Vertical graphene based solar cell with silicon nano hill structure

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ABSTRACT

- Solar cell application which is based on directly grown vertical graphene nano hills (VGHN) was fabricated with optimized Al_2O_3 interfacial layer on the n-type bare silicon substrate for minimizing the electron-hole recombination rate on the surface.
- To avoid graphene transfer process which usually causes degradation of power conversion efficiency performance and small active area due to metal and polymer residue remaining on graphene.
- Through VGHN structure, low reflectivity is achieved with about 4.7 eV work function measured and PCE was 6.4% at 0.9 cm^2 active area. With PEDOT: PSS and HNO_3 co-doping, PCE improved up to 10.97%.

INTRODUCTION

- Since the discovery of two-dimension (2D) materials, there has been great interest developed to overcome limitation of previous silicon-based devices, that 2D materials were functionalized into wide variety of applications and proved their feasibility.
- Silicon-based solar cells has notable disadvantages such as high refractive index of silicon (~3.5), which causes limitation of photon absorption and limited wavelength spectrum to obtain energy. Also, process to acquire p-type and n-type silicon to fabricate p-n junction is complicated and it needs subtle controls.
- Recently reported graphene-silicon Schottky solar cells mostly utilized graphene by transferring chemical vapor deposition (CVD) grown graphene to target substrate. However, instead of transfer, by plasma enhanced chemical vapor deposition (PECVD) method, single-atom thick layer was grown directly on the silicon substrate.
- Interfacial layer works as a hole transporting layer which minimizes dark current and reduce recombination rate. Therefore, Al_2O_3 layer was deposited with atomic layer deposition (ALD) technique on the n-type silicon substrate, before the graphene growth.

EXPERIMENTAL DETAILS

Device fabrication process

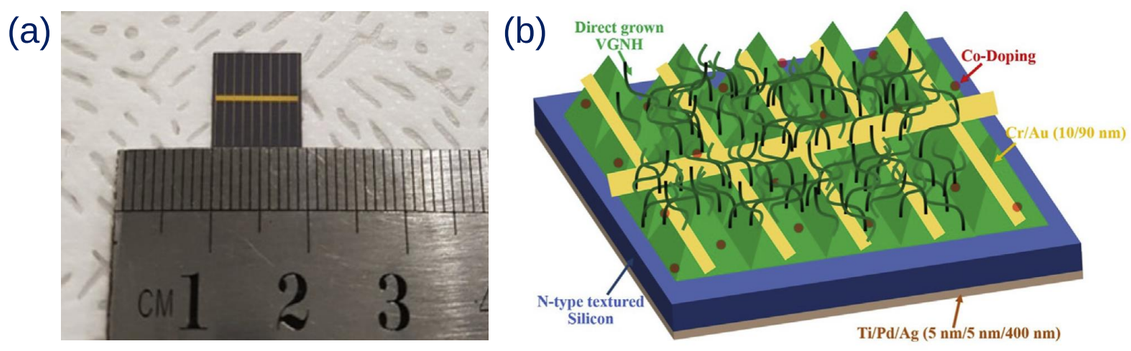


Fig 1. (a) Photograph of directly grown VGNH solar cell device. (b) Device illustration that shows the schematic of device composition layers and substances.

- The n-type silicon substrate (1-5 Ω • cm) was firstly cleaned with trichloroethylene (TCE), acetone and RCA-1 standard method ($NH_4OH/DI/H_2O_2$) (1:5:1) to remove surface contamination.
- After cleaning, texturing was performed with (DI/TMAH/IPA) (12:1:1) solution, stirring at 150 rpm with 80 °C heating for 35 minutes. Here RCA-2 standard method ($HCI/DI/H_2O_2$) (1:4:1) was adopted after texturing and etching native oxide layer.
- To grow Al_2O_3 interfacial layer, ALD was put into use and Al_2O_3 layer was grew to 30 Å thick, which is optimized value to efficiently increase performance of solar cell samples.
- After deposition of Al_2O_3 layer, graphene was directly grown inside PECVD vacuum chamber at 750 °C for 30 minutes. Here, CH_4 (10 sccm) and H_2 (20 sccm) precursor gases were injected to the chamber.
- Finally, Ti (5 nm)/Au (95 nm) emitter layers (top electrodes) and Ti (5 nm)/Pd (5 nm)/Ag (400 nm) base layers (rear electrodes) were deposited with e-beam evaporator, forming ohmic contacts, respectively.

