

Nanostructures to control spectrum and direction of light in PV architectures

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Nanotechnology for colorful building-integrated PV



Green in landscapes



Red on rooftops

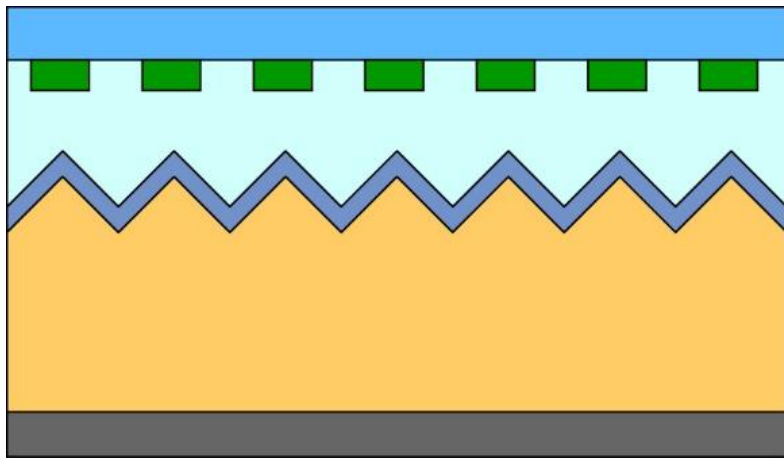


White on house walls

Current technologies:

- Absorbing dyes: Reduced efficiency
- Microoptic structures : Specific applications
- Multilayer interference: Expensive technology

Green colored HIT solar module



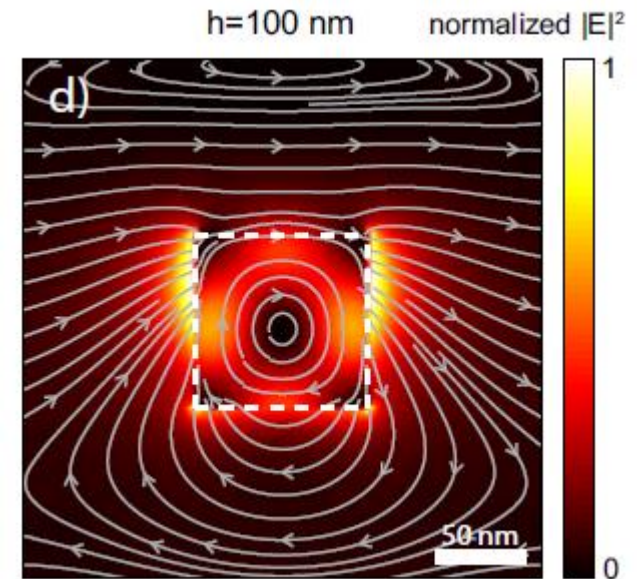
Sapphire +
Si cylinders

Immersion
oil

ITO ARC

HIT-cell

Ag contacts



- Structures can be integrated on front module glass (Sapphire)
- EVA instead of immersion oil

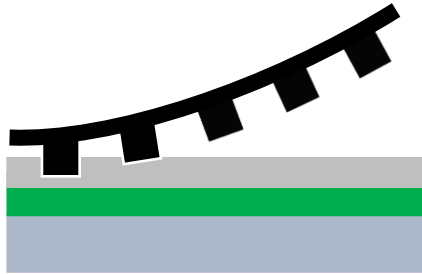
- Mie resonance in Si cylinder
- Field lines of magnetic dipole

SCIL fabrication of Si nanocylinders

Solgel
Si
Sapphire



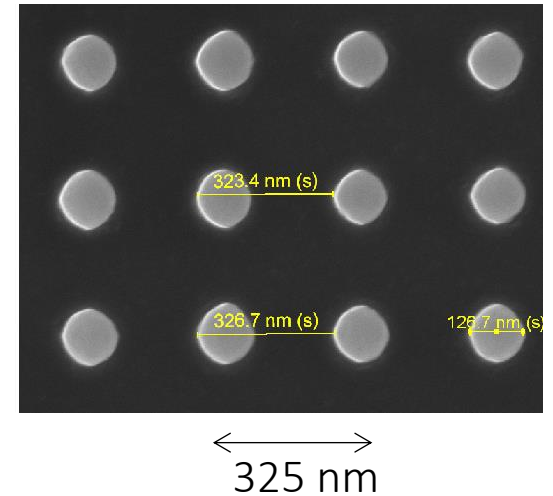
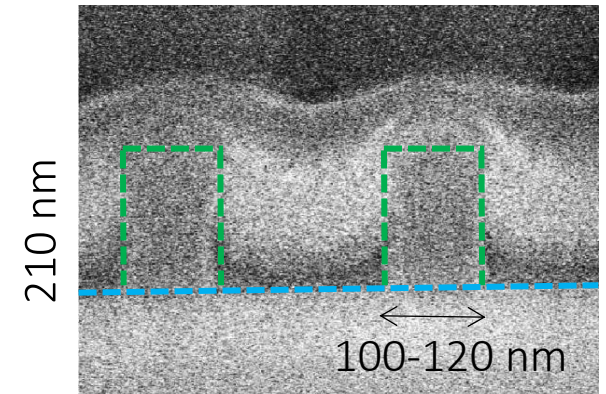
1. Spin-coating of SiO₂ Solgel SoS-wafer



