Optimal Design of Luminescent Down-Shifting for High Efficiency and Stable Perovskite Solar Cells

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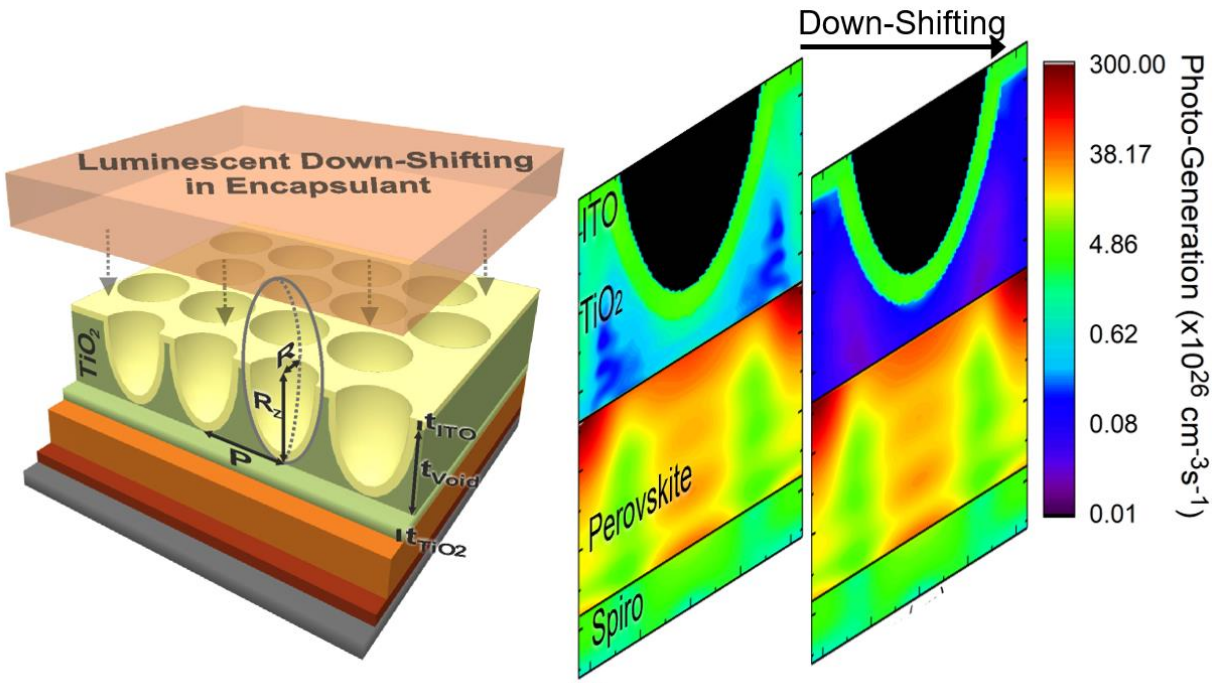
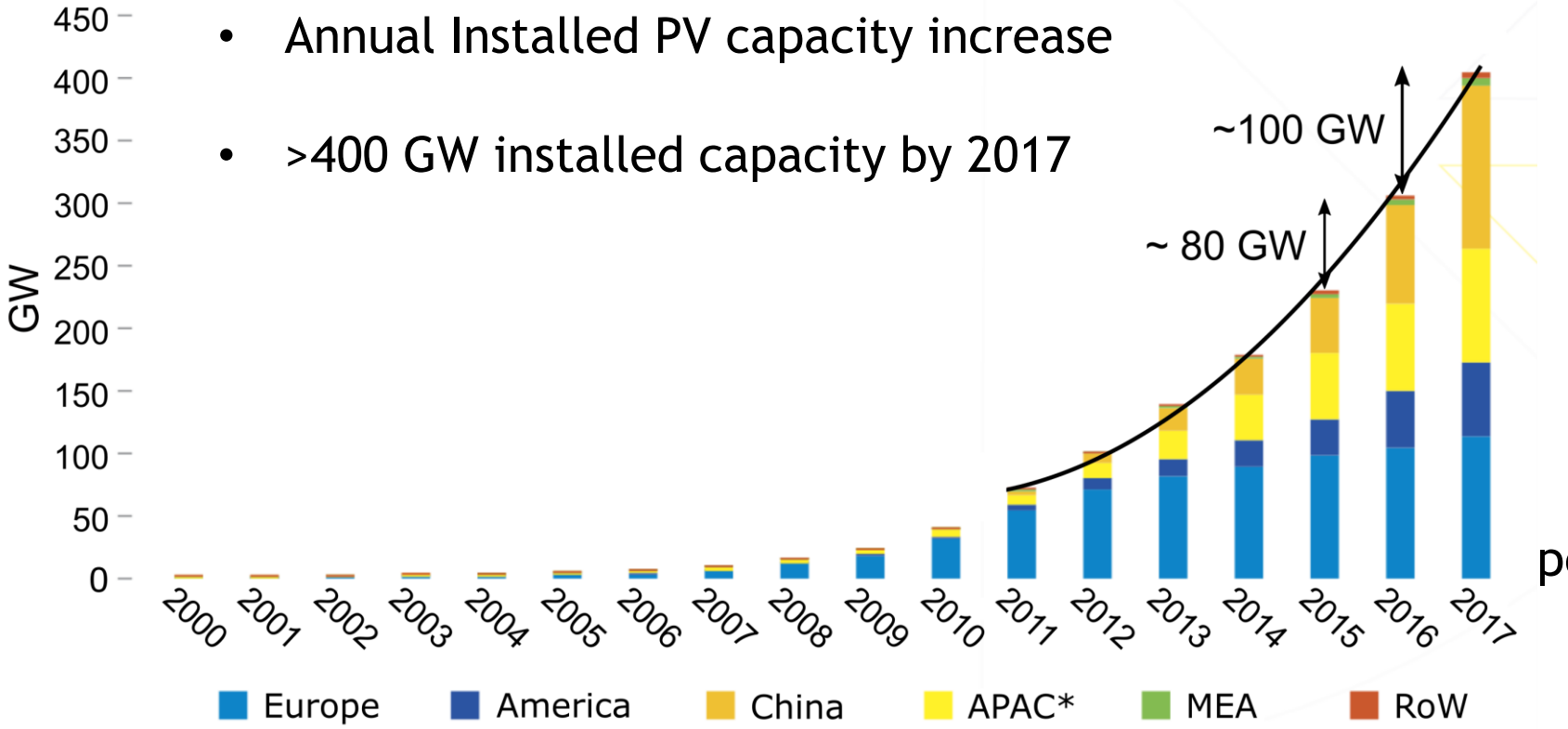


