Light trapping in plasmonic solar cells

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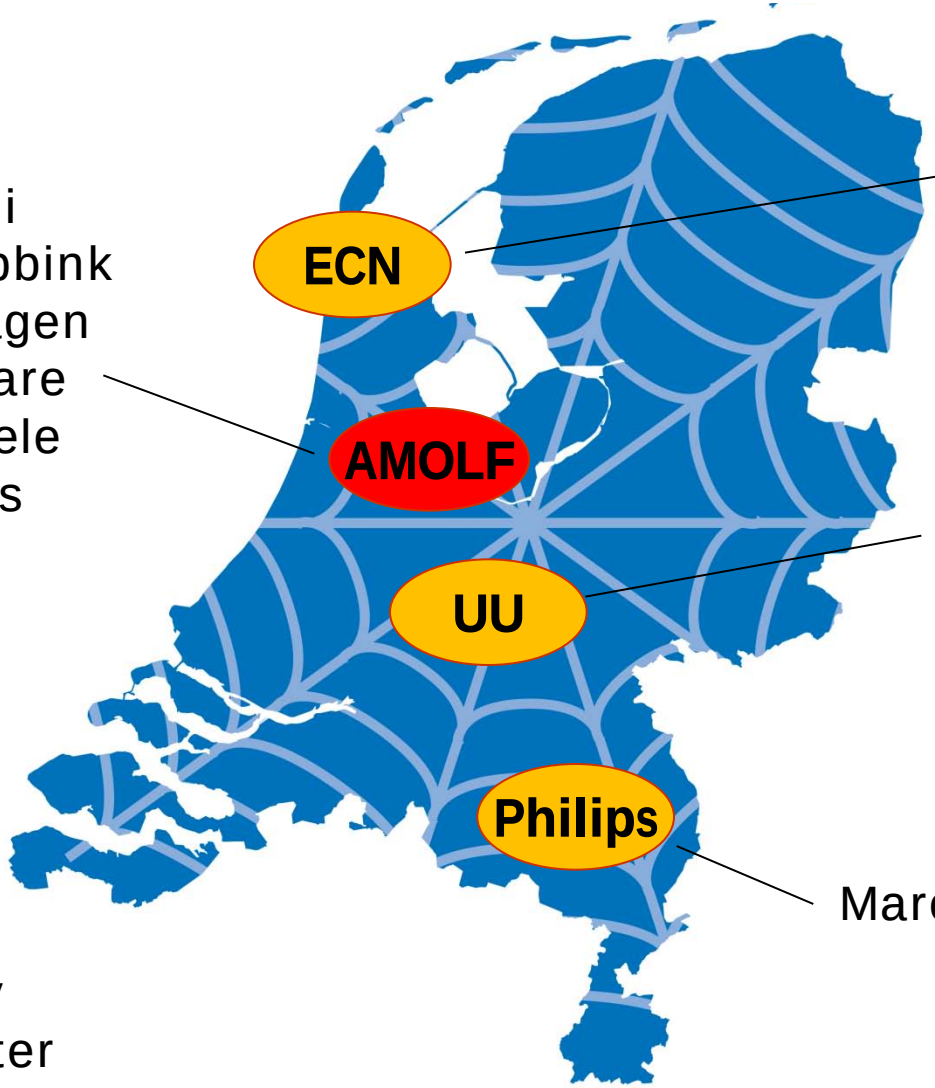
Collaborators

Advanced light management team



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Piero Spinelli
Maarten Hebbink
Ewold Verhagen
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Rene de Waele
Robb Walters

Lachlan Black
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Frank Lenzmann

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ECN

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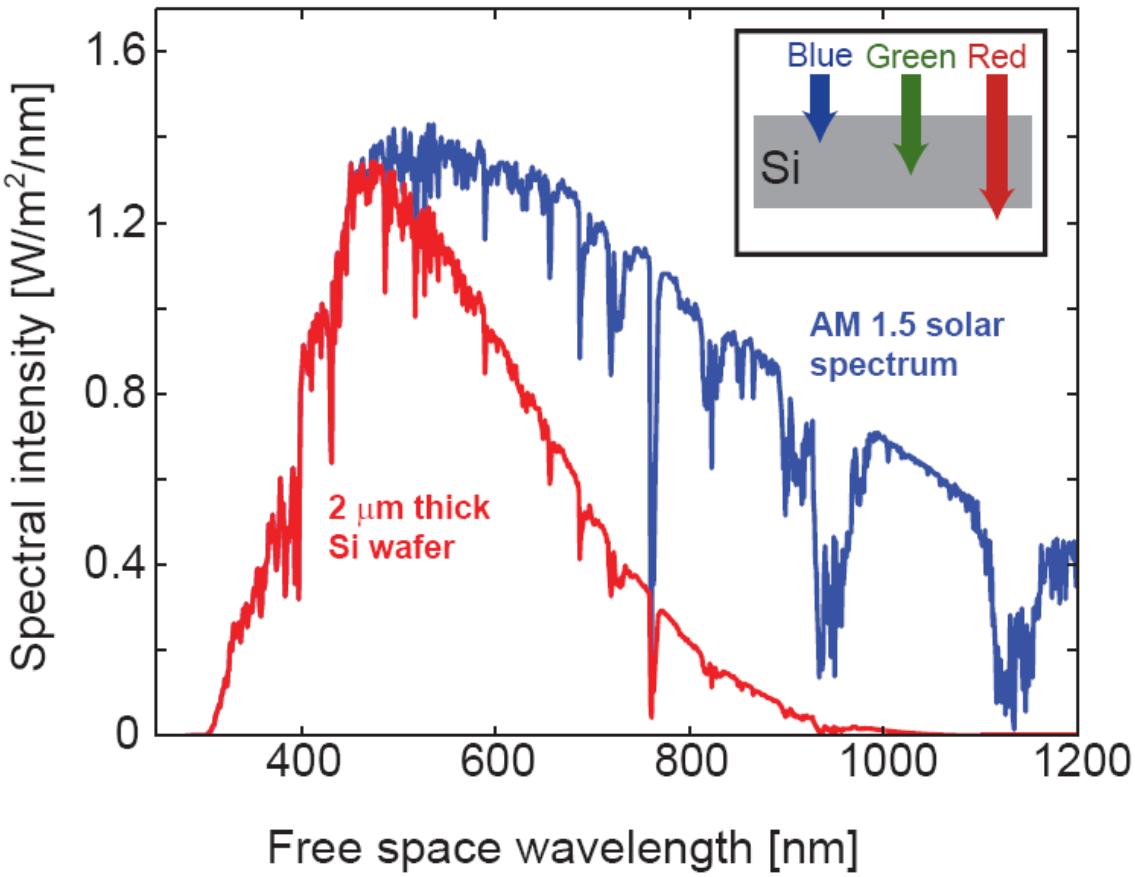
CALIFORNIA INSTITUTE OF TECHNOLOGY 1891

Light is poorly absorbed in a thin-film solar cell



Solar spectrum absorbed in 2 μm thick Si

Materials resources for photovoltaics

Requirements to construct 1 TW of PV with optically thick cells at 15% efficiency

Solutions:

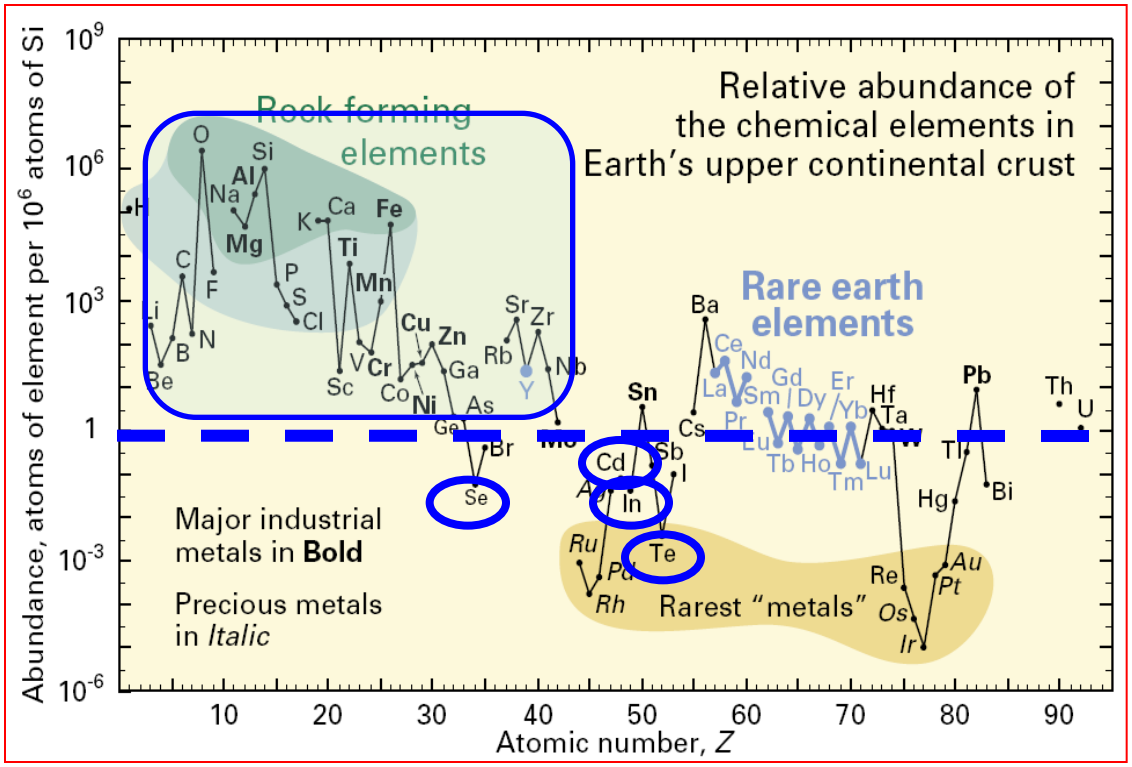
1) Earth Abundant Semiconductors (Si, other)

2) Reduce semiconductor volume

Enhance light absorption

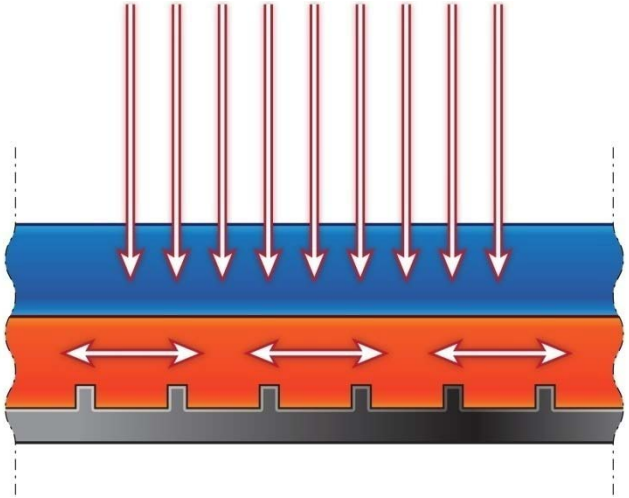
Advanced Light Management

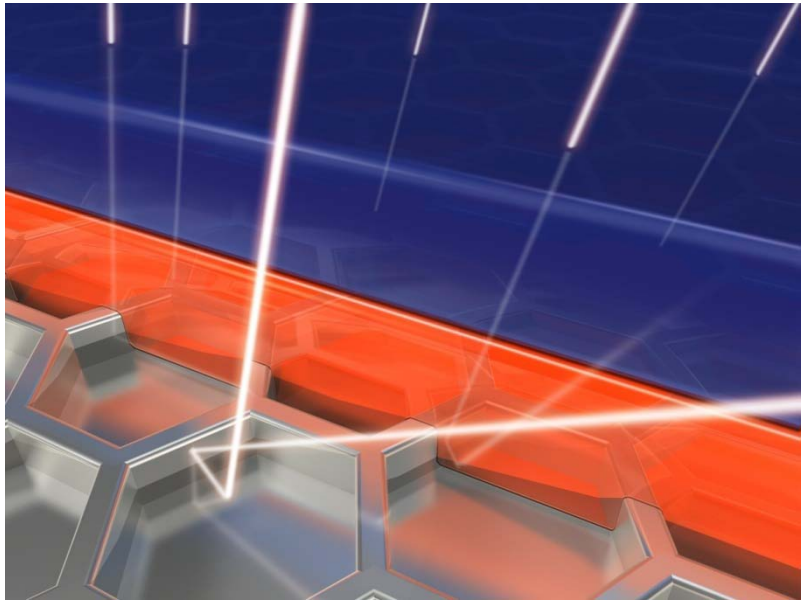
Relative abundance of elements vs. atomic nr.



from P.H. Stauffer et al, Rare Earth Elements - Critical Resources for High Technology, USGS (2002)

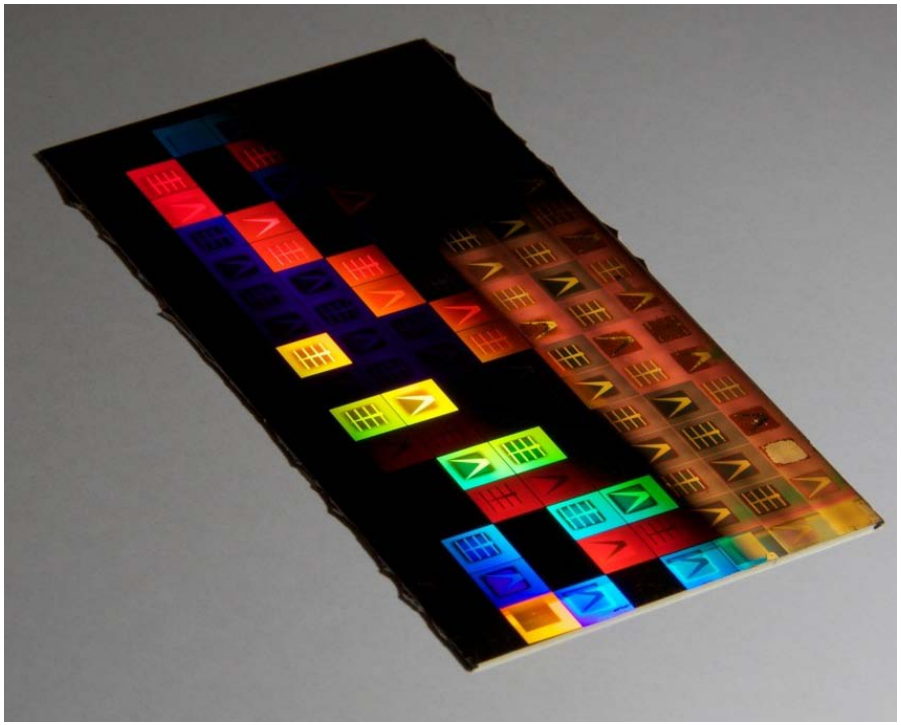
Light trapping in a thin-film solar cell