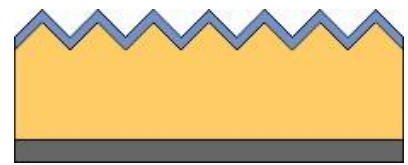
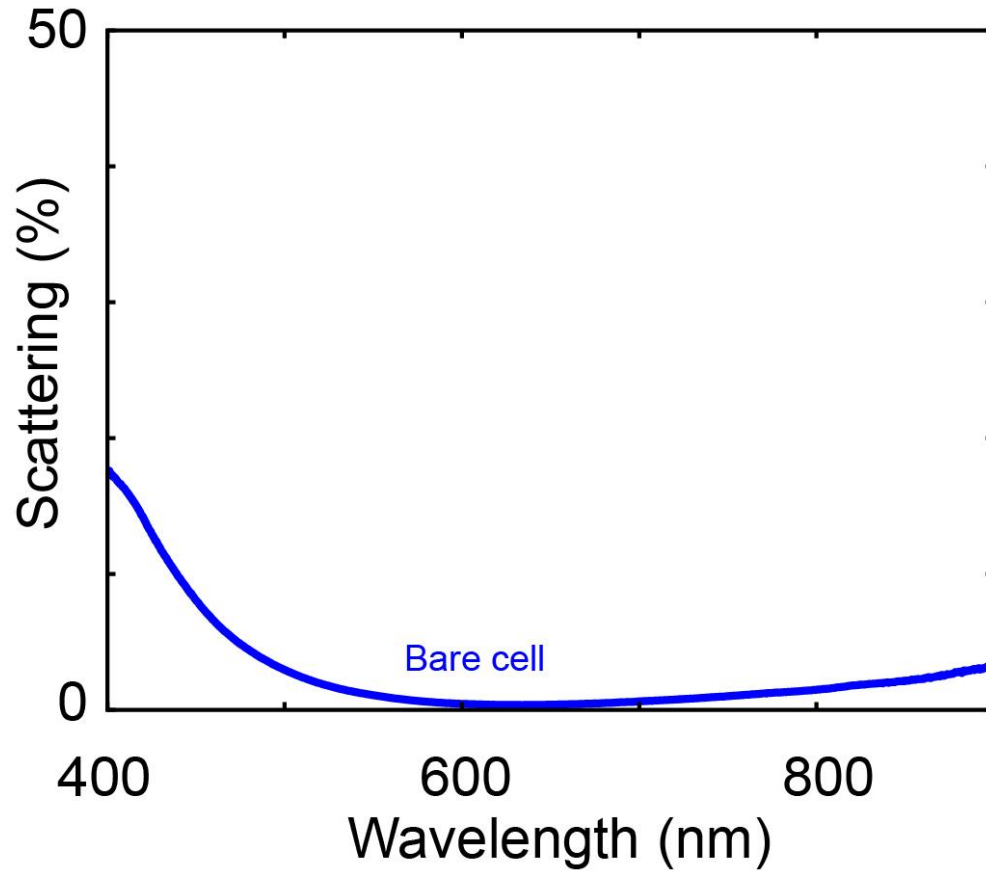
2. SCIL imprint in Solgel



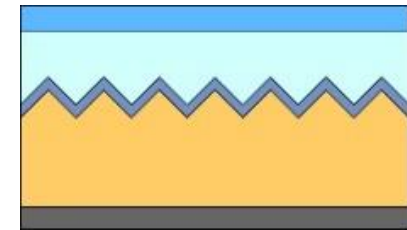
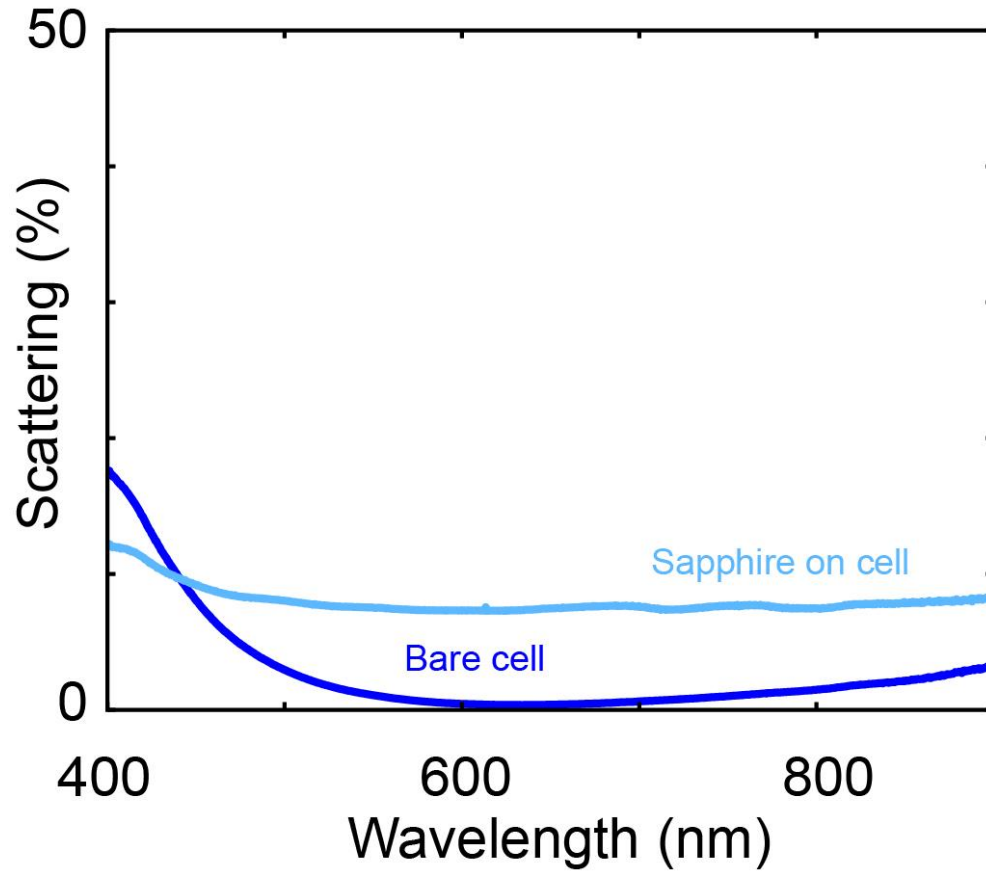
3. Reactive Ion Plasma Etching