Solar Cell Market

- Annual Installed PV capacity increase
- >400 GW installed capacity by 2017



Adapted from SolarPower Europe: Global Market Outlook 2018-2020

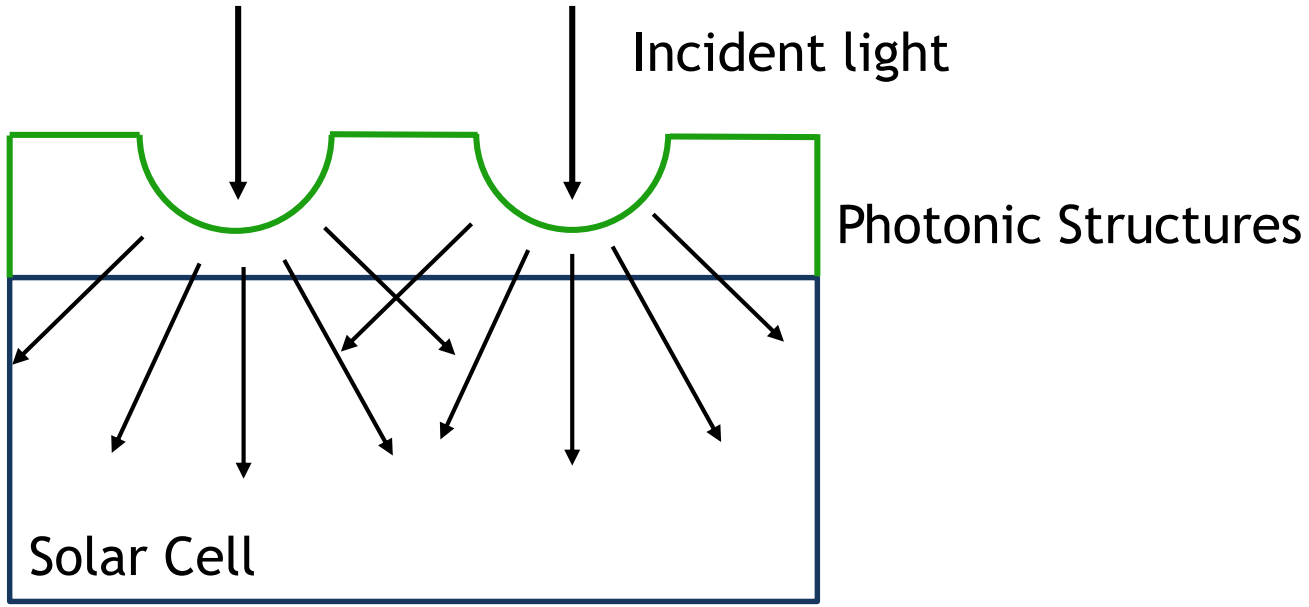
Increased cost-competitiveness

Increase device's performance

Lower/Cheaper material usage (<g/Wp)

