2014 International Workshop on Environment and Alternative Energy

# Light Trapping in High Efficiency Interdigitated Back Contact Si Solar Cells


Javaneh Boroumand

Prof. Debashis Chanda

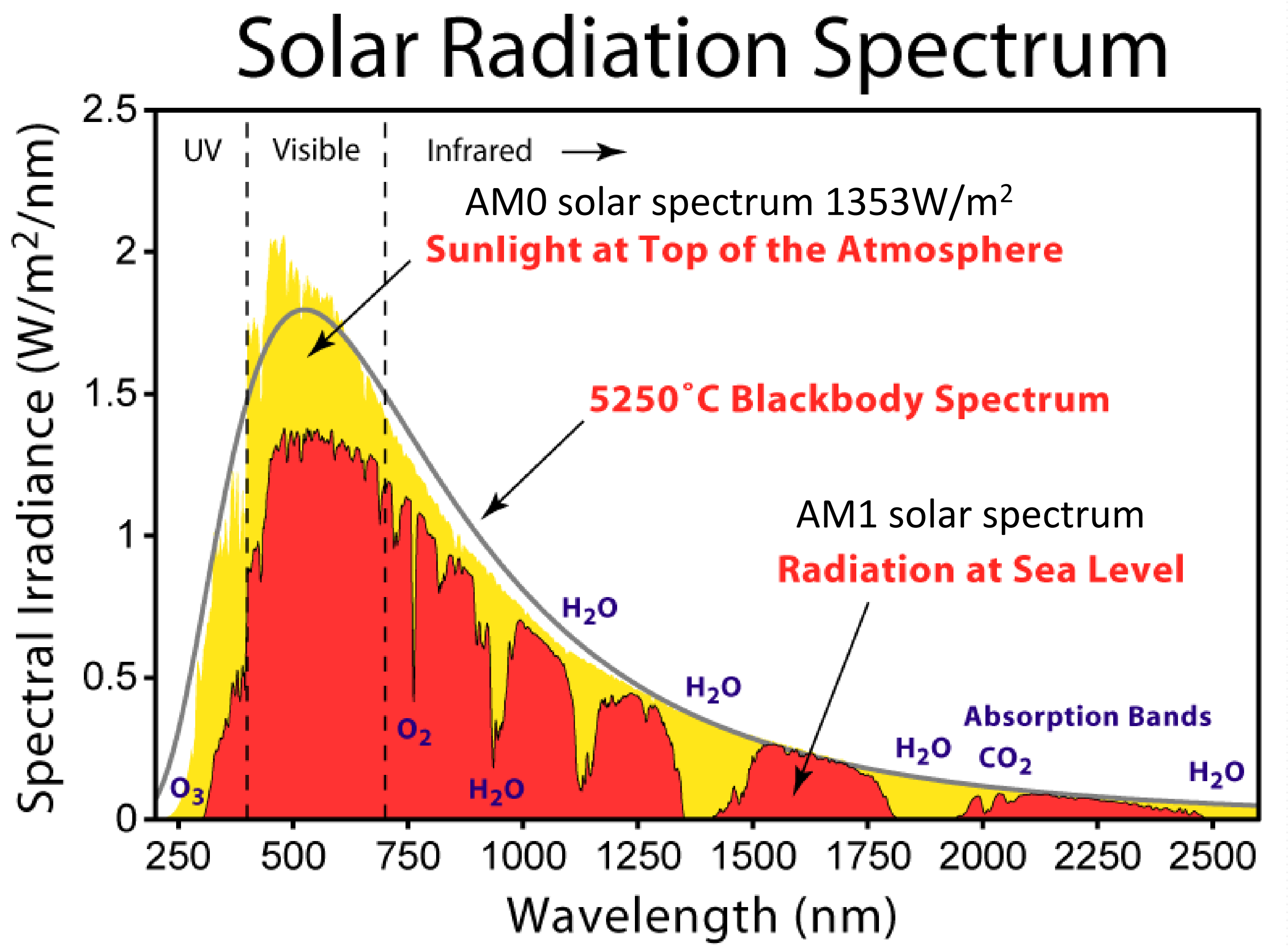
Physics, NSTC, CREOL

University of Central Florida

# Outlines

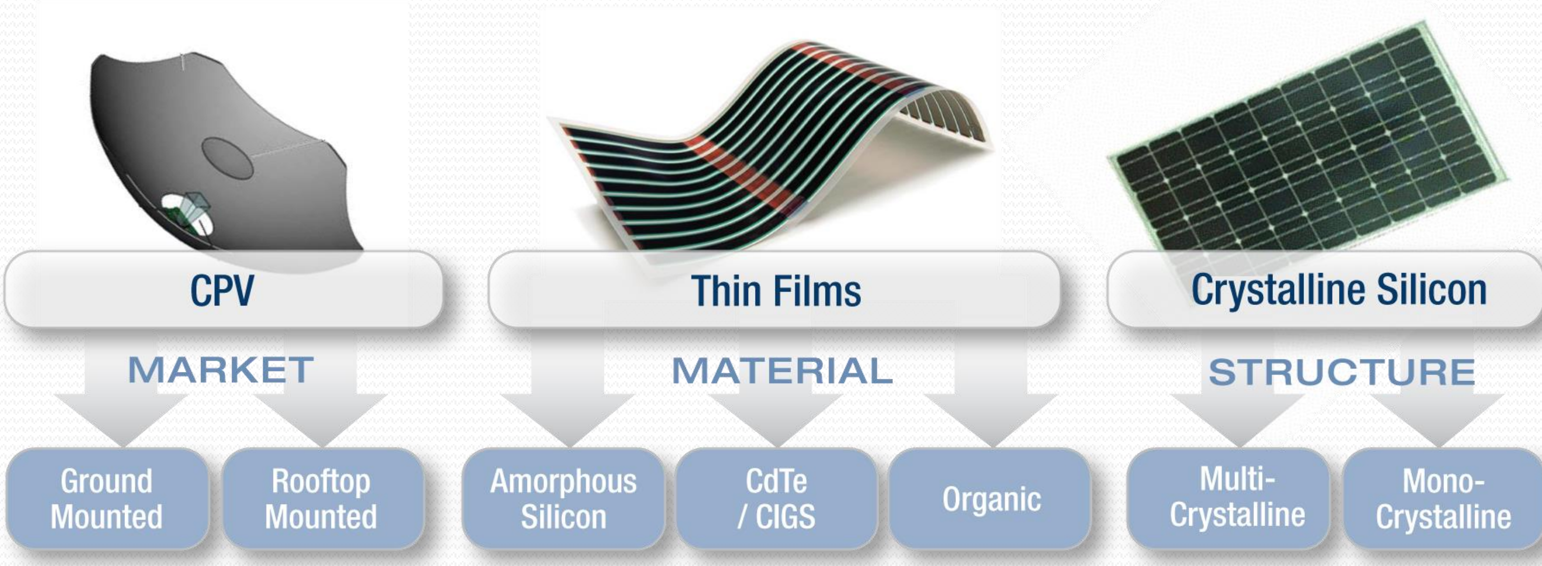
- **Basic solar cell overview**
  - Solar spectrum
  - Different types of solar cells
  - Advantages of c-Si cell
- **Light Trapping in Thin Film Solar Cells**
  - Absorption loss and need of light trapping
  - Make nano-patterns over large area
  - Prior work in thin silicon films
- **IBC cell for >20% efficiency**
  - Combining Electron and Photon Harvesting
- **Conclusion**