Scattering by nanopatterned HIT cells

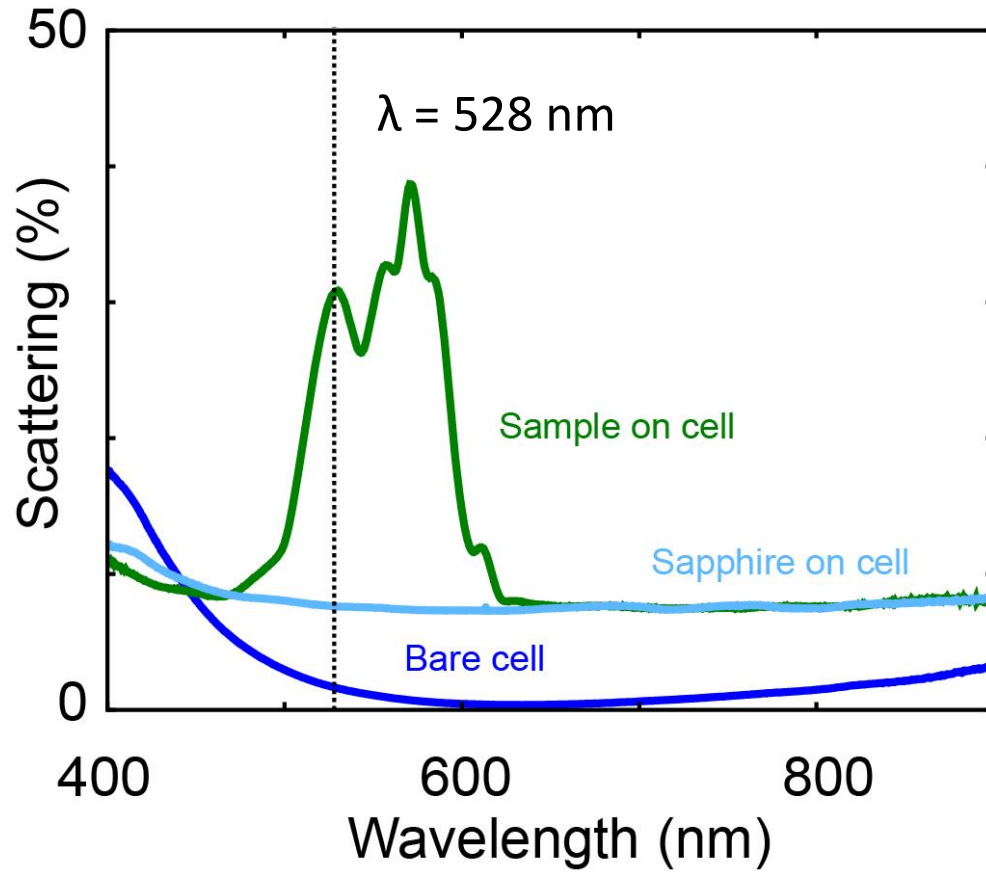


Scattering by nanopatterned HIT cells

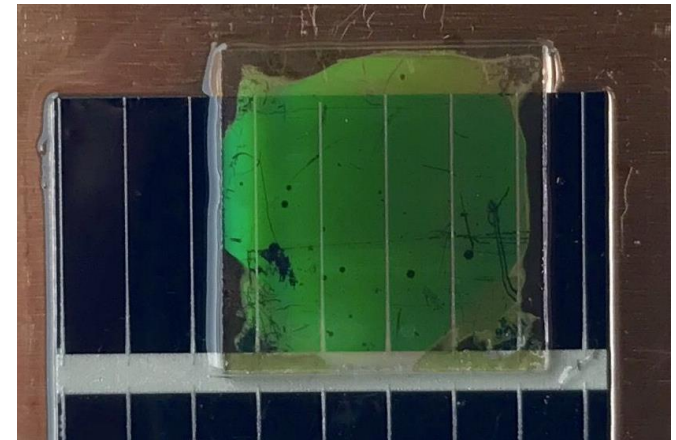
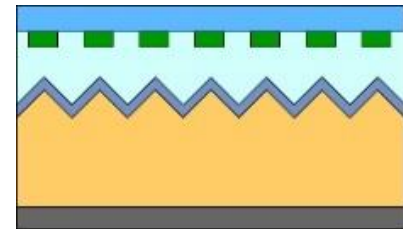