Light Trapping

Use of light trapping techniques



Higher light travel path
Resonant modes

↓

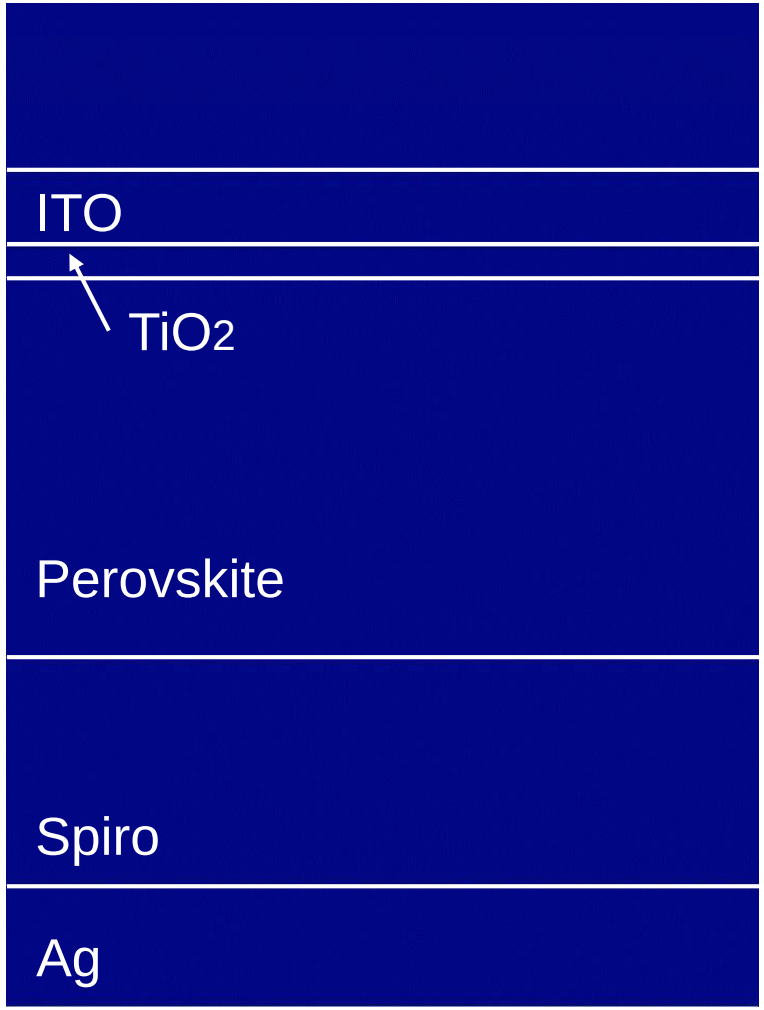
Thin-film PV

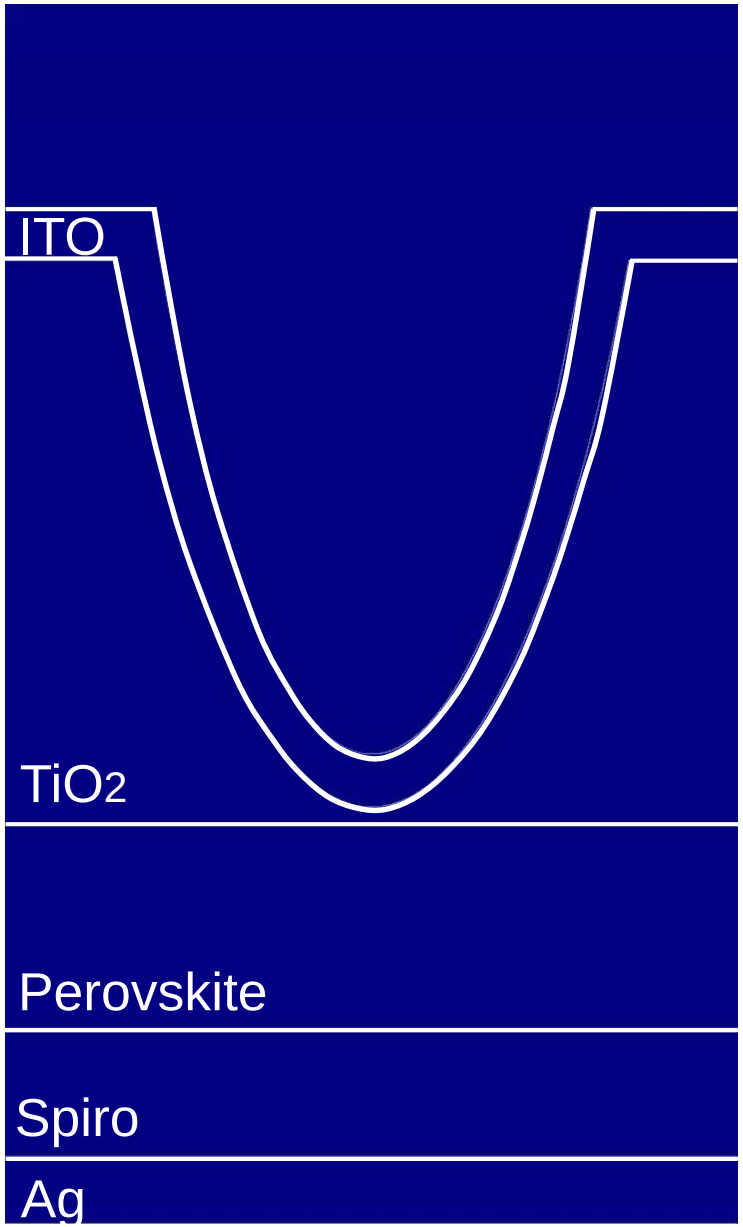
↓

Less material usage

↓

