Silicon Nanostructures for Photovoltaics

ECE 4803

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Background

Wafer Based Bulk Si cells

- Bulk Si cells currently dominate the market but are not cost-effective compared to thin-film cells [1]
- Achieved efficiency of 25%

Thin-Film cells

- More cost-effective in the long run
- Reduced absorption rate, which requires light trapping methods to increase efficiency
- Nanopattering and bandgap engineering (nanocrystals and nanowires) increase efficiency [1]

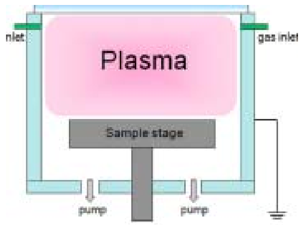
Fabrication of Si Nanostructures

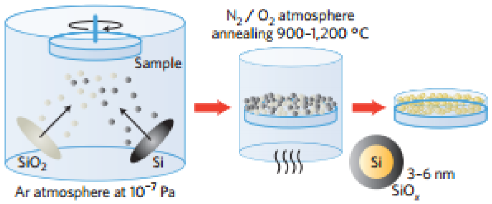
Plasma Processing

- Allows for precipitation of Si nanoclusters in SiO layer
- Suitable for Photovoltaic Systems [2]

Silicon Oxide Matrices

- SiO_2 is formed by various thin-film techniques (magnetron sputtering and chemical vapor deposition)
- High temperature applied to produce nanoclusters [1]





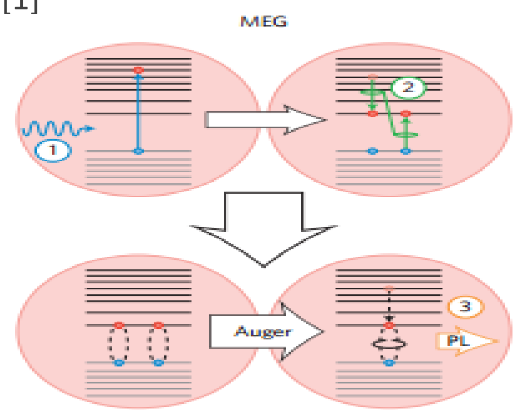
Nanostructures

Solar Shaper

- Extract energy from parts of the solar spectrum that are not efficiently converted
- Add-on that supplements traditional cells by converting incoming spectrum into a new spectrum [1]

Photon Cutting

- Multiple exciton generation efficiency enhanced due to high density carriers in confined environment
- Utilizes green and blue light from solar spectrum (up to 50% efficiency) [1]
- Lifetime of carriers is short



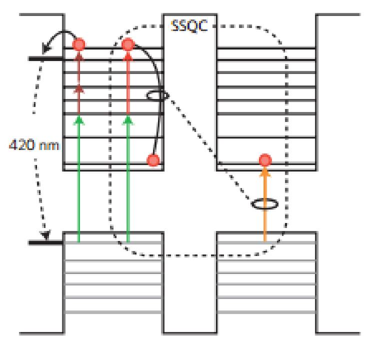
Nanocrystals

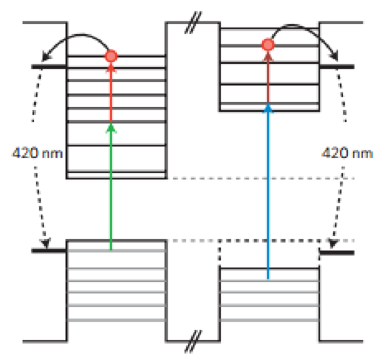
Photon Pasting

- Phononless Recombination
- Larger cross section for the absorption of infrared photons [1]

Quantum Confinement

- Can change the bandgap absorption and recombination rate
- Bandgap energy changes as dimensions get smaller (nanoscale) [3]





Nanowires

Axial Junctions

- p-i-n diode fabricated along length of nanowire by varying doping density during growth
- Fabricated coaxially by core-shell method
- Extremely strong absorber [1]

Radial Junctions

- Very short electrical path-length for carrier extraction
- Efficiency depends on extracted current and open-circuit voltage
- Quantum Confinement can be used to build cells [1]

Light Trapping

Lambertian Limit

- Photon can travel up to $4n^2$ time further than without light trapping
- Limit increases or decreases based on absorption strength [2]

Black Silicon

- Normal silicon reflects ~30% of incoming light
- Nanosized silicon completely suppresses back reflection [2]

Challenges

Light Trapping

- Very limited degrees of freedom for manipulating its photovoltaic properties
- Very difficult to trap light and reproduce on a large scale thereby limiting potential

Nanocrystals

- Carrier extraction is difficult; the potential barrier that aids quantum confinement impedes carrier extraction
- Tunneling and percolation between nanocrystals to extract carriers (not efficient)
- High doping density in nanowires without decreasing nanowire size to avoid depletion

References

[1] http://www.nature.com/nnano/journal/v9/n1/pdf/nnano.2013.271.pdf

[2] http://www.sciencedirect.com/science/article/pii/S0040609005024703

[3] http://rsta.royalsocietypublishing.org/content/364/1849/3493