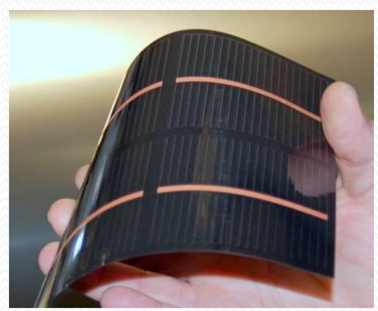
# Solar basics

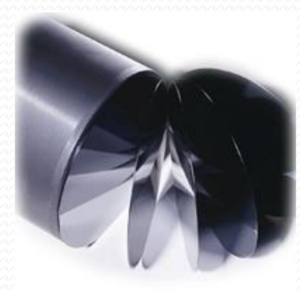



Spectral distribution of solar radiation.

# Different types of solar cells





GaAs

$Cu(In,Ga)Se_2$ ~ 1-2 um

c-Si ~ 180 um

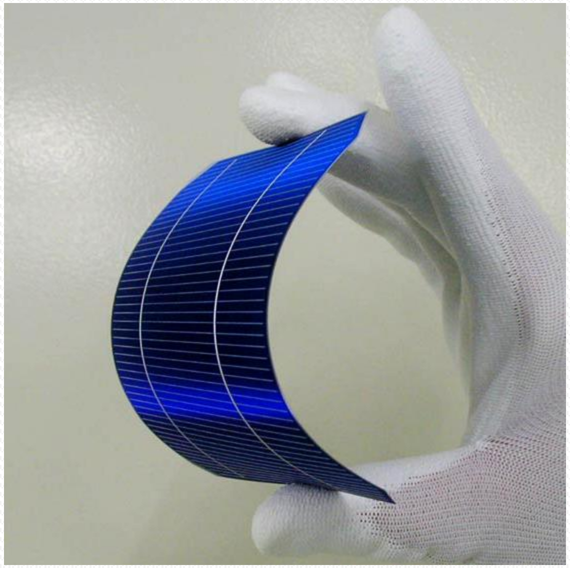
http://web.stanford.edu/group/mcgehee/presentations/McGehee2011.pdf

# Advantages of c-Si cell

**Why c-Silicon solar cell?**

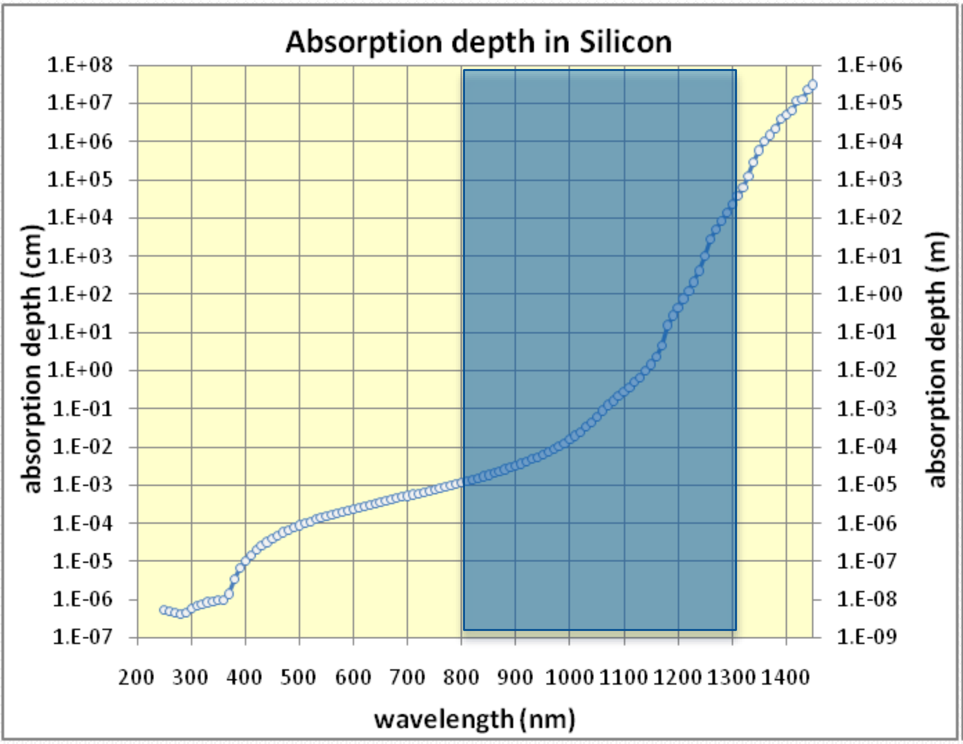
- Natural abundance
- Non toxic
- Superior electronic properties
- Chemical/radiation hardness
- Low degradation over time
- Great heat resistant