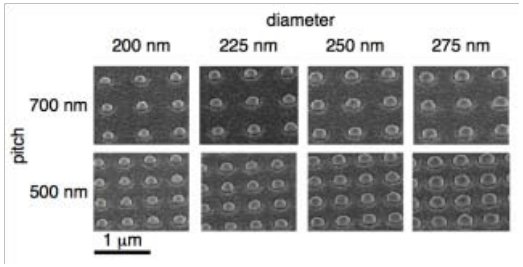


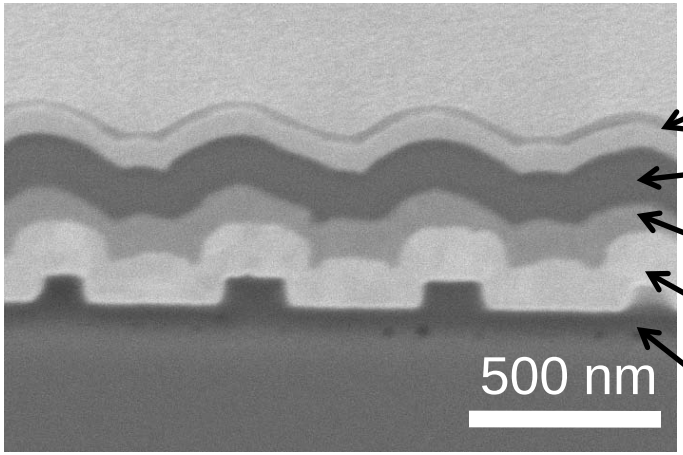
Nature Mater. **9**, 205 (2010)

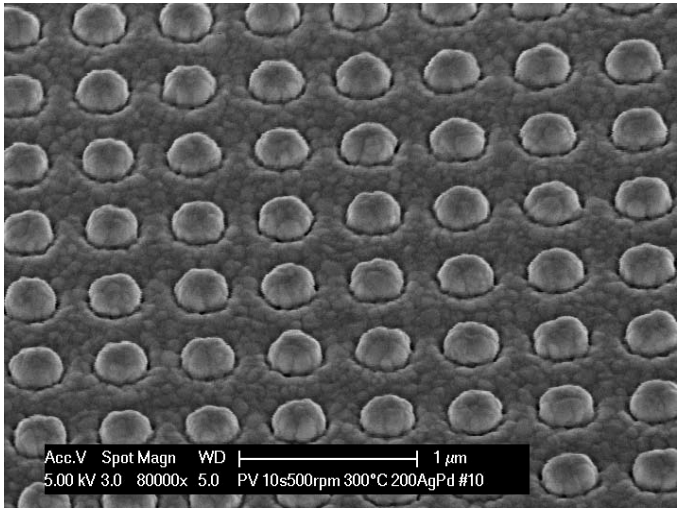
Back contact nanopatterns on ultrathin a-Si:H solar cells



160 nm thick
a-Si:H cells







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Vivian Ferry, Hongbo Li, Marc Verschuuren
Optics Express **18**, A237 (2010)

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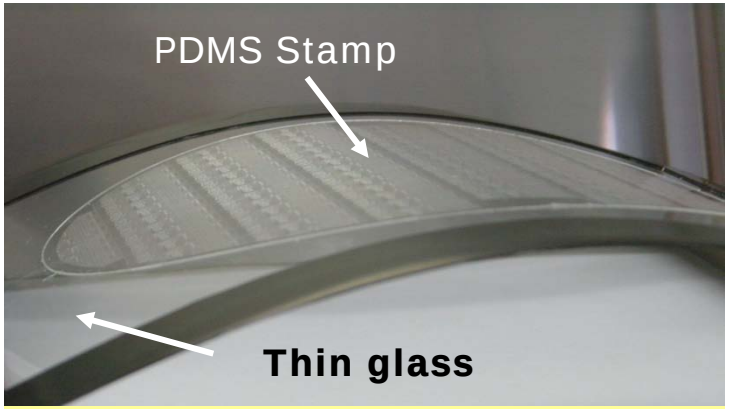
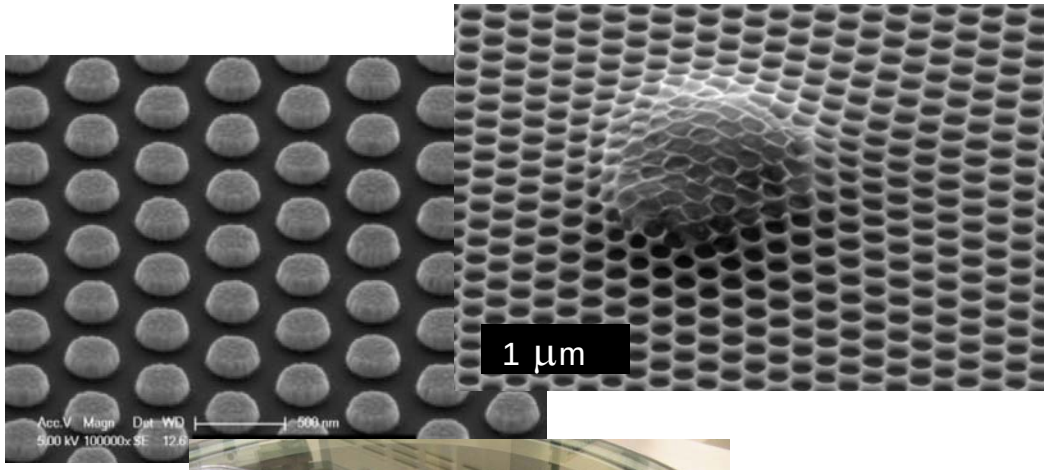
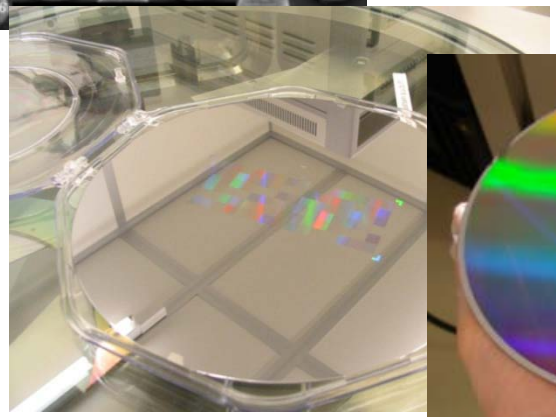
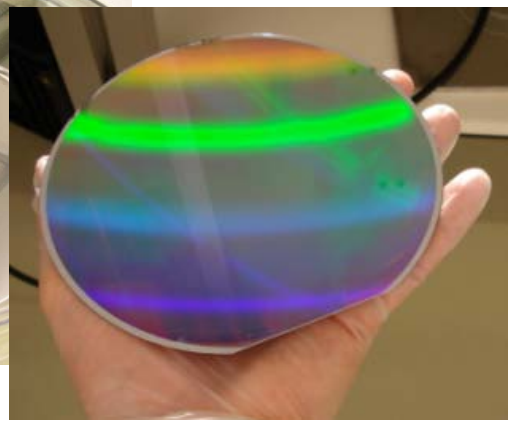
Substrate Conformal Imprint Lithography



PDMS stamp (6”) on 200 µm AF-45 glass



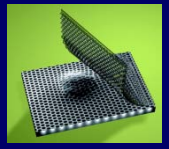




Full-wafer soft nano-imprint

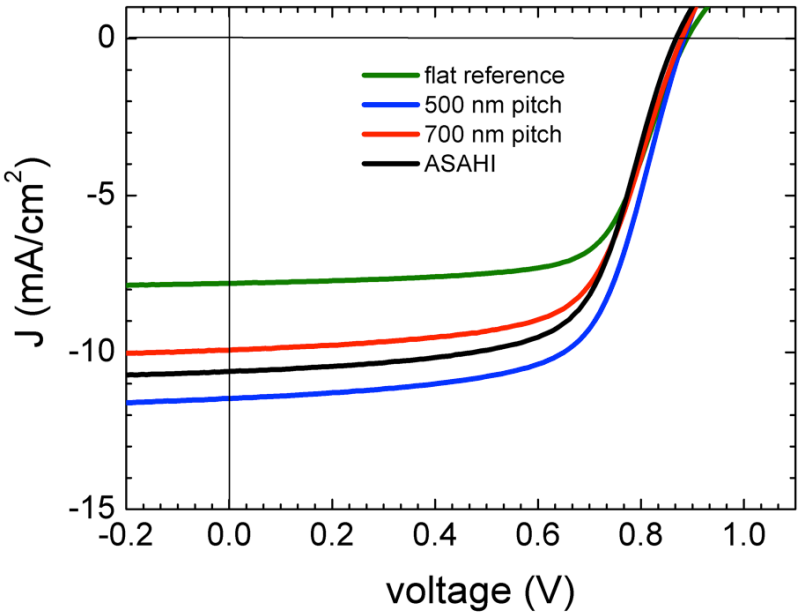
- Flexible rubber on thin glass
- Conforms to: substrate bow, roughness, particles: no stamp damage
- SCIL option for Suss MicroTec MA/BA 6/8 maskaligner