Scattering by nanopatterned HIT cells

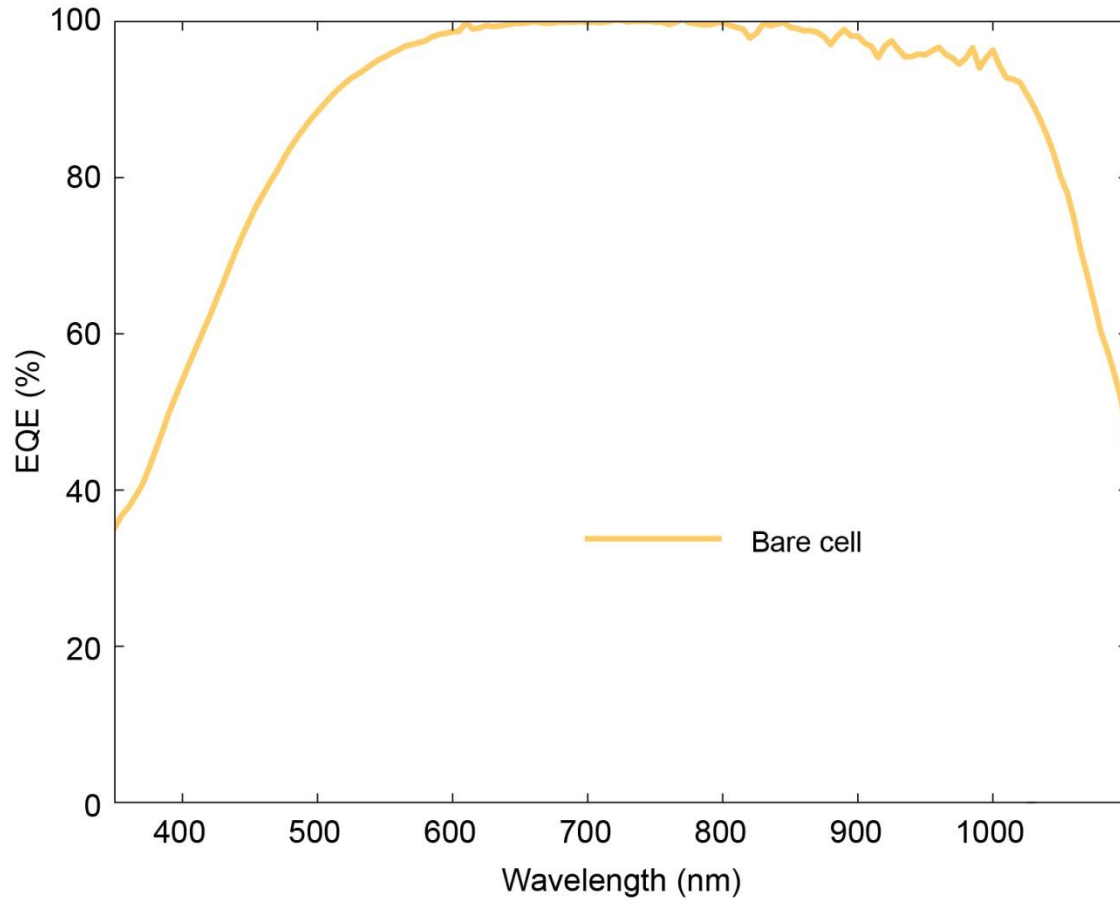
Resonant scattering



Green appearance



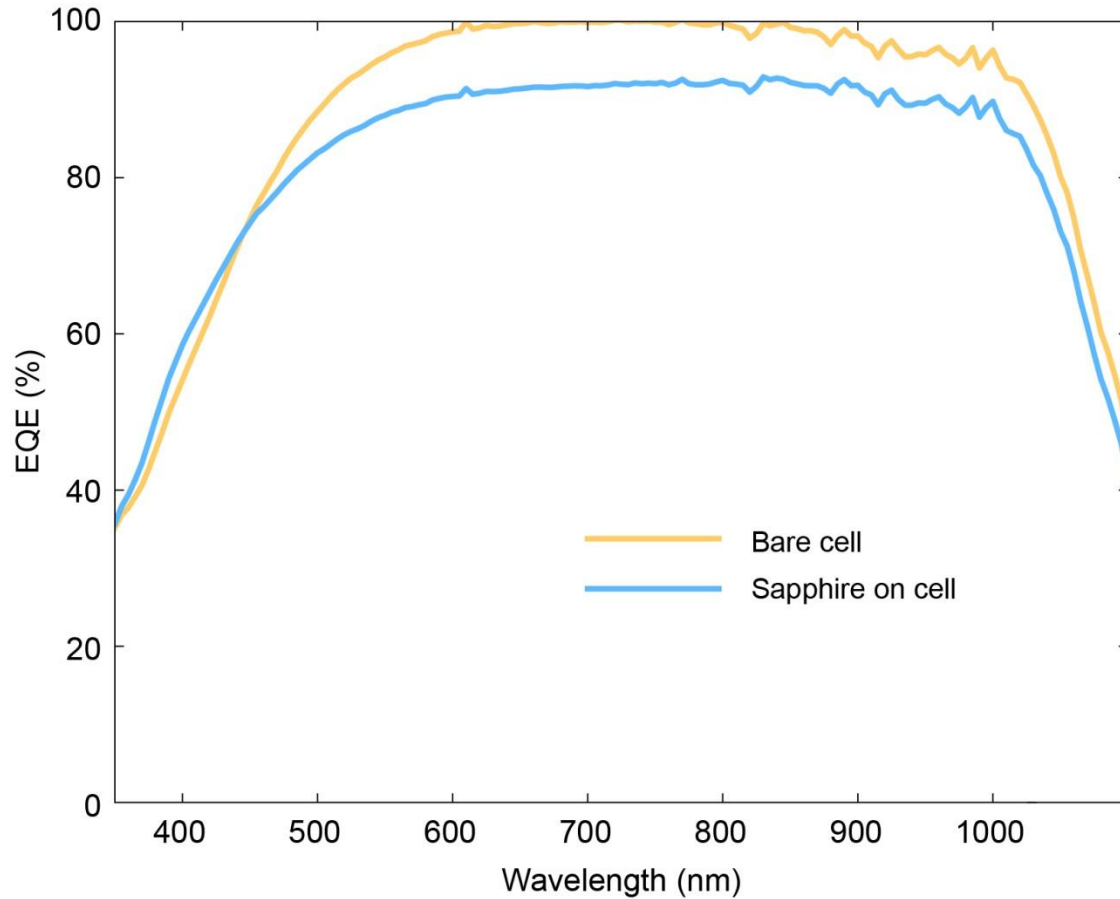
EQE measurement



J_{sc} [mA/cm²]

39,5

EQE measurement



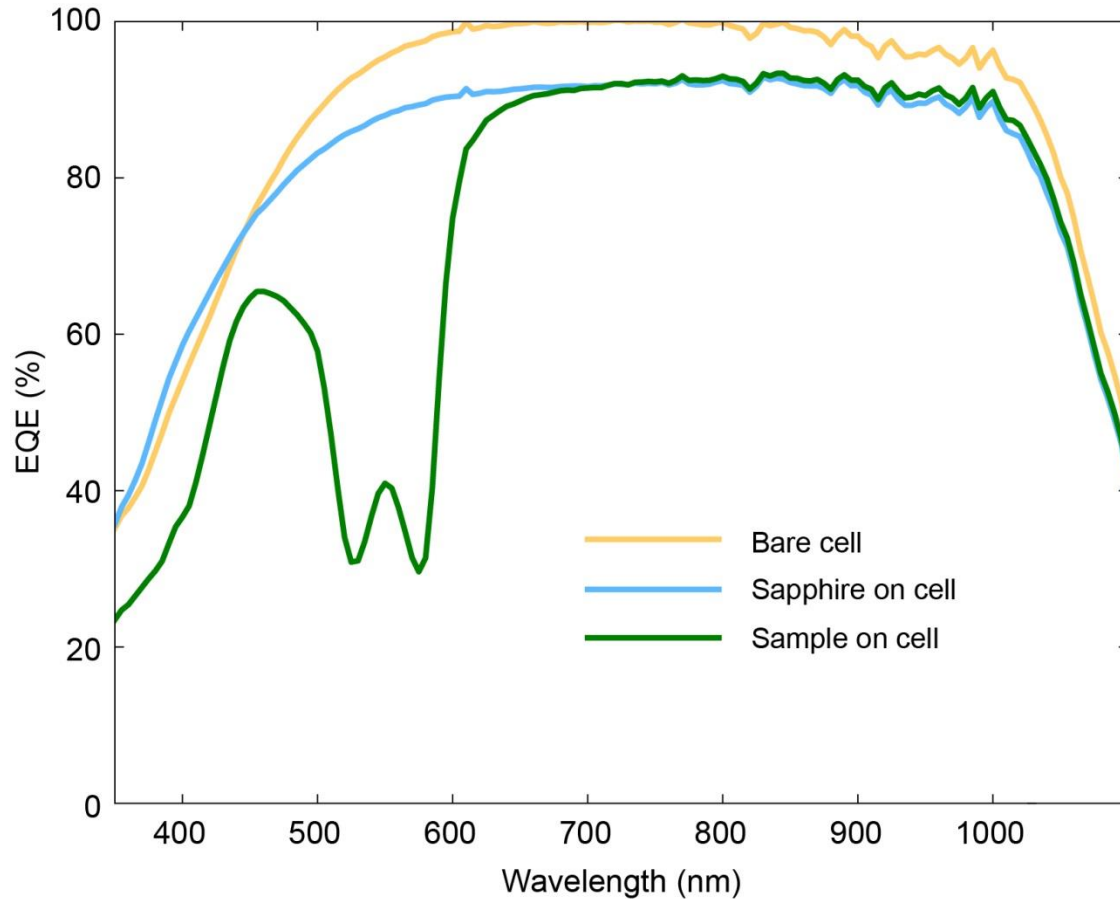
J_{sc} [mA/cm²]