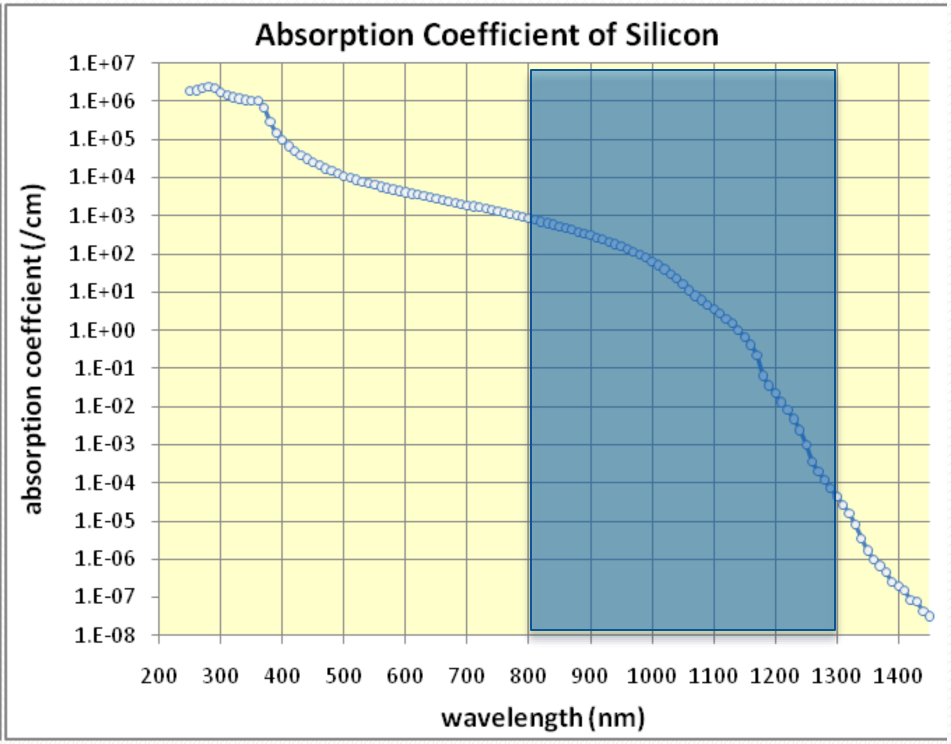
c-Si Cell



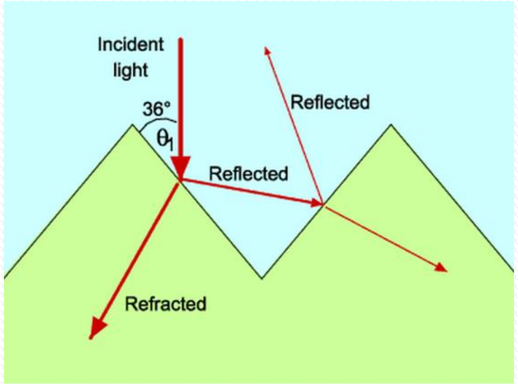
# Near band absorption loss

The absorption depth is the inverse of the absorption coefficient.



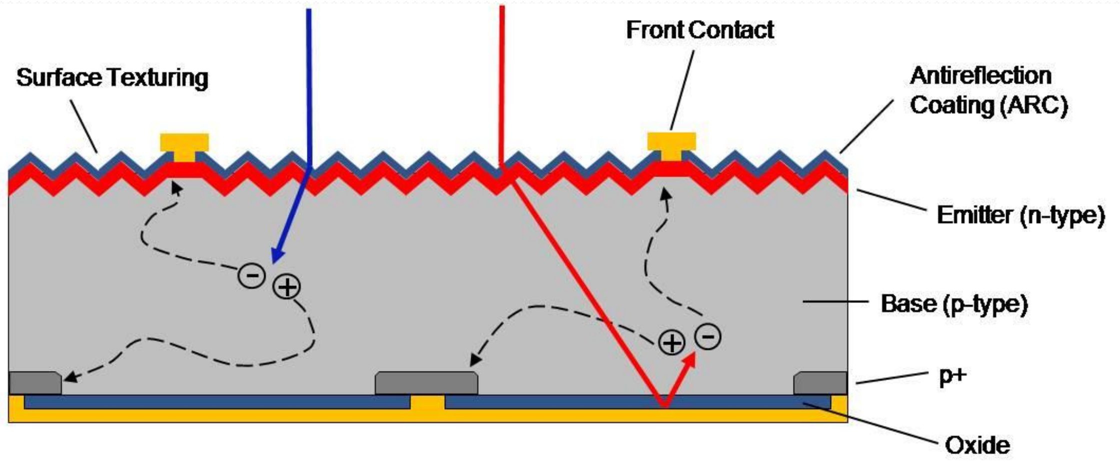



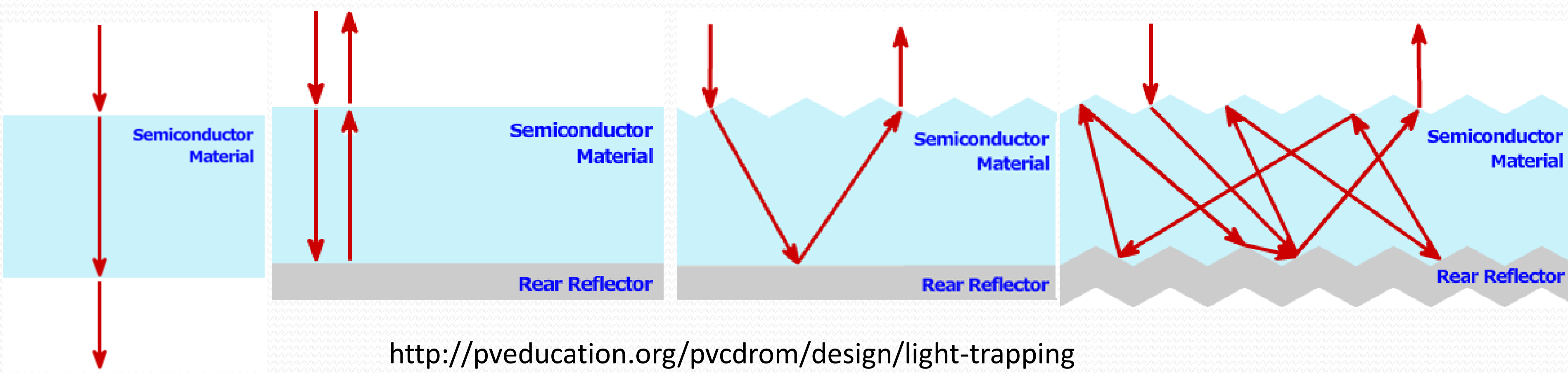

For the c-Si case where silicon strongly absorbs blue-green portion of the spectrum, the light trapping scheme is designed to trap light close to silicon band-edge where silicon is a weak absorber.