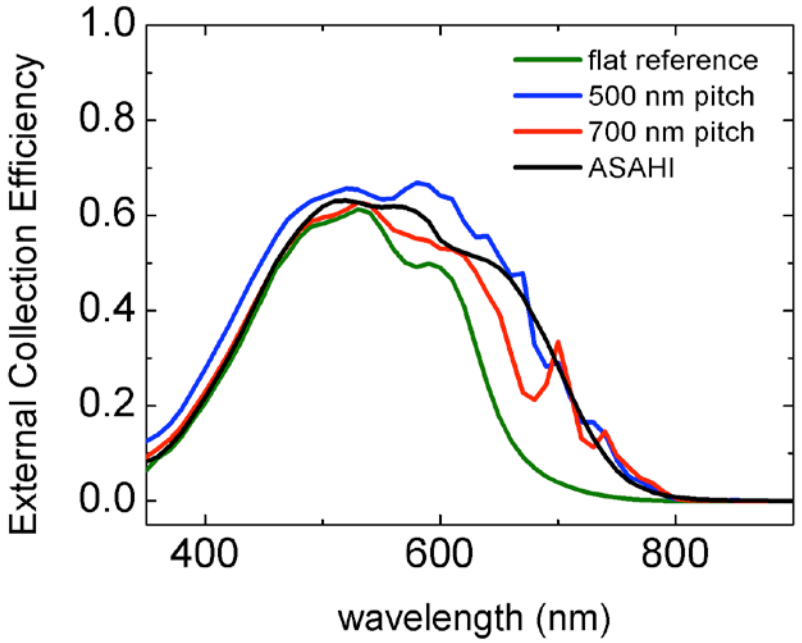
SCIL @ Philips booth L2/H4/D36

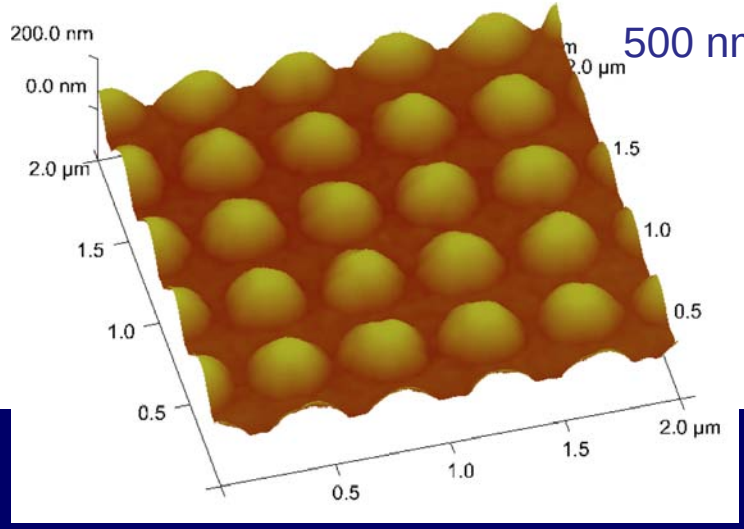


Marc Verschuuren
PhD thesis, Utrecht University (2010)

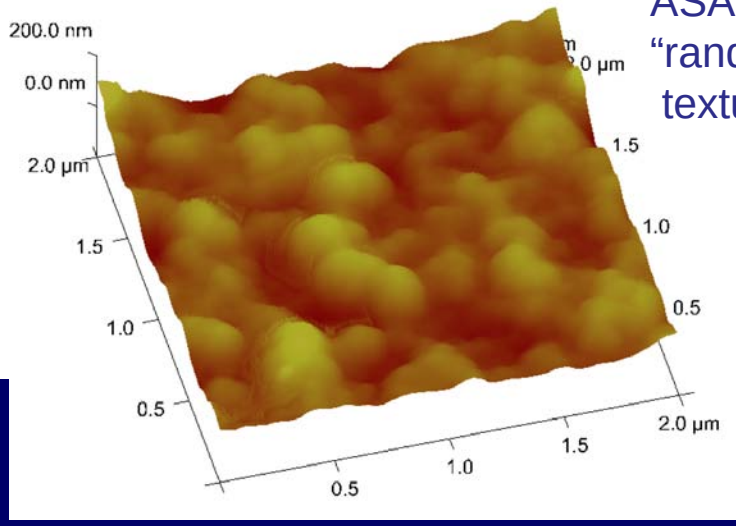
Nanopattern is better than ASAHI random texture







500 nm pitch

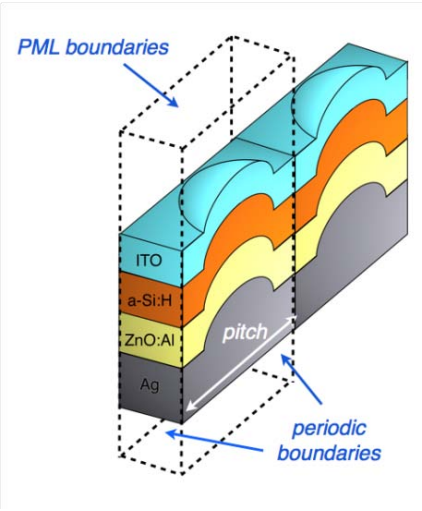


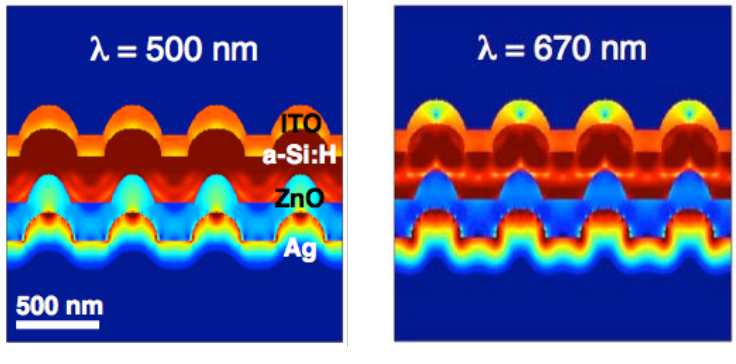
ASAHI "random texture"

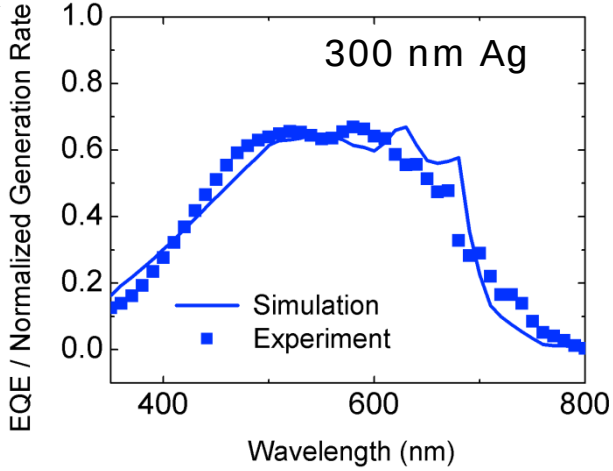
Light intensity modulated at the nanoscale