39,5

36,8

-7%

EQE measurement



J_{sc} [mA/cm²]

39,5

36,8

32,7

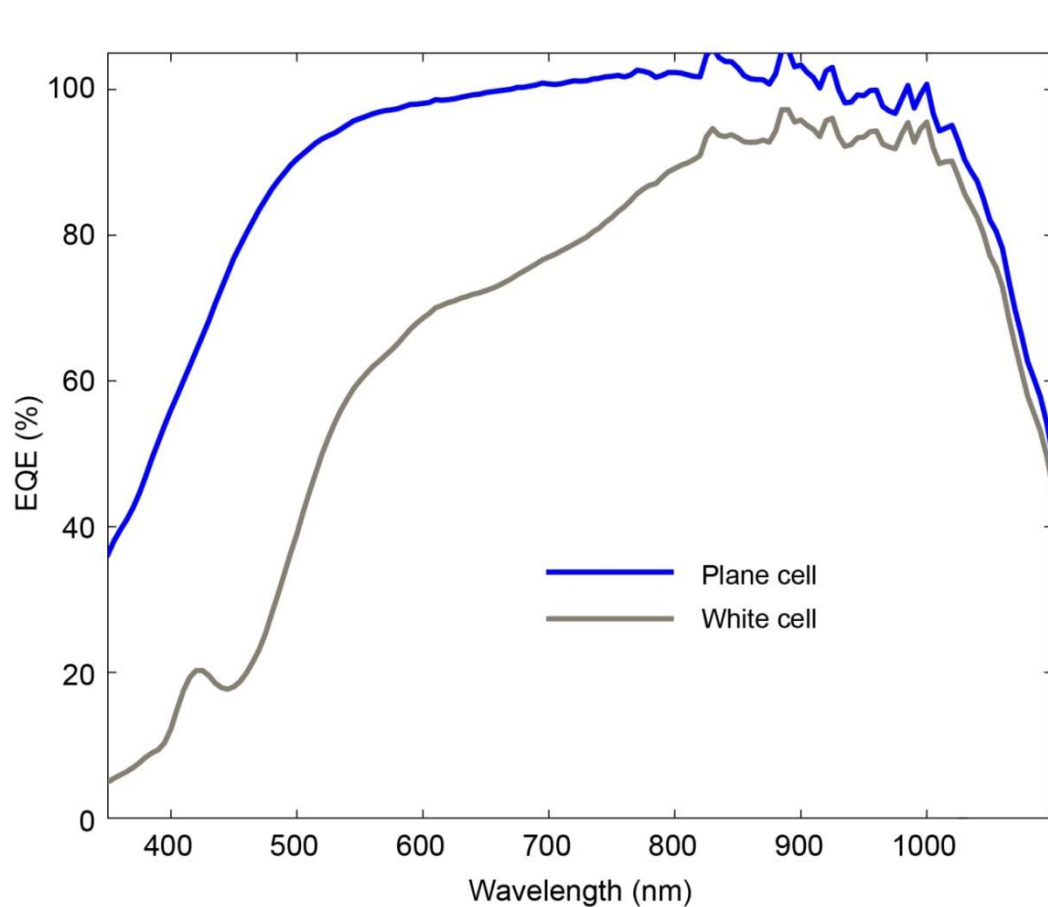
-7%

-17%

-11%

Low loss color reflection by application on HIT solar cell

A „white“ solar cell with little losses: EQE measurement

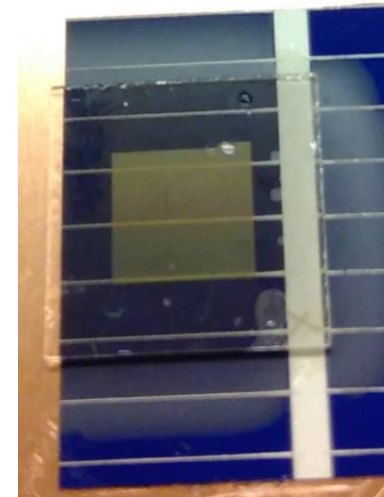
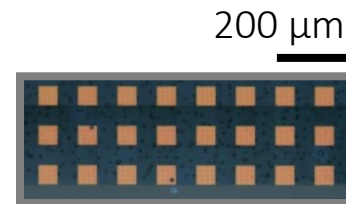


J_{sc} [mA/cm²]

