Transferring Carbon Nanotubes and Graphene onto Antireflective Surfaces for High-efficiency Solar Cells

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Solar cells and flexible electronics are important topics today as the energy and technology industries are two of the fastest growing ones. By texturing a silicon surface, it develops antireflective properties for use specifically in CNT film and graphene solar cells, where we will also be able to test the limits of flexibility of those two materials across a rough surface. Based on a recipe from literature, for substrate preparation we etched pyramids out of the silicon substrate along the 111 plane by using sodium hydroxide after cleaning the native oxide from its surface and then etched it using a solution of Metasilicate-nonahydrate, potassium hydroxide, and isopropyl alcohol. By varying the concentrations, we constructed relationships between the variables and pyramid size and optimized the surface to have the most uniform, smallest pyramids possible. We investigated the contact between the etched surfaces and graphene and carbon nanotube films by SEM imaging and Raman mapping. While similar substrates have been previously studied; our research brings more detail to the subject as we investigate specifically the substrates covered with CNT films and graphene beyond fine tuning the etching process. We compared the efficiency of CNT and graphene solar cells and quality of contact between CNT films and graphene using substrates with variously rough silicon surfaces. Finding the limits on the flexibility and relative solar cell efficiencies of CNT film and graphene on these surfaces leads to improving CNT and graphene solar cells as well as sets new opportunities into flexible electronics.

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Background

Advantages of CNT and graphene
- High electrical conductivity
- High optical transparency
- High mechanical flexibility

Challenges: The high mechanical flexibility of CNT and graphene has not been fully exploited.

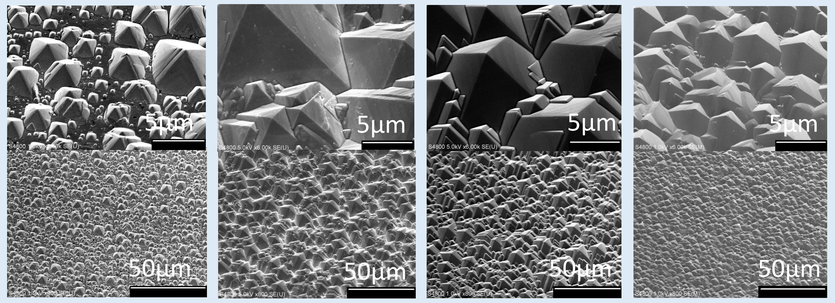
Target

- To explore the possibility of transferring CNTs and graphene to AF surfaces.
- To exploit the excellent mechanical properties of CNT and graphene in solar cell applications

Silicon Etching

Silicon Etchings by Temperature

Solution: 5% Silicate, 2% Hydroxide, 8% IPA; Hydroxide time: 120 min; Solution time: 90 min



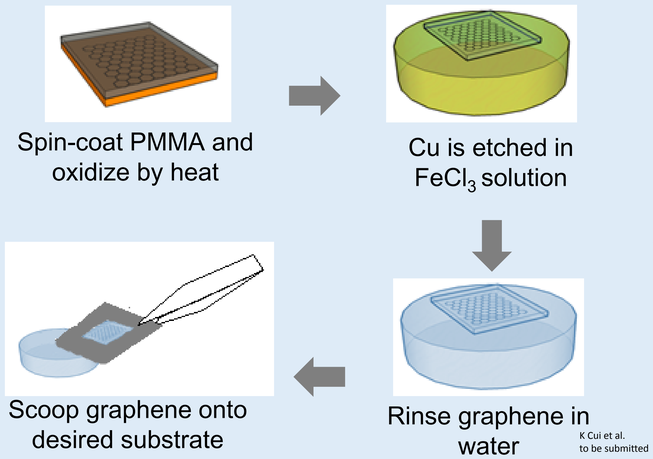
90°C 80°C 65°C 50°C

Average Etching Sizes by Temperature

Sample name	Temp (°C)	Base (µm)	Height (µm)	Surface Area per Pyramid (µm²)
N/A	90	10.0	17.5	364.55
Rough 1	80	13.0	22.8	616.09
Rough 2	70	11.0	19.3	441.10
Rough 3	50	5.40	9.47	106.30

Etching conditions have been modified based on the following article:
S. M. Iftiquar, Youngwoo Lee, Minkyu Ju, Nagarajan Balaji, Suresh Kumar Dhungel and Junsin Yi (2012). Fabrication of Crystalline Silicon Solar Cell with Emitter Diffusion, SiNx Surface Passivation and Screen Printing of Electrode, Photodiodes - From Fundamentals to Applications, Dr. Ilgu Yun (Ed.), ISBN: 978-953-51-0895-5, InTech, DOI: 10.5772/51065.
*All substrates were p-doped silicon

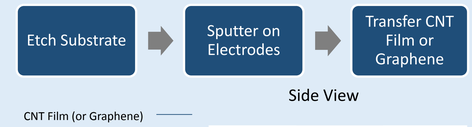
Graphene Transfer

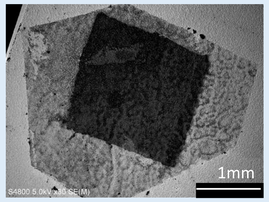


CNT Wet transfer: To spread out the CNT film, first rinse it in ethanol then follow the same last two steps of graphene transfer.