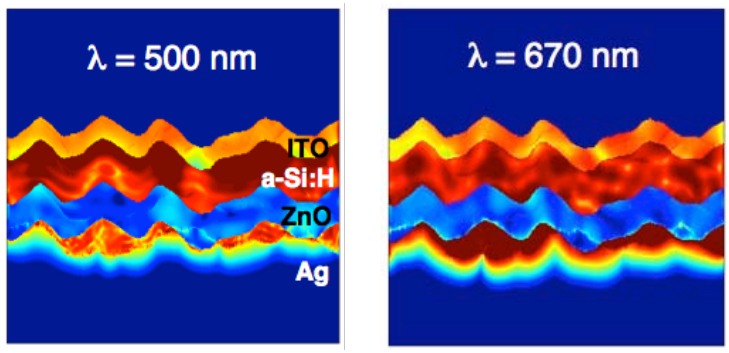
160 nm thick
a-Si:H cells

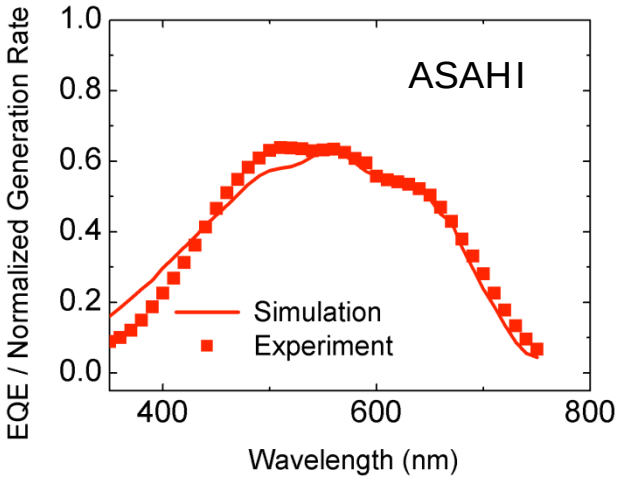
Full-field 3D EM simulations





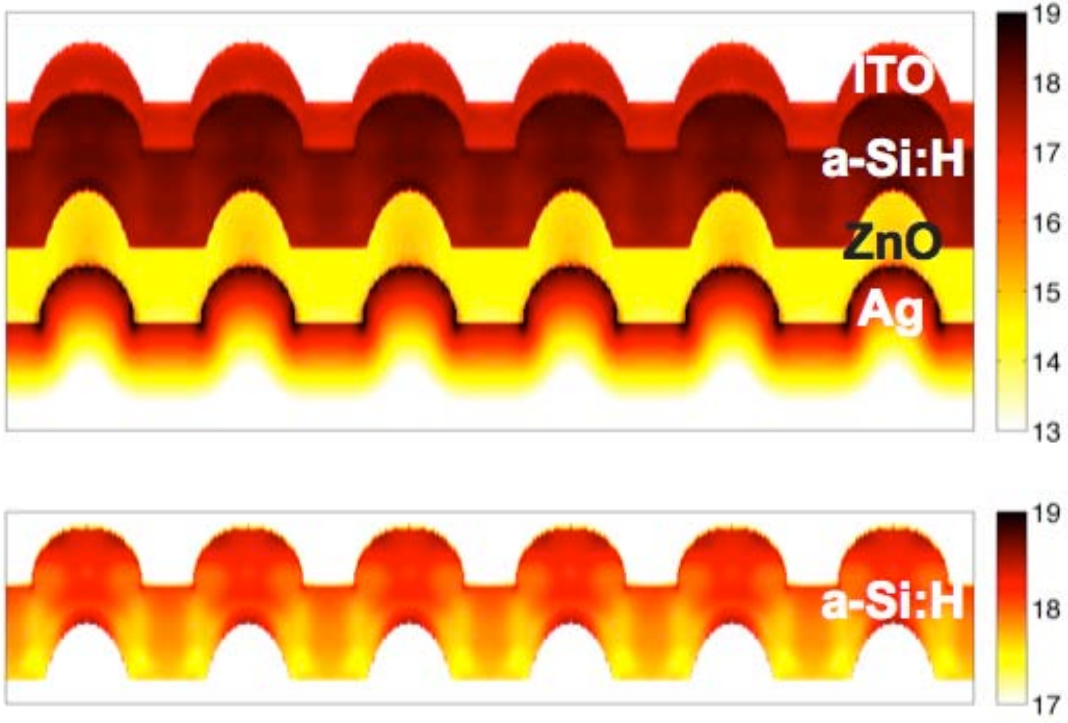




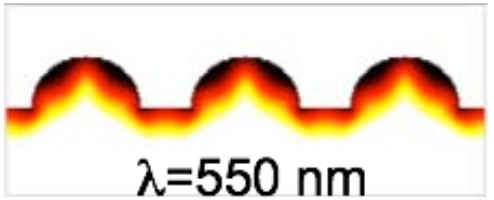


Nanoscale engineering of light-absorption profile

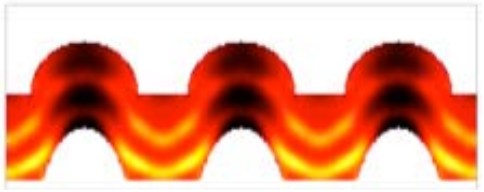
Spectrally Integrated



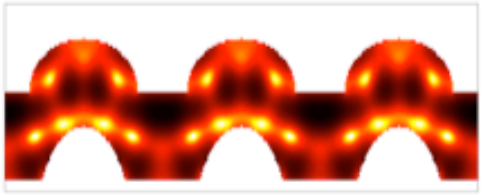
λ=400 nm



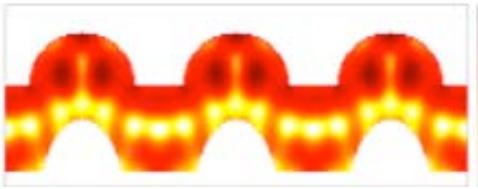
λ=550 nm



λ=680 nm

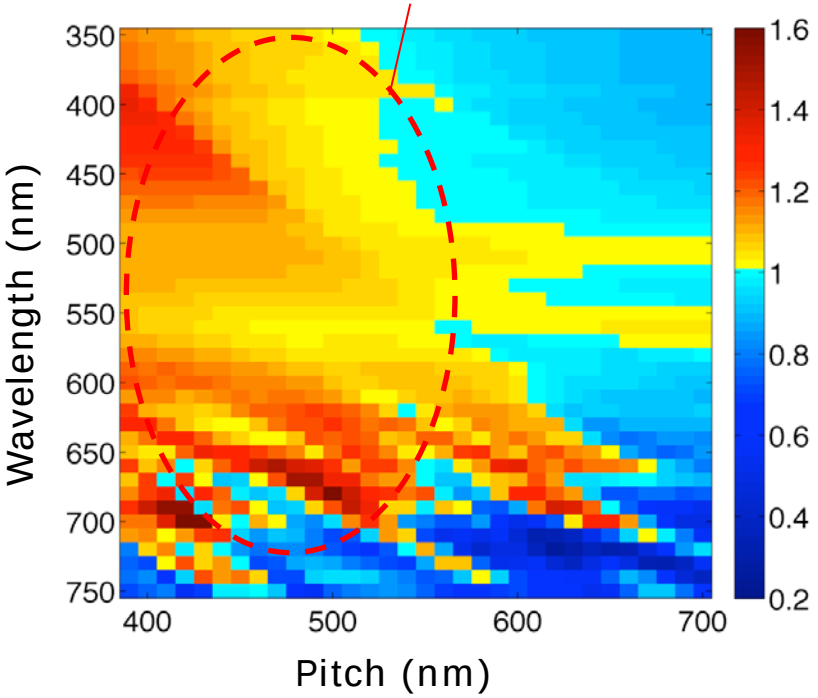


λ=690 nm



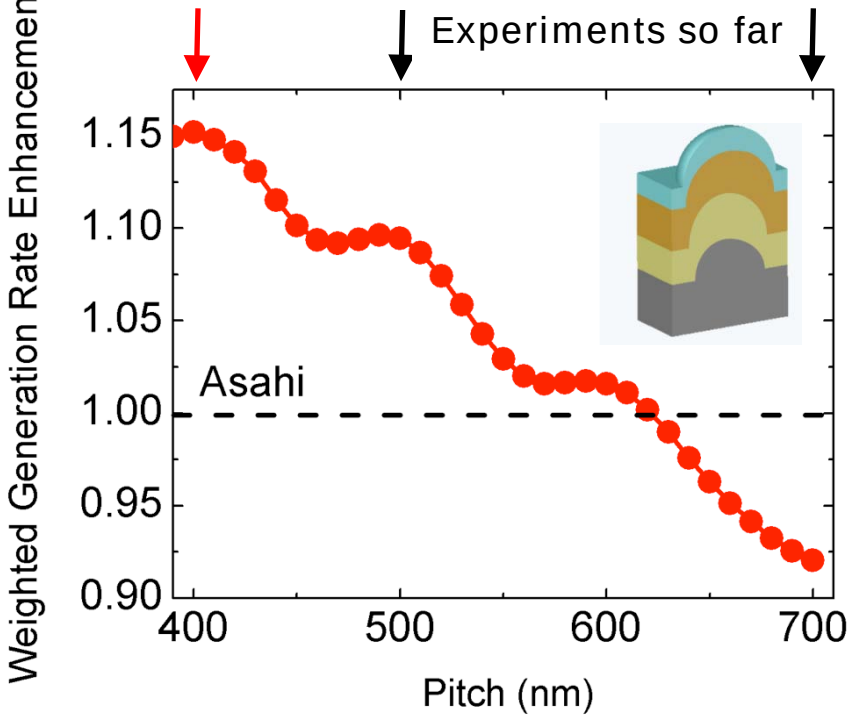
Effect of pitch: 3D full-field simulations of light trapping in nanostructured thin-film solar cell