http://pveducation.org/pvcdrom/design/light-trapping

# Need for light trapping

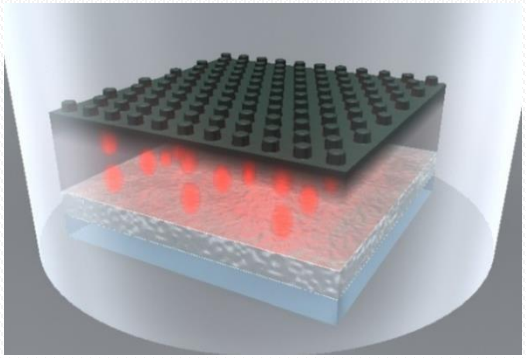


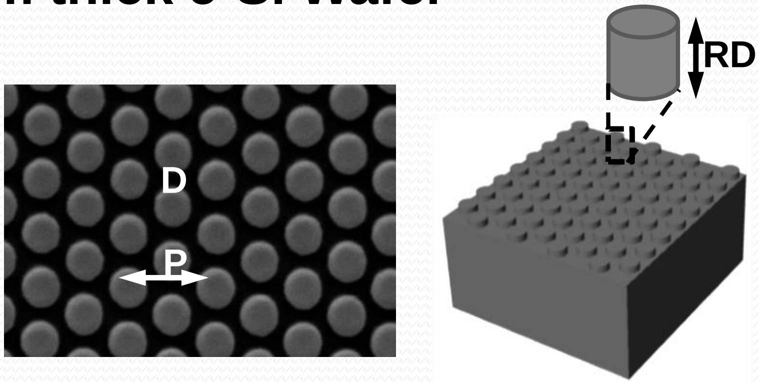




http://pveducation.org/pvcdrom/design/light-trapping

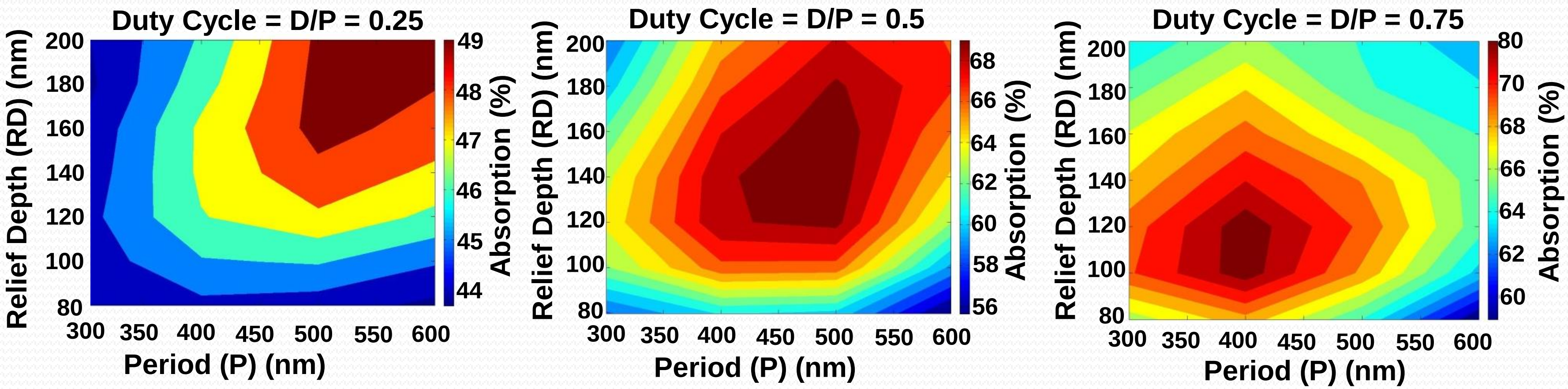
# Electromagnetic Design Optimization

- **Light Trapping Geometry for 6 μm thick c-Si Wafer**





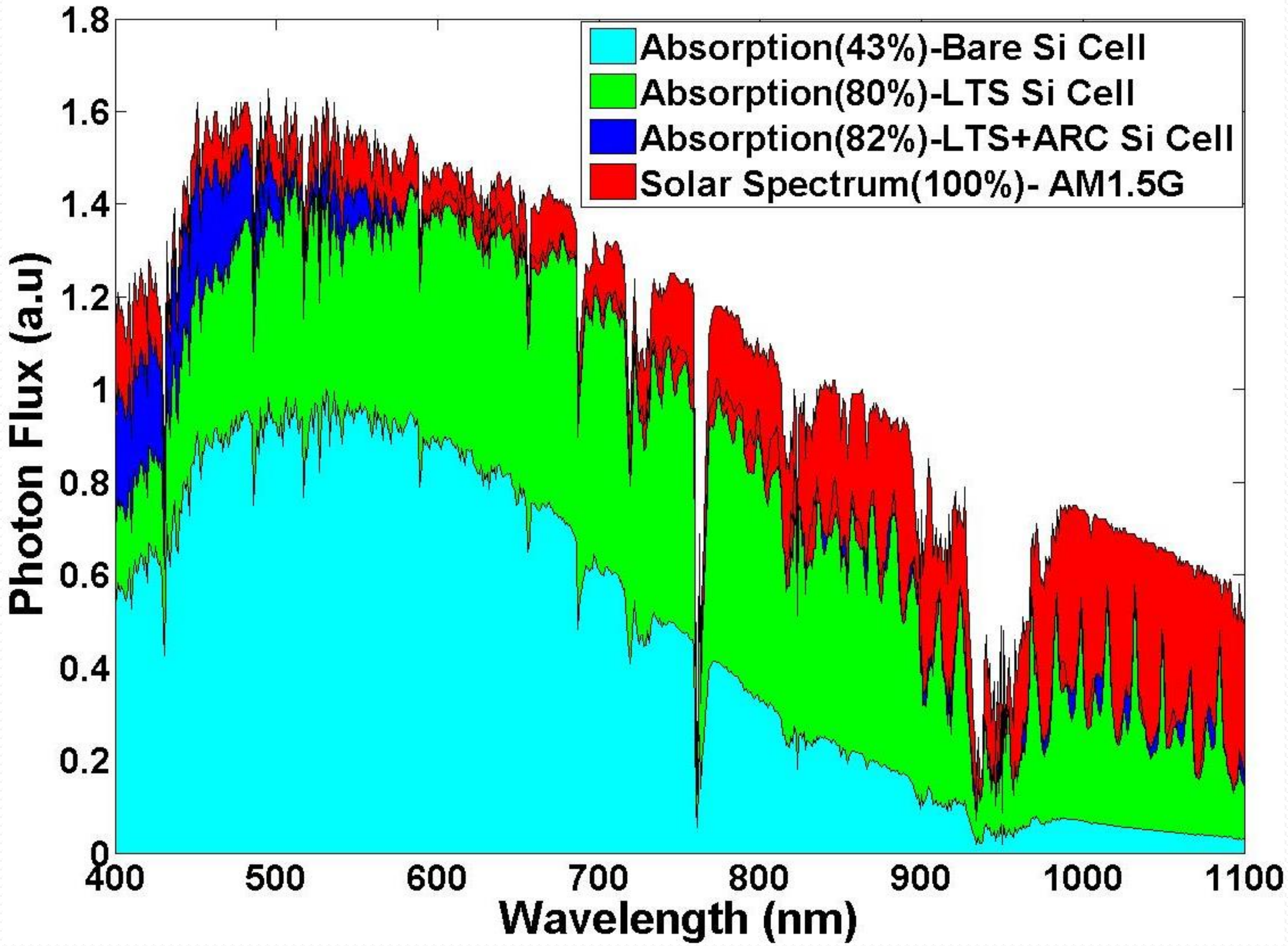

(left) Schematic of trapped light inside thin-film silicon wafer as waveguide and cavity modes. The layout of diffractive optics schematic and SEM image of patterned Si surface.