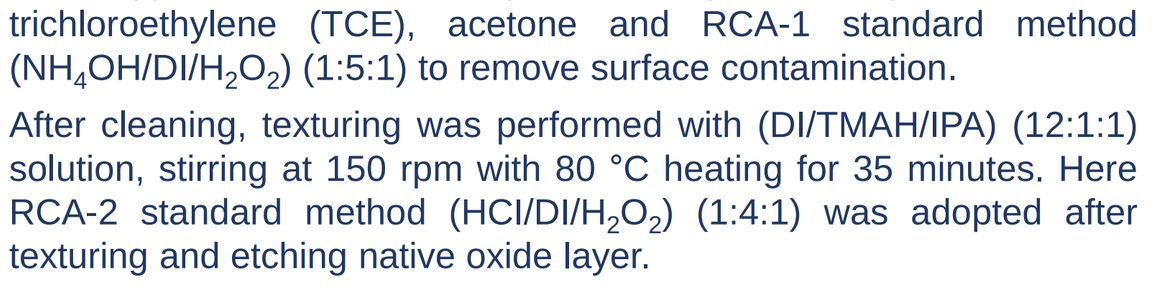


Fig 2. (a) Schematic of graphene grown on textured silicon. (b)VGNH formed on Al_2O_3 interfacial layer. (c) Final device, co-doped with PEDOT: PSS and HNO_3.

RESULT AND DISCUSSION

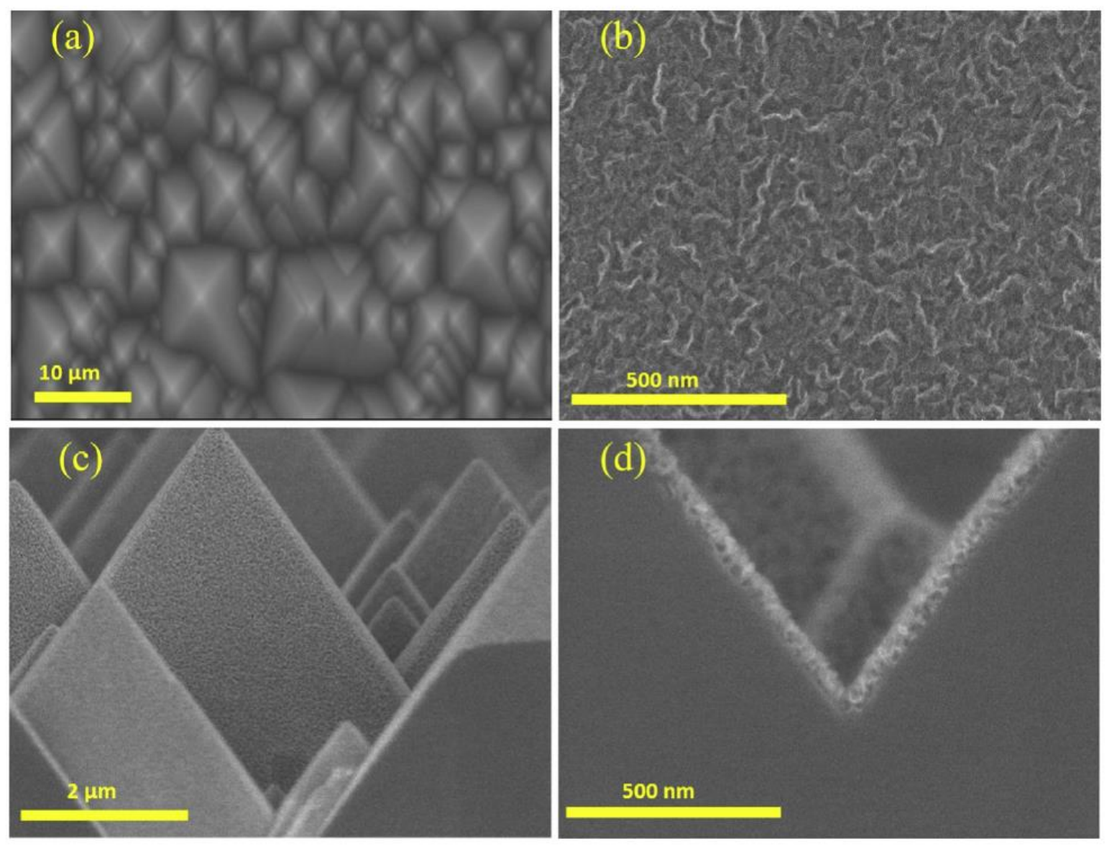


Fig 3. (a) Low resolution FE-SEM image displays morphology of textured silicon substrate. (b) Top view image of textured substrate at high resolution. (c, d) The cross-sectional images which confirms uniform VGNH growth.

- Fabricated samples were investigated with FE-SEM to identify the uniformity of VGNH formation. They developed curly shapes which are closely distributed on the silicon substrate. Cross-section shows that VGNH were grown with uniform thickness which means thickness doesn't depend on angles.