Photocurrent enhanced over full spectral range

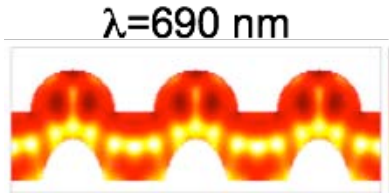


Optimum = closest packed

Experiments so far

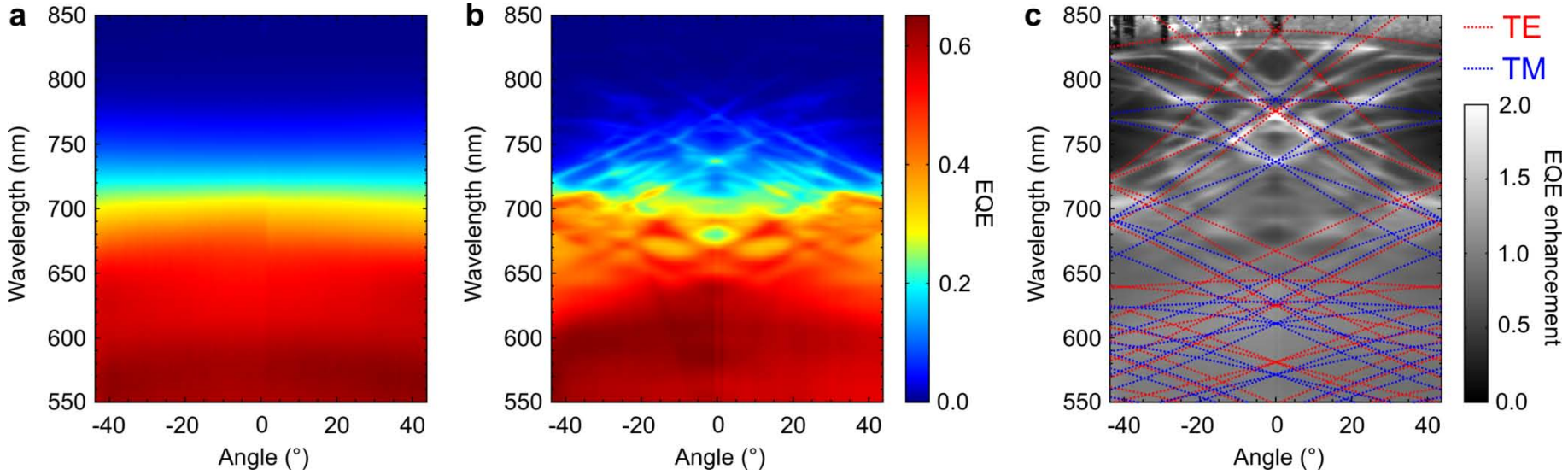


Angle-resolved photocurrent spectroscopy:
Light couples to waveguide modes of the a-Si layer



ASAHI
"random texture"

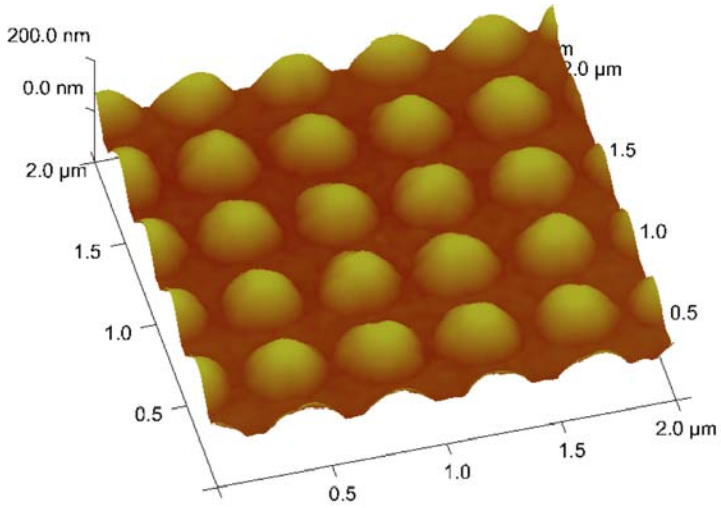
500 nm pitch

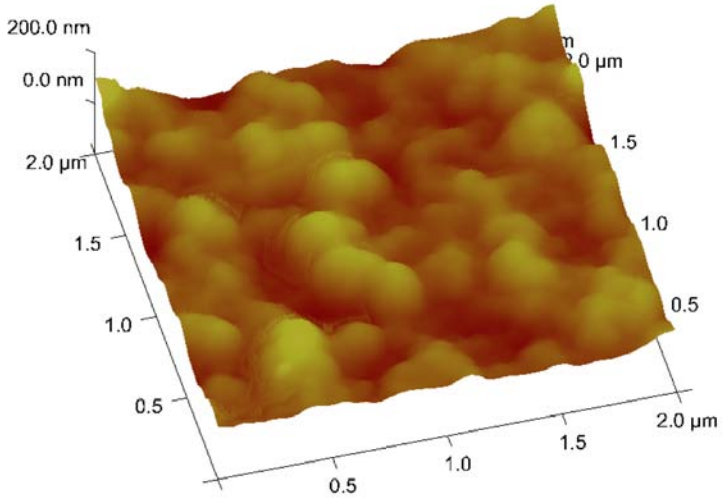


Preferential scattering into high-Q modes:
Phys. Rev. Lett. **103**, 027406 (2009)

Vivian Ferry
Ewold Verhagen, Robb Walters
Optics Express **18**, A237 (2010)

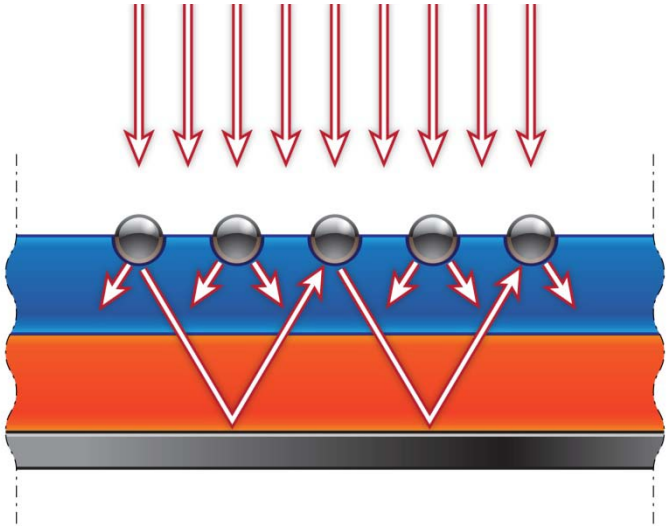
What is the best light trapping structure ?