FDTD predicted integrated absorption of AM1.5G spectrum in 6 μm thick top diffractive optics etched c-Si wafer as a function of grating period (P) and relief depth (RD) for three duty (D/P) cycles of 0.25, 0.5 and 0.75 where D is the diameter of nanopillers.

# Absorption of Solar Spectrum

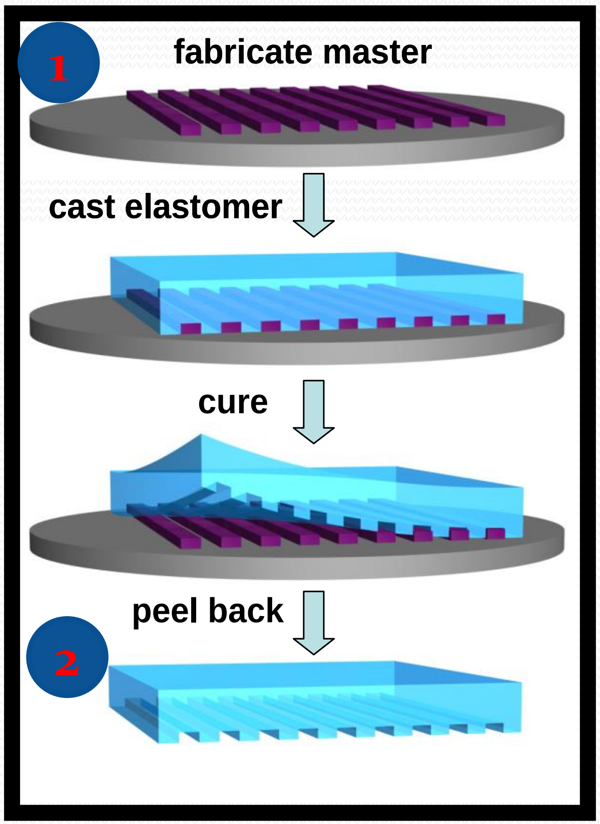
- 2D Si Grating Period = 500 nm, W =368 nm, H = 130 nm
- Si Slab = 5.87 µm + H (Total Length Simulation) = 6µm