Solar Cell Structure

Etch Substrate → Sputter on Electrodes → Transfer CNT Film or Graphene



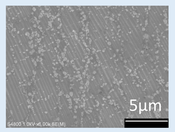


Single domain graphene over solar cell window

Contact

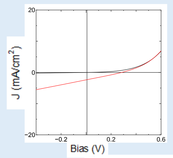
Graphene

Smooth

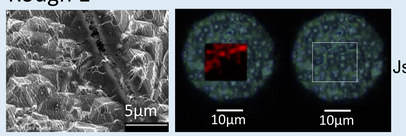


PCE: 0.179%
FF: 26.4%
Jsc: 2.38 mA/cm²
Voc: .285V

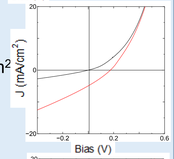
Cell Efficiency



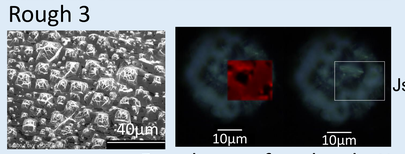
Rough 1



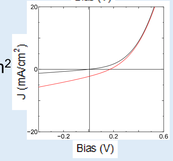
PCE: 0.243%
FF: 28.0%
Jsc: 4.95 mA/cm²
Voc: .175V



Rough 3



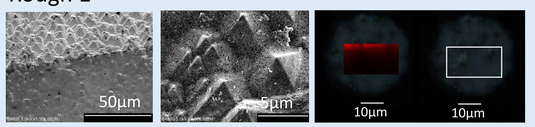
PCE: 0.114%
FF: 29.0%
Jsc: 2.30 mA/cm²
Voc: .170V



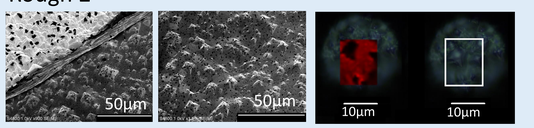
Rougher surface has better contact;
Appearance of cracking could be broken graphene
Graphene has PMMA layer of 300nm thickness

CNT

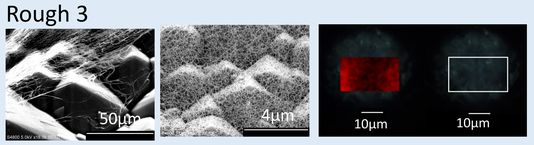
Rough 1



Rough 2



Rough 3



Rougher surface has better contact;
Film could still be suspended at base of pyramids
CNT film has transparency 90% and 80nm thickness

Solar Cell Doping

Doping Properties

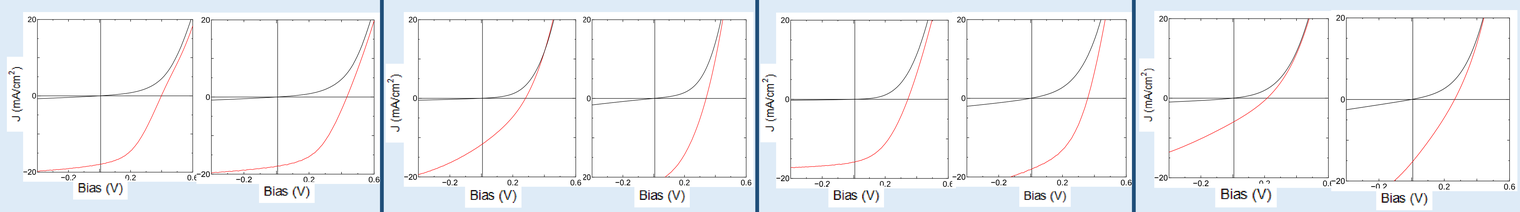
- Particles help with antireflection
- Increase charge carrier density
- Increase FF and Voltage
- Decrease Sheet Resistance

Methods

Copper Chloride solution was dropped onto the solar cell surface and allowed to dry before the "After" testing

CNT Solar Cells with $CuCl_2$ Doping

	Smooth		Rough 1		Rough 2		Rough 3	
	Before	After	Before	After	Before	After	Before	After
PCE	3.02%	3.49%	1.04%	2.85%	2.24%	2.69%	0.373%	1.14%
FF	42.2%	44.9%	31.3%	38.5%	41.1%	41.5%	28.5%	28.0%
Jsc	18.0 mA/cm²	17.96 mA/cm²	11.8 mA/cm²	21.8 mA/cm²	15.9 mA/cm²	18.1 mA/cm²	6.08 mA/cm²	15.5 mA/cm²
Voc	0.397 V	0.433V	.280V	.340 V	0.343V	0.265V	.215 V	.262 V
		PCE Increase 15%		PCE Increase 174%		PCE Increase 20%		PCE Increase 305%



Observations

- Doping is effective regardless of roughness
- Cells with lower original efficiency have higher efficiency after doping

Significance

- Testing the flexibility of Graphene and CNT films
- $CuCl_2$ doping can be applied to variety of cells

Future Modifications

- Adjust transfer process to damage films less
- Measure antireflective properties of pyramids
- Minimize natural SiO_2 layer formed between etching and sputtering

Acknowledgements
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