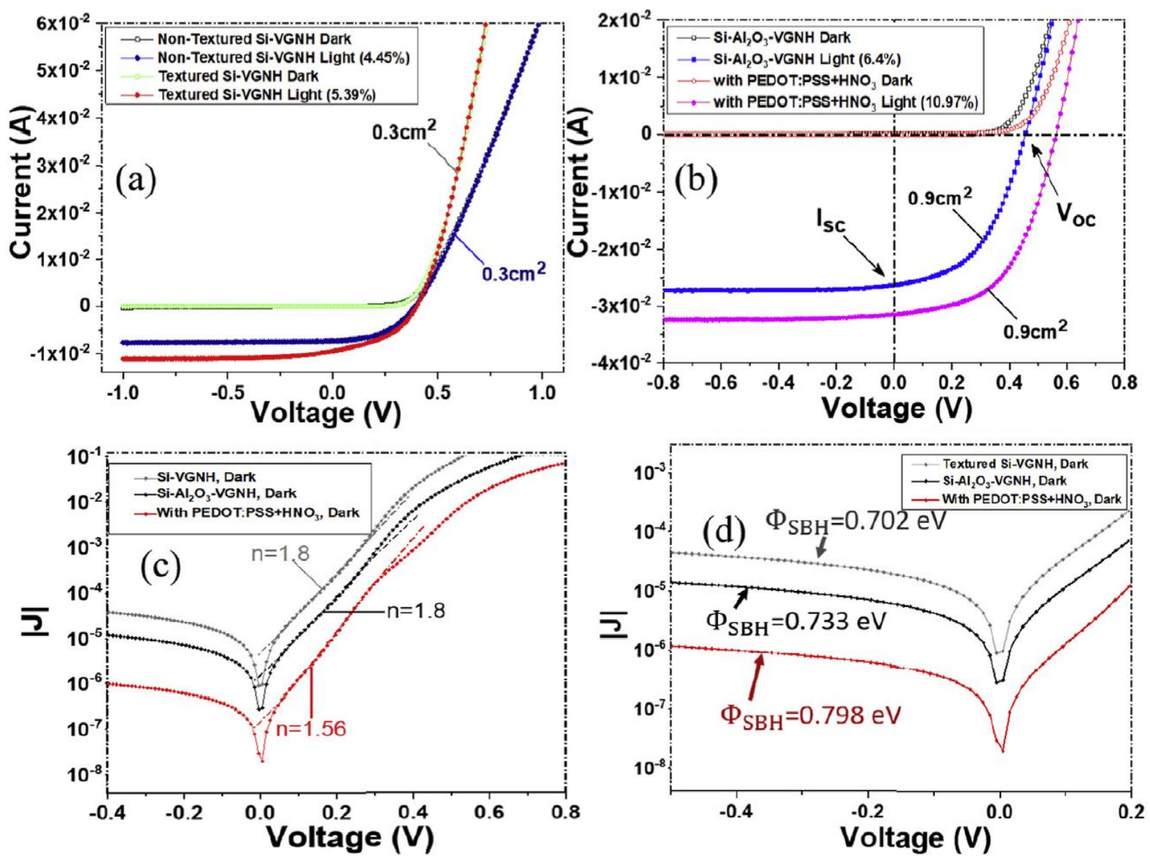


Fig 4. (a) I-V curve measured on non-textured Si-VGNH and textured Si-VGNH Schottky junction solar cells. (b) Effects of Al_2O_3 interfacial layer and co-doping is demonstrated. (c) J-V curve of semi-log scale for ideality factor estimation. (d) J-V data extraction to deduce Schottky barrier height.

- I_{SC} and PCE were increased after silicon texturing attributed to enhanced photo-absorption and broaden active areas. Nonetheless, ideality factor resulted in n=1.8 was obtained for both low built-in potentials and high combination rate. Co-doping effect increased PCE and lowered ideality factor since it reduced resistance and raised work function.
- With interfacial layer, it not only improved efficiency but also stabilized the solar cell that it reduced aging effect, which resulted no notable performance degradation after 2 months.
- As Schottky barrier height (SBH) increases recombination rate is lowered that electrons are remained at silicon side for longer time. This enhances PCE of solar cell that with co-doping, 10.97% is achieved.

CONCLUSION

- This work demonstrates genuine method to functionalize graphene for solar cell application without graphene transfer process. VGNH/Si and VGNH/Al_2O_3/Si based solar cell devices were fabricated under optimized growth conditions. The efficiency of 10.97% was acquired after co-doping p-type dopants; PEDOT: PSS and HNO_3. This was possible owing to VGNH's low resistance, high absorption rate and high photocarrier generation rate. Overall, it is confirmed that texturing, doping, and interfacial layer positively affects performance of graphene-silicon Schottky junction solar cell.