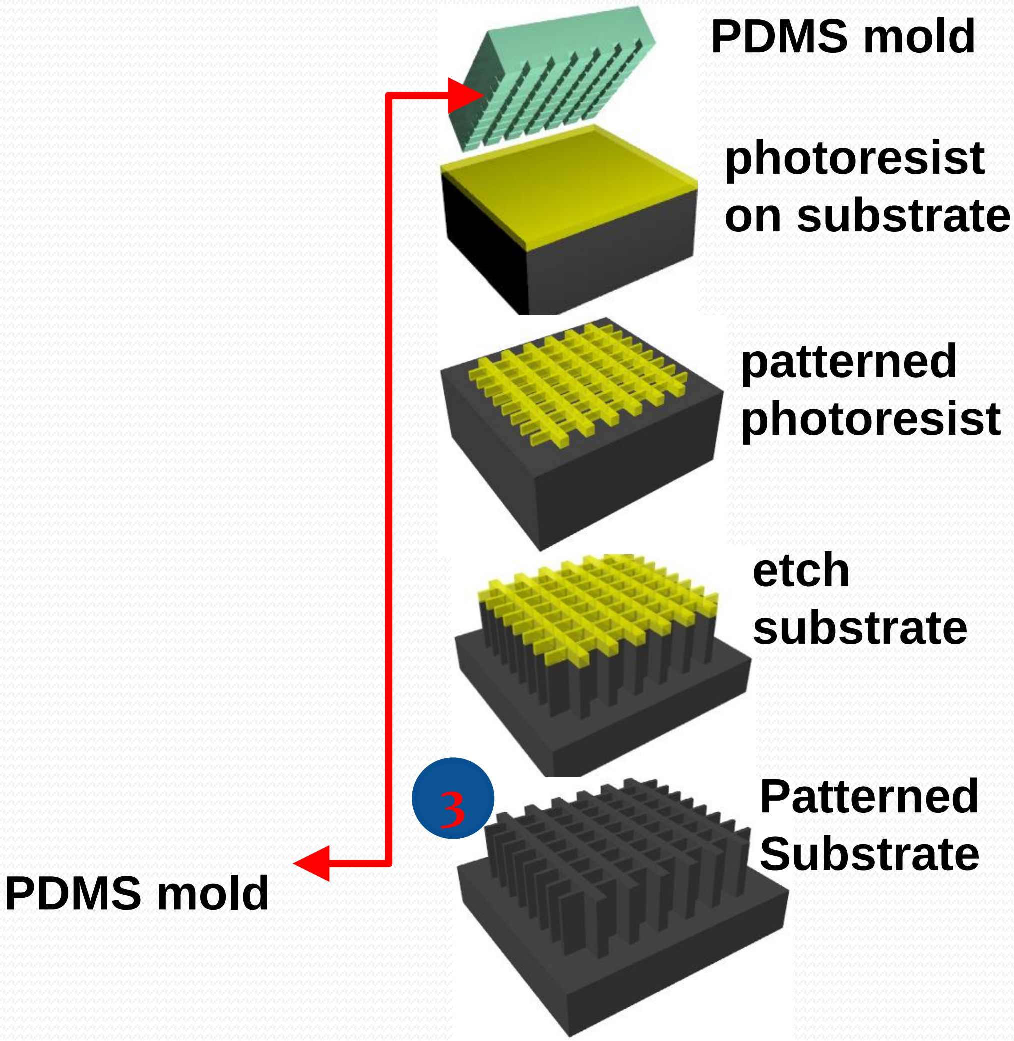
# Soft Lithography

## PDMS Mold Making

### Master made using DLW

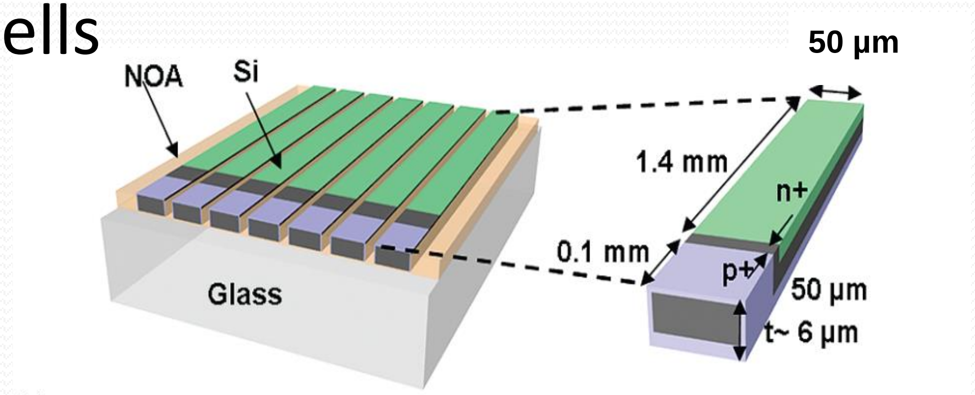



## Soft Nanoimprinting



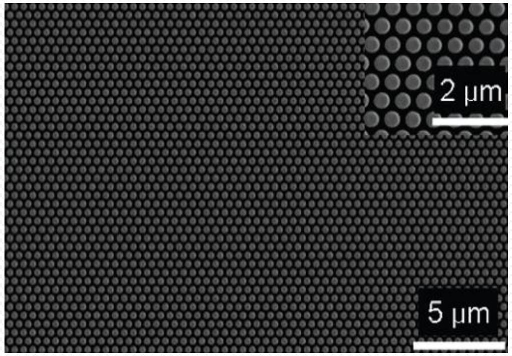
# Measurements data in 6 μm thick working light trapping c-Si cells

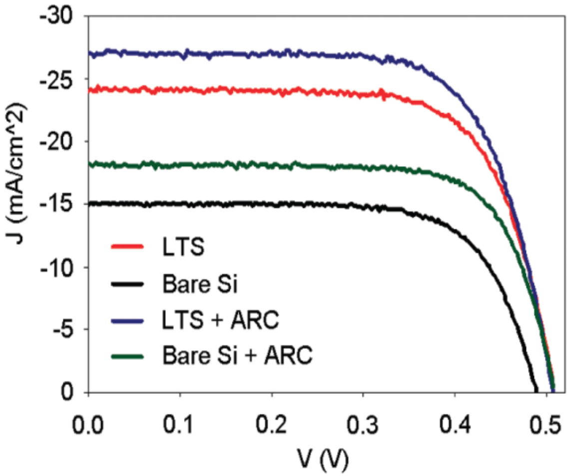
Microbar c-Silicon Solar Cells




Soft Lithography based
Hexagonal
Light Trapping Pattern

Period = 500 nm,
Relief Depth = 120 nm,
Diameter = 375 nm

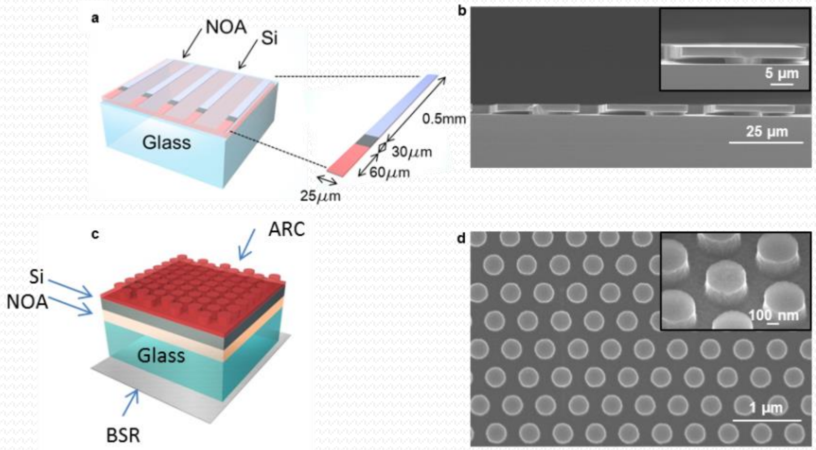


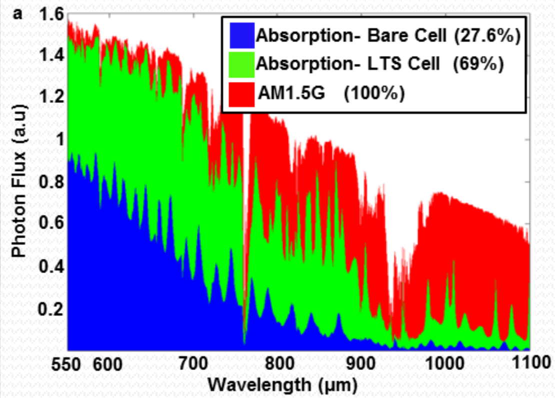

**Light Trapping Efficiency = 9.5%**

**D. Chanda** et. at., **Nano Letters,** 10, 3041-3046 (2010).

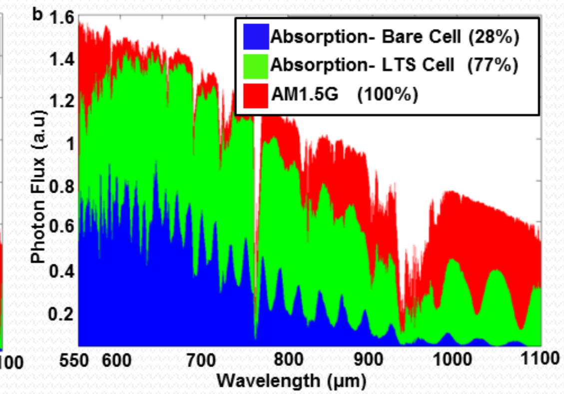
# Light Trapping in 2.8 μm thick working c-Si cells




FDTD




Measured




| Color | Methods | Efficiency | Enhancement |
|---|---|---|---|
| | Bare Si | 3.2% | 0% |
| | LTS | 6.8% | 112% |
| | LTS+ARC | 7.7% | 141% |
| | LTS+BSR | 9.3% | 190% |
| | LTS+BSR+ARC | 10.8% | 237% |

**-Overall, efficiency improved by 237%**

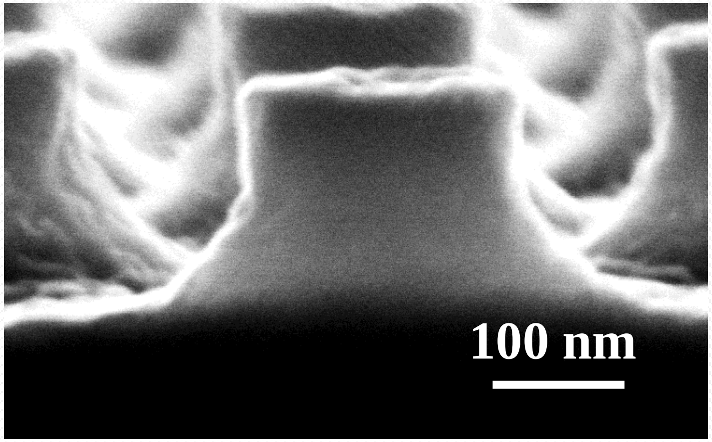
**-Max Efficiency = 10.8%**


**D. Chanda** et. at., , Light Trapping in Ultra-thin Mono-crystalline Silicon Solar Cells", (Cover Article) Advanced Energy Materials , (DOI: 10.1002/aenm.201300542 ), Nov 2013.

