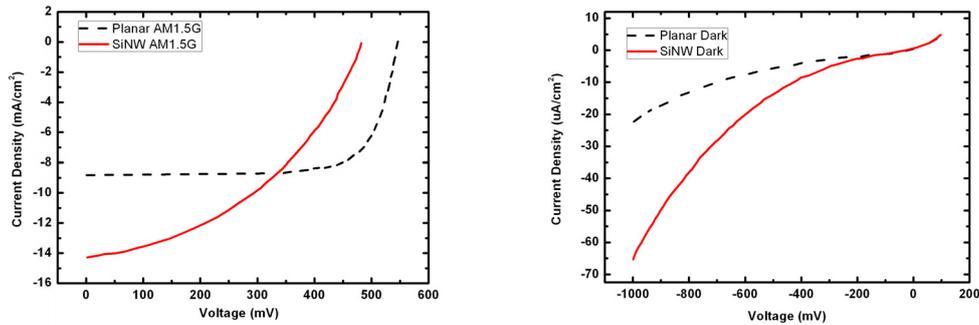


Fig. 1: (a) Comparison of IV characteristic of core-shell SiNW and planar Si solar cell under AM 1.5G illumination. (b) Comparison of dark IV characteristics between core-shell SiNW and planar Si solar cell.

4. Conclusion

In this paper, we focus on the core-shell SiNW solar cell based on Si wafers. Our results show that core-shell SiNW device performs drastic reduction of optical reflectance and increased current density compared to that of Si planar control device. J_{sc} can reach up to 14.2 mA/cm^2 which leads to a PCE of 2.95% without optimization. Low FF of 42.9% is mainly due to large series resistance, which can be reduced by optimizing the metal contact on SiNWs.

5. Acknowledgements

This work is supported by Institute of Microelectronics under Agency for Science, Technology and Research (A*STAR) Singapore and Silicon Nano Device Laboratory at Department of Electrical and Computer Engineering, National University of Singapore. Helpful discussions and support from fellow research scientist Jian Wang is gratefully acknowledged.

6. References

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