# Enhanced solar cells and modules through advanced photon management and light capture

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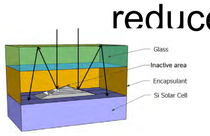
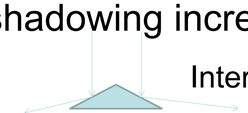
## Capabilities

- Predictive simulation
- Scattering matrix simulation and optical simulation
- Design of light capturing and light trapping solar architectures
- Thermal radiation nanoarrays to keep modules cool
- Nanoparticles for up conversion – design and synthesis (collaborator A. Mudring)
- Ab initio simulations of defects and electronic states
- Fabrication of patterned substrates with soft lithography
- Accelerated light soaking for cell degradation
- I-V and Quantum efficiency measurements

## Light capturing architectures

- Thin film stacks and coatings for infrared rejection
- Cooling the module and increasing lifetime by IR rejection
- Materials with modified thermal radiation to reduce operational temperature and degradation
- Measurement of IR response with FTIR spectrometers
- Design of interconnect lines and metal vias on module to reduce shadowing increase module performance.



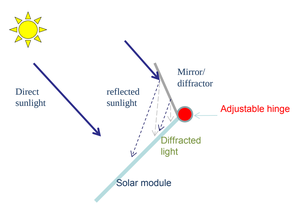



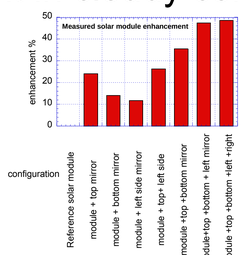
Interconnect or via

Active area of module

## Peripheral light capture

- Utilizing inactive areas of the module frame
- Substantial photocurrent gain (>20%) found in outdoor test s
- Collection of diffuse light in cloudy conditions

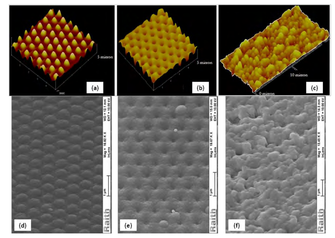


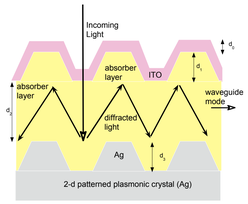



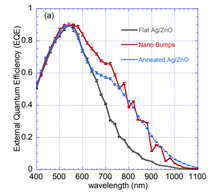

**Measurement**

Accelerated light soaking in $N_2$,
I-V, quantum efficiency
FTIR spectrometers to analyse bonding changes
Soft lithography

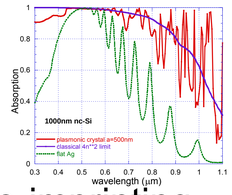
## Light trapping in thin Si cells





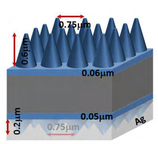



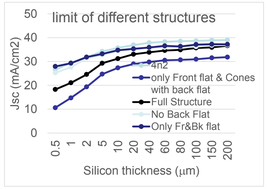

| substrate | Jsc (mA/cm$^2$) | enhancement |
|---|---|---|
| Bare Stainless steel | 14.2 | |
| SS + Ag | 16.1 | |
| Annealed Ag/ZnO | 20.4 | 27% / 43% |
| Nano hole array | 20.4 | 27%/ 43% |
| Nano cone array | 21.5 | 34% / 51% |

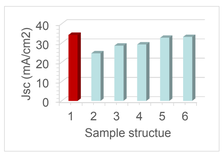


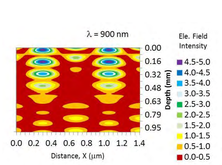

- Photonic-plasmonic nano-arrays made with nano-imprinting
- Solar cell grows conformally on all periodic substrates- Pitch a~750 nm
- 34% enhancement waveguiding modes in thin film
- Light enhancement and surface plasmon modes at back
- Currently working with Powerfilm and Triton

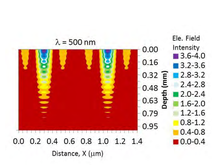
## Light trapping in c-Si solar cells



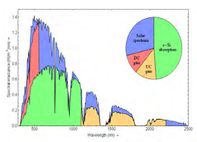



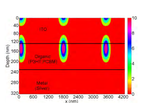



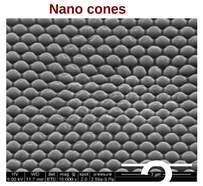



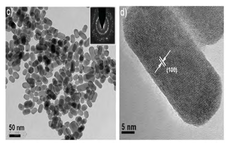

- Enhanced trapping of near IR light through diffraction by nano arrays (nano arrays are below glass)
- Improved anti reflection
- Si has flat surfaces to minimize surface recombination
- Maxwell's equations solved in *Fourier space in 3-dimensions*

## Up-conversion with nano particles








Absorption in the 1500 nm band can increase photo-currents by 20%
Lanathanide doped nanocrystals NaGdF4:Yb/Er/Tm
Field intensities can be enhanced by lens and nanoparticles need to be positioned at the maxima of the E field
Synthesis at Ames Lab is being performed by Anja Mudring

**Publications**: Nanoscale **8**, 4657 (2016); J Physical Chemistry C, **119** 23883, (2015) **119** (35), 20265 (2015); SOLMAT **129**, 115 (2014). ACS Photonics 1, 840 (2014).