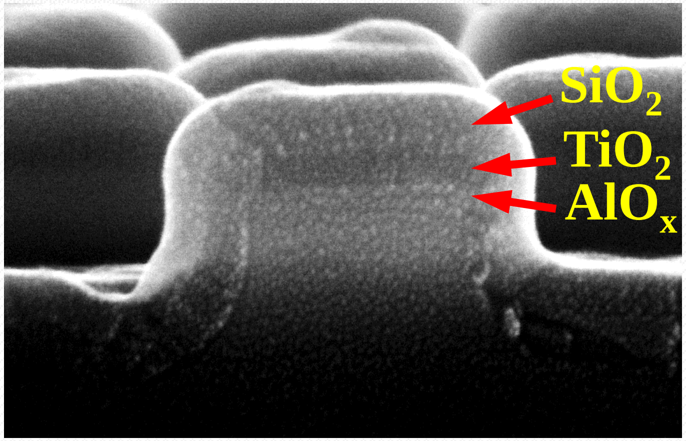
# Achieve high efficiency in thin c-Si solar cells

Light Trapping Pattern, Surface Passivation and Anti-Reflection Coating

**Si nanopillars**




**APCVD Coated Si nanopillars**

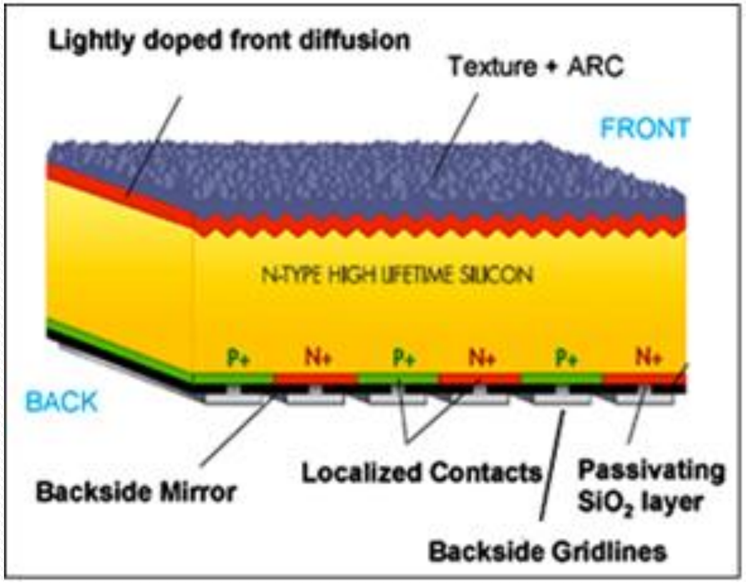


# On going

IBC cell for > 20% Efficiency

# Need combined Electron and Photon Harvesting

- **Minimizing carrier loss**
  - Passivation of front and back electrode
  - Shallow doped p-n junction
  - Locally p+ doped back surface field
- **Minimizing photon loss**
  - Front textured surface.
  - Single or multi layer ARC.
  - Back contact cell structure
- **Minimizing electrical loss**
  - Fine gridline front contact.
  - Selective emitter n- or p-type Si substrate with minority carrier diffusion length longer than the base thickness.