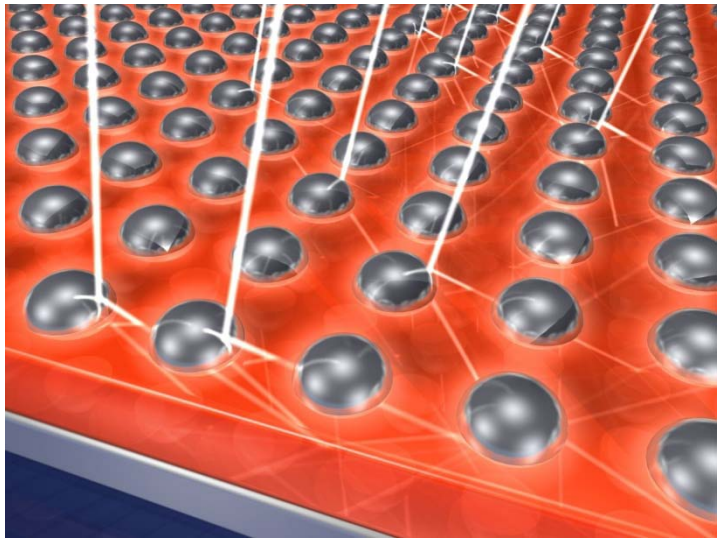




Finding the optimum spectrum of spatial frequencies of the scattering structures

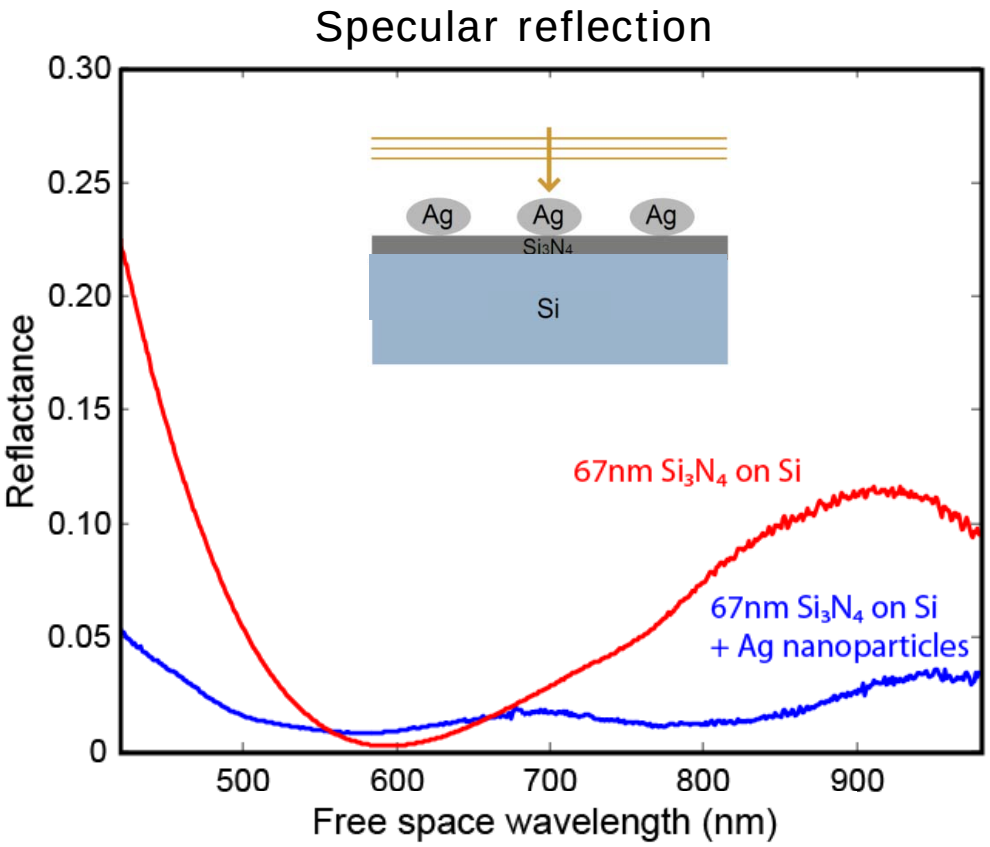
Light trapping in a thin-film solar cell

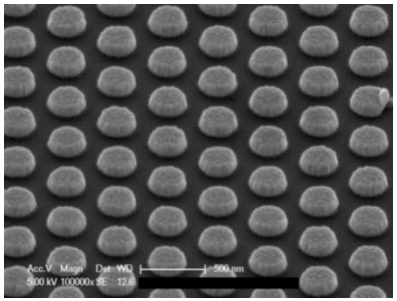




Nature Mater. **9**, 205 (2010)

Reflectance spectroscopy





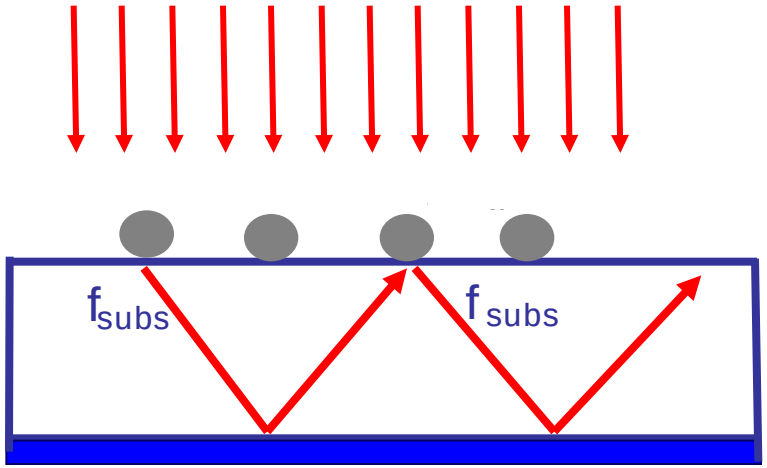
Particle arrays show lower reflection than Si_3N_4 AR coating