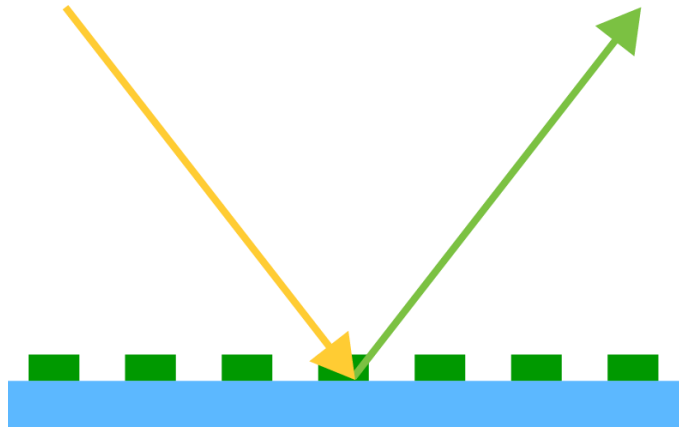
40,0

30,3

-25%

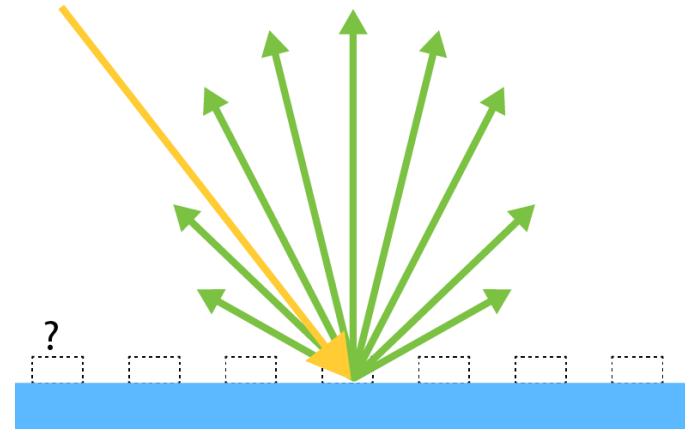


From spectrum control to direction control



Specular reflection

Mie resonances to select spectrum of reflection

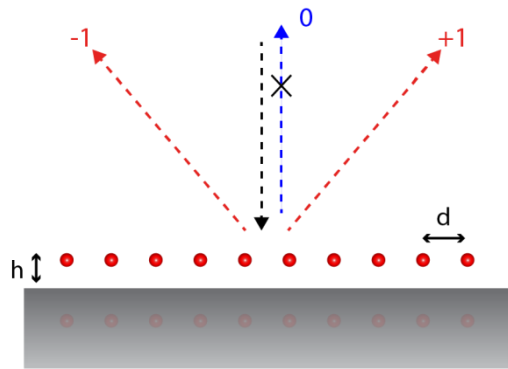


Lambertian scatterer

$$I = I_0 \cdot \cos \theta$$

Metasurfaces to change the reflection direction

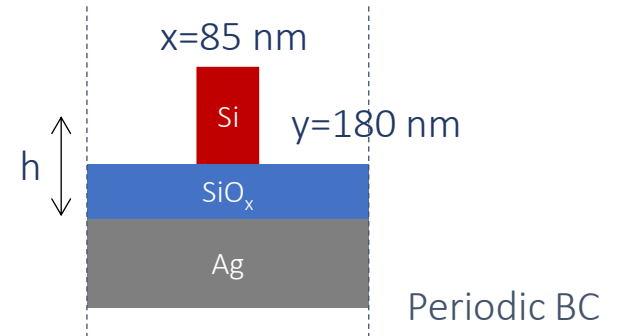
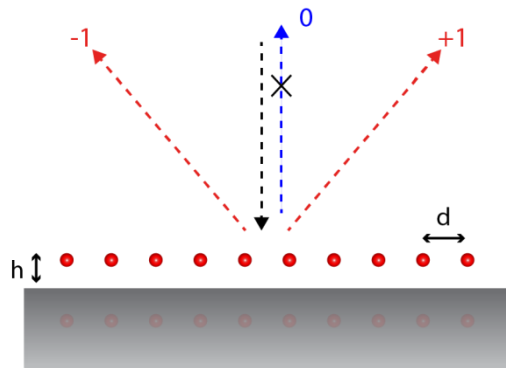
A combined metagrating for broad-angle reflection



Design equation:

$$\cos^2(k_0 h) = \frac{2}{\cos(\theta_1)} \cos^2(k_0 h \cos(\theta_1))$$

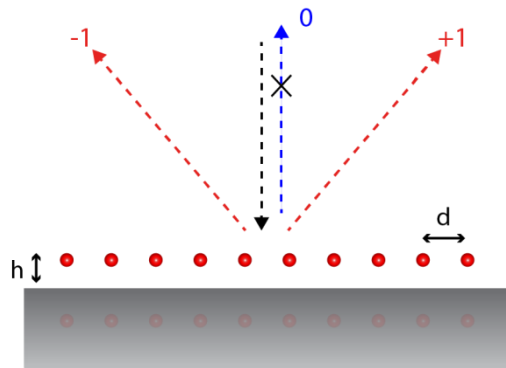
A combined metagrating for broad-angle reflection



Design equation:

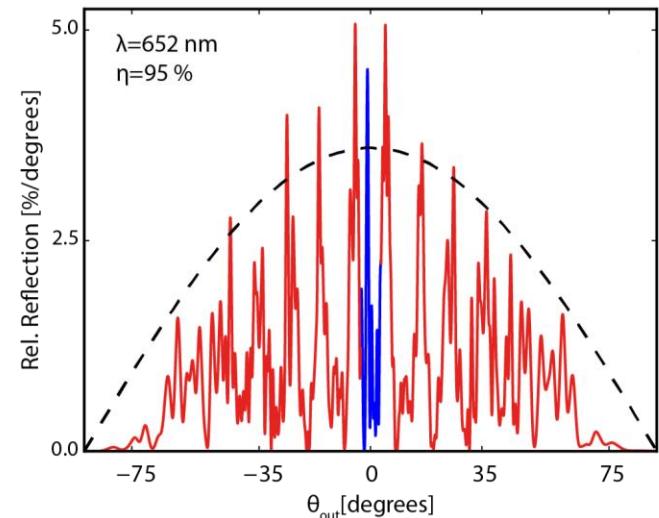
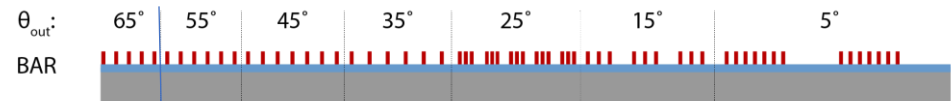
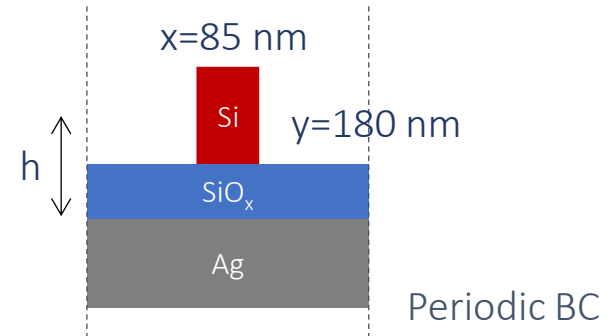
$$\cos^2(k_0 h) = \frac{2}{\cos(\theta_1)} \cos^2(k_0 h \cos(\theta_1))$$

A combined metagrating for broad-angle reflection



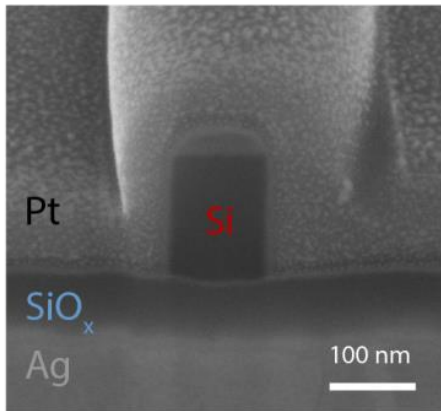
Design equation:

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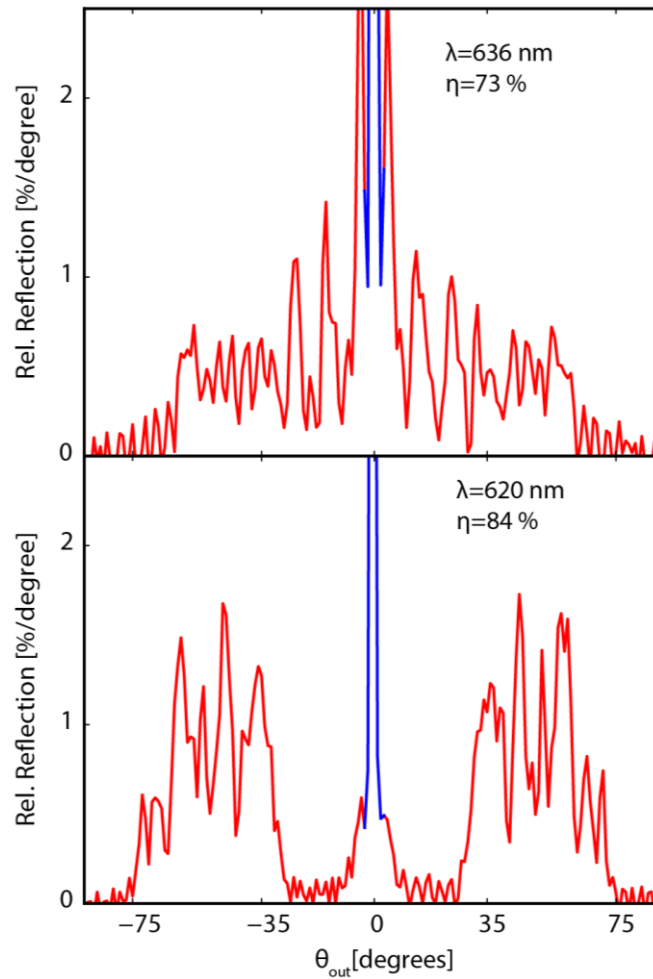
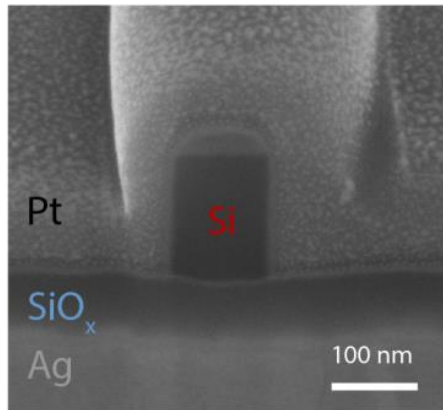
Fabrication and experimental results

Cross section

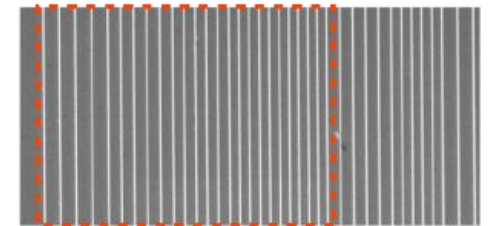
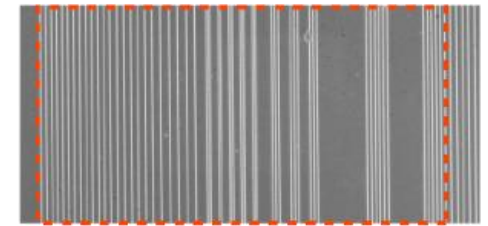


Fabrication and experimental results

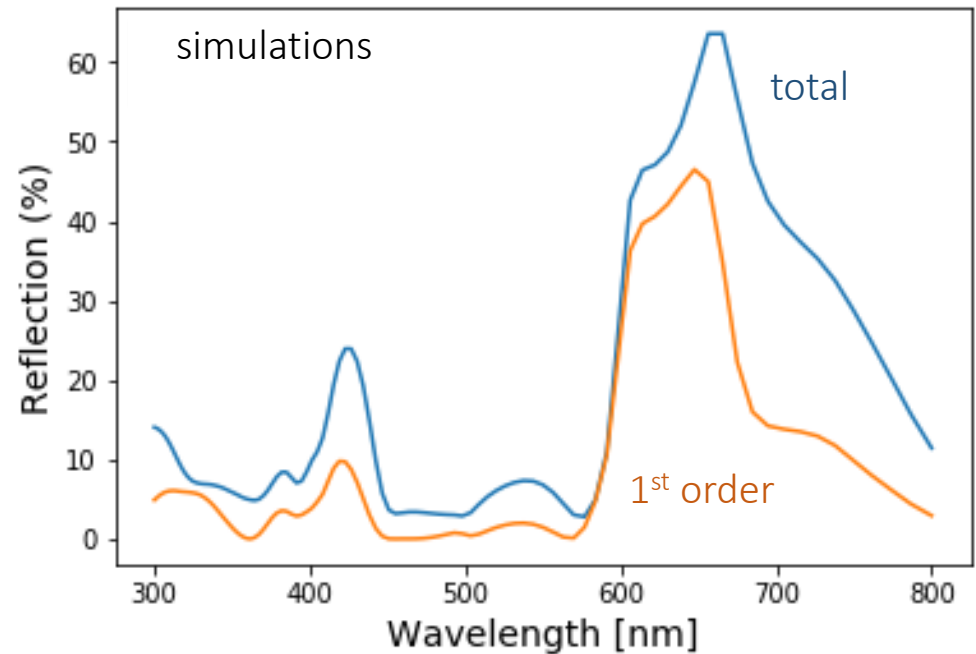
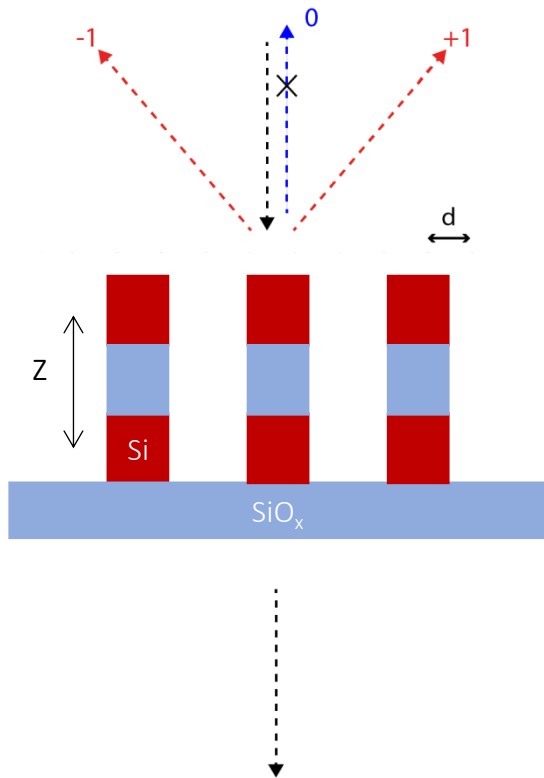
Cross section