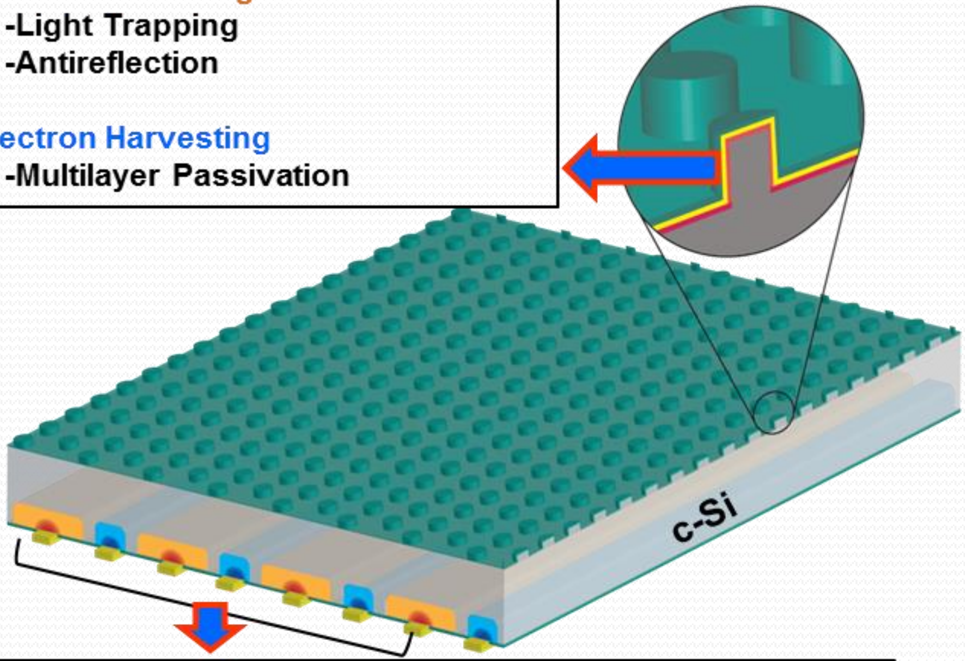


# 25 µm interdigitated back contact (IBC) cell

**Multi-Functional Patterning**

Photon Harvesting
- -Light Trapping
- -Antireflection

Electron Harvesting
- -Multilayer Passivation



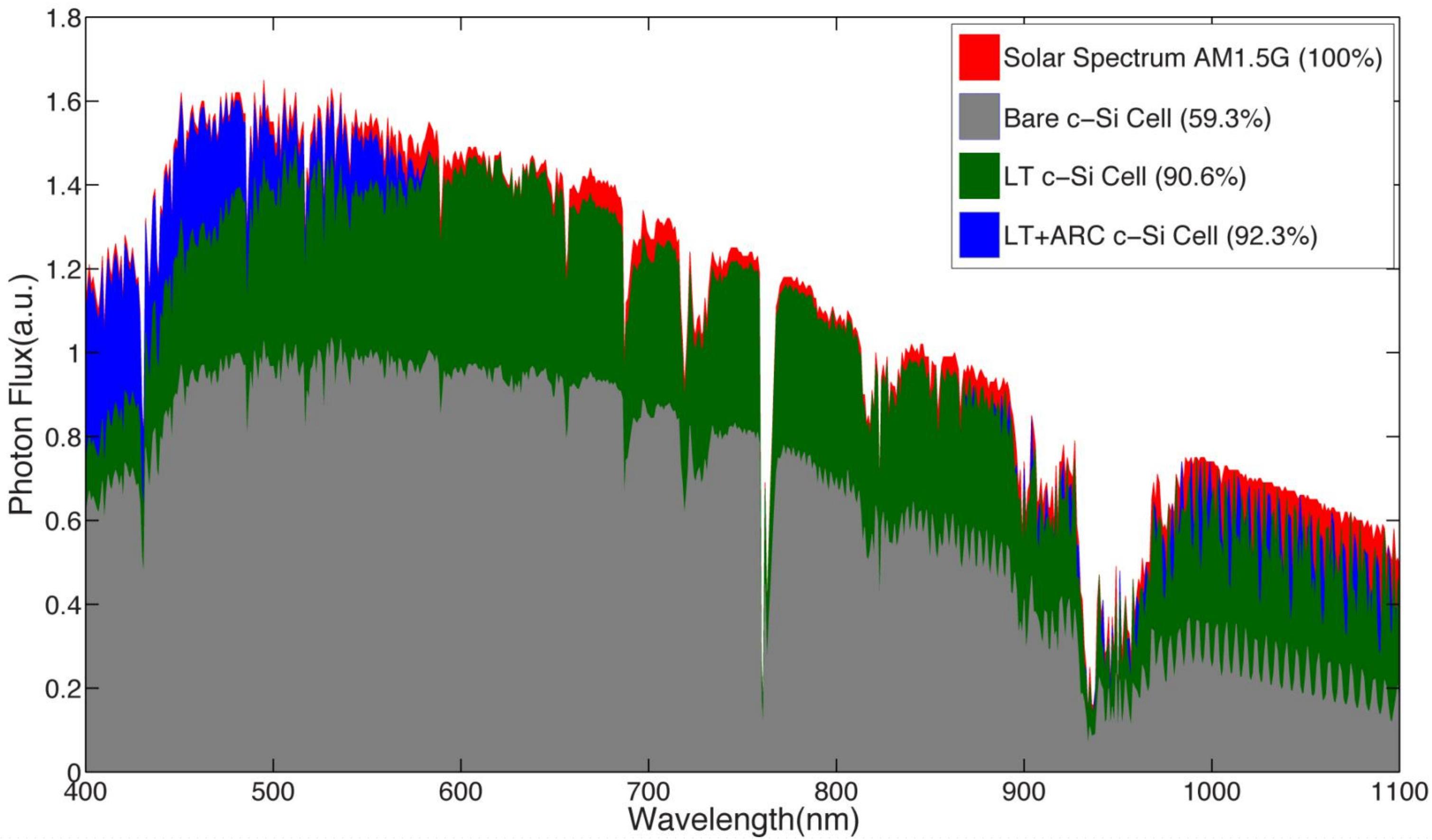

**Interdigitated Graded Doping Profile**

Photon Harvesting
- -No Front Contact Shadowing
- -About 80% Metal Back Contact as Back Side Reflector to form Optical Cavity

Electron Harvesting
- -Graded Doping Profile for better Charge Separation
- -Interdigitated Contacts for better Charge Collection

# Achieve 20% efficiency in 25 μm thick c-Si Wafer

The proposed hexagonal nanopillar array based light trapping scheme in presence of back side reflector demonstrated absorption of 78% of integrated solar spectrum in 3 μm thick c-Si slab which scales up to 90% when implemented on 25 μm thick wafer.



# Fabricating 100 micron IBC cell

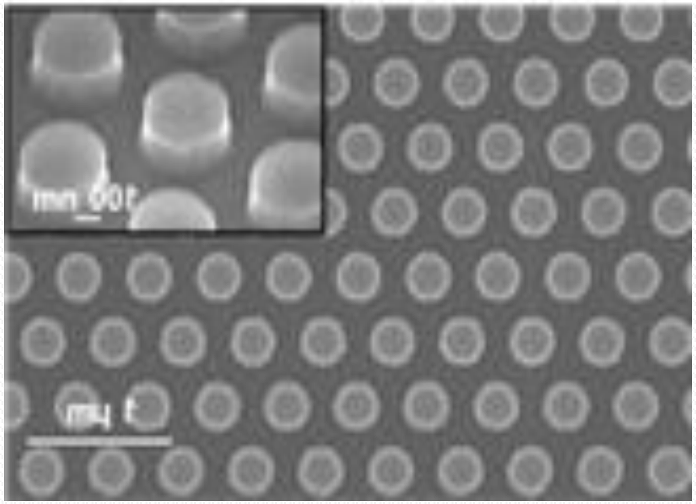


Image of hexagonal light trapping nanopillars on Silicon substrate

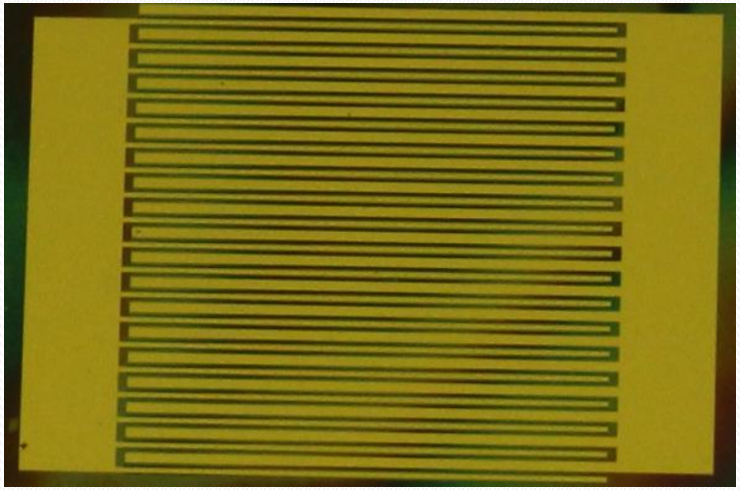


Image of interdigitated contact of 1 cmxcm IBC solar cell

# Conclusions

- Absorption optimization of thin silicon solar cells with/out light trapping, ARC, BSR is studied and simulated.
- Thin silicon solar cells was fabricated and electronically characterized.
- Nano patterning was developed on large area, 6”×6”.
- Ultimate goal is fabricating 25 μm c-Si solar cell with optimized light trapping and broadband coating design to absorb 100% of solar spectrum.

# Thank you!

Javaneh@knights.ucf.edu