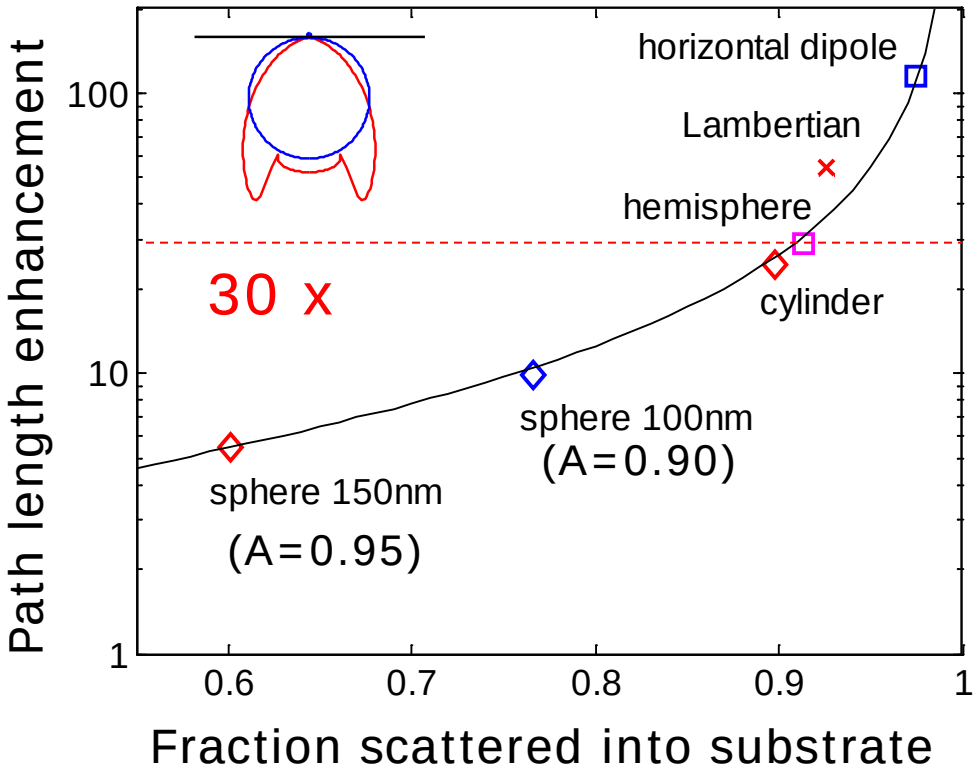
light scatters preferentially into the substrate

Flat substrate: conformal deposition
Flat surface: low surface recombination

Light trapping: maximum path length enhancement first-order estimates

Geometric series: Ag particles on Si



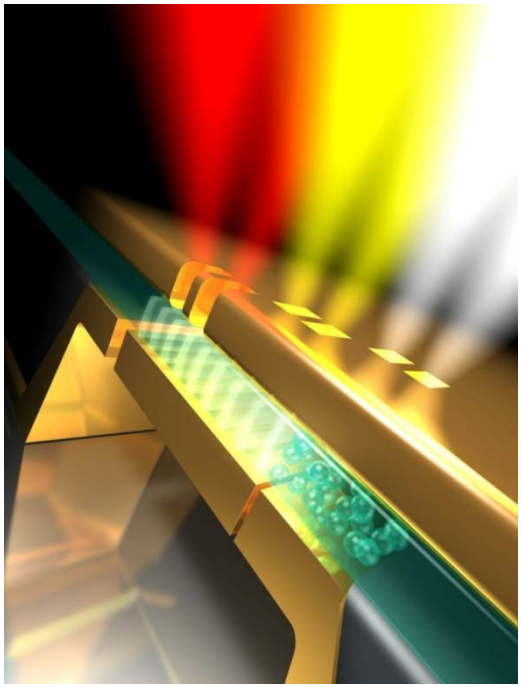


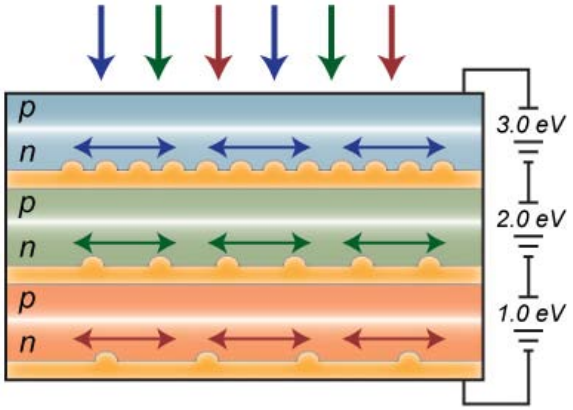
Kylie Catchpole

Appl. Phys. Lett. **93**, 191113 (2008), Opt. Expr. **16**, 21793 (2008)

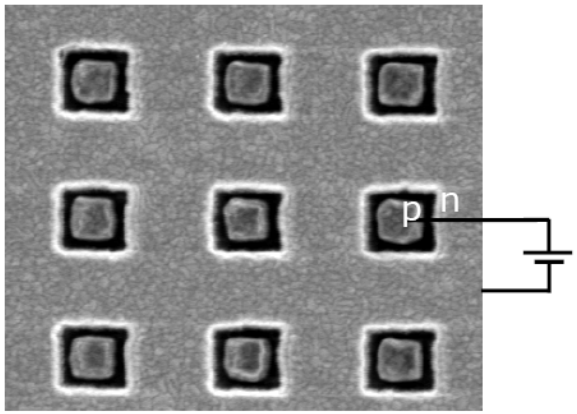
Other novel plasmonic solar cell designs
nanoscale light management

Plasmonic light trapping in 1 monolayer of QDs, organic layers





Tandem cell
with advanced multi-spectral light trapping structure



Nano-concentrator cell
Light trapping in plasmonic cavity

Carrier diffusion
< 20 nm

For details, see:

Nature Mater. **9**, 21 (2010)
Nature Mater. **9**, 205 (2010)
Nature Mater. **9**, 407 (2010)

More details

nature materials

REVIEW ARTICLE

PUBLISHED ONLINE: 19 FEBRUARY 2010 | DOI: 10.1038/NMAT2629

Plasmonics for improved photovoltaic devices

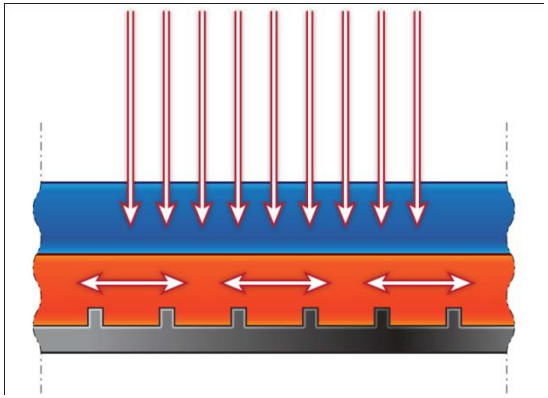
Harry A. Atwater[1]* and Albert Polman[2]*

The emerging field of plasmonics has yielded methods for guiding and localizing light at the nanoscale, well below the scale of the wavelength of light in free space. Now plasmonics researchers are turning their attention to photovoltaics, where design approaches based on plasmonics can be used to improve absorption in photovoltaic devices, permitting a considerable reduction in the physical thickness of solar photovoltaic absorber layers, and yielding new options for solar cell design. In this review, we survey recent advances at the intersection of plasmonics and photovoltaics and offer an outlook on the future of solar cells based on these principles.

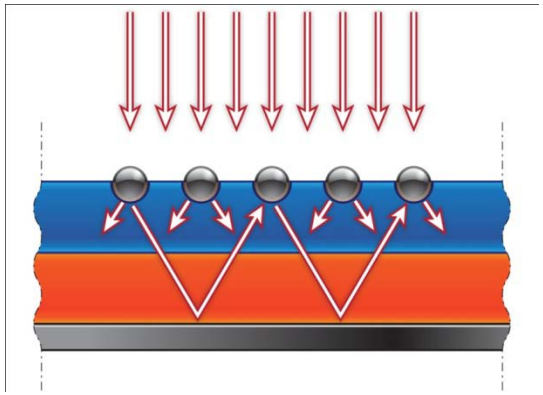
Nature Mater. **9**, 205 (2010)

For details/references visit: www.erbium.nl

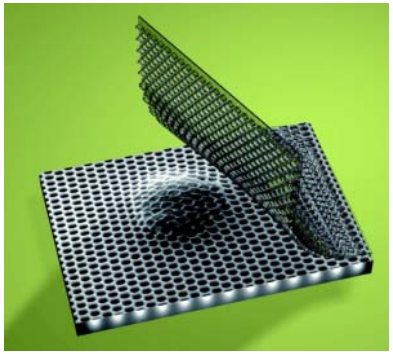
Conclusion: Light management in thin-film solar cells



Arrays are better than random



Nanoparticle AR coating + light trapping



+ many other options