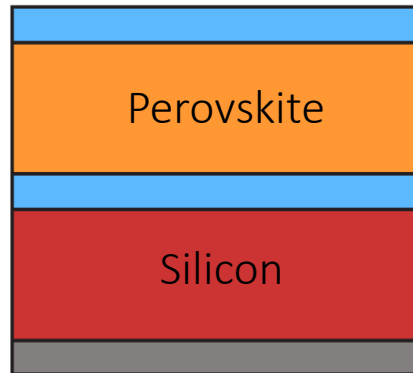
Top view



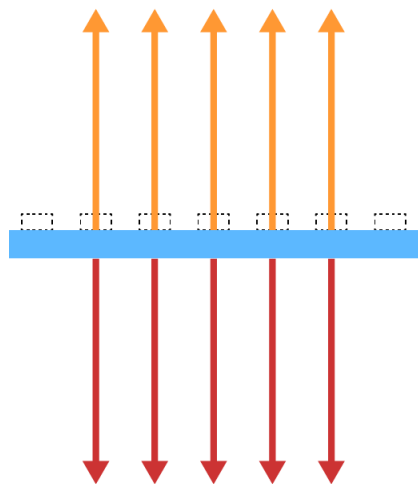
Next step: Transparent metagrating design



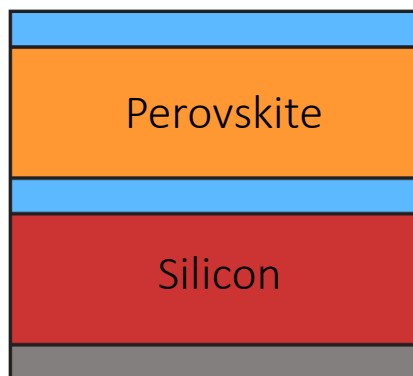
Perspective for metasurfaces in perovskite/silicon tandem cells



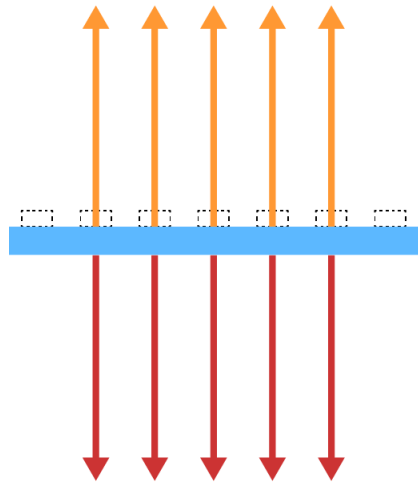
Perspective for metasurfaces in perovskite/silicon tandem cells



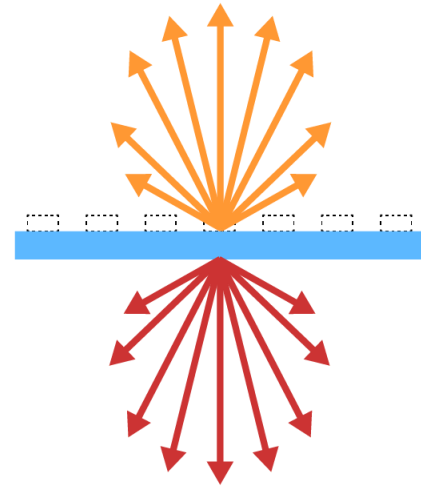
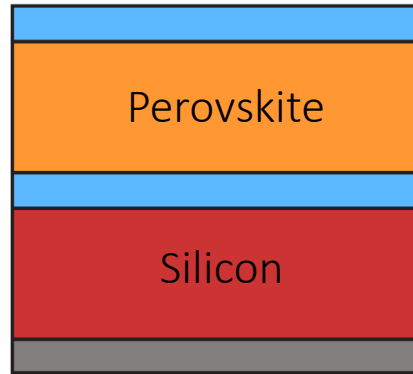
Spectral splitting



Perspective for metasurfaces in perovskite/silicon tandem cells

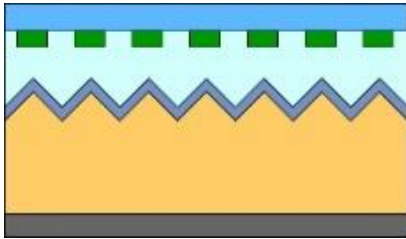


Spectral splitting

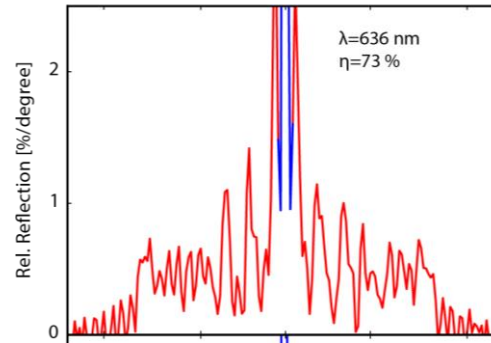


Light trapping +
spectral splitting

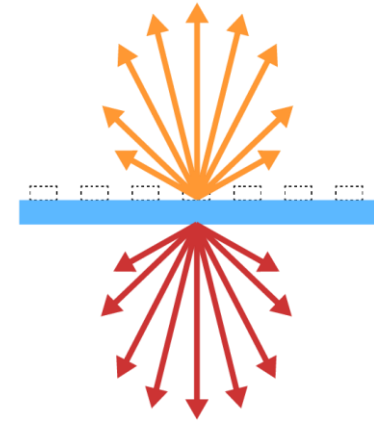
Conclusion



Spectrum control:
Colored solar cells using
integrated resonant
dielectric nanoscatterers



Direction control:
Combined metagrating
for broad-angle
reflection



Next steps:
- Transparent metagrating
- Integration into Si-
Perovskite tandem cells

Thank you!