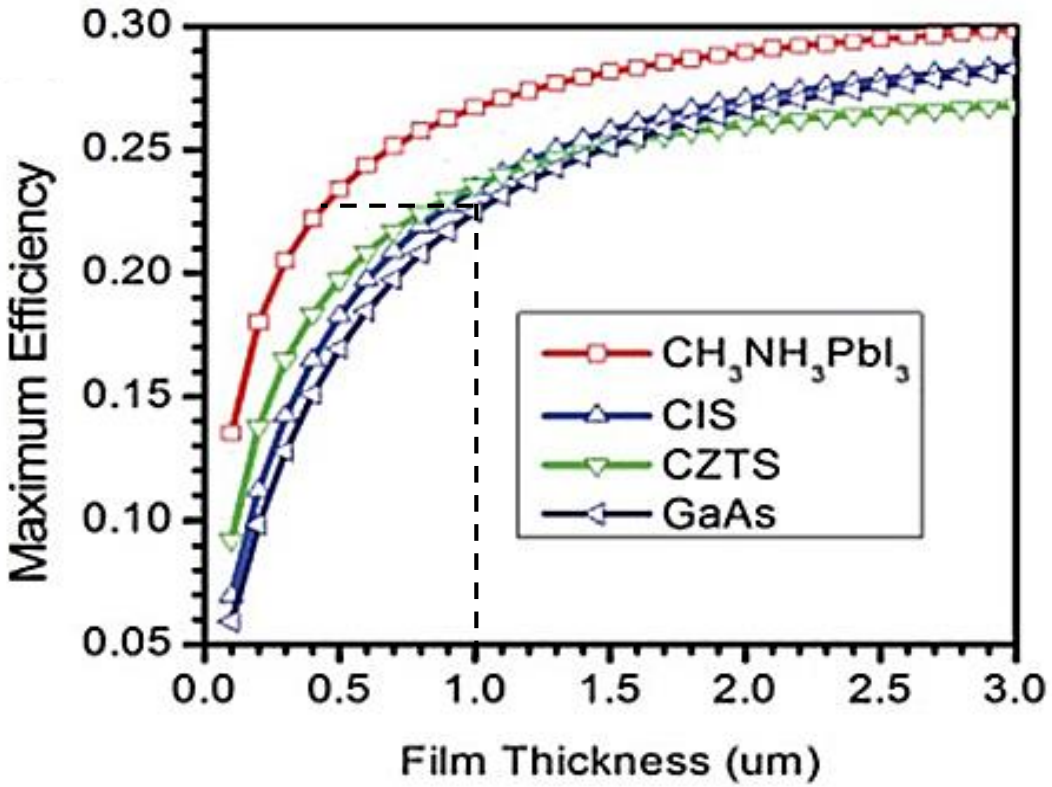
Lower solar cell cost


ITO
TiO2
Perovskite
Spiro
Ag


ITO
TiO2
Perovskite
Spiro
Ag

Perovskite Solar Cells

Study of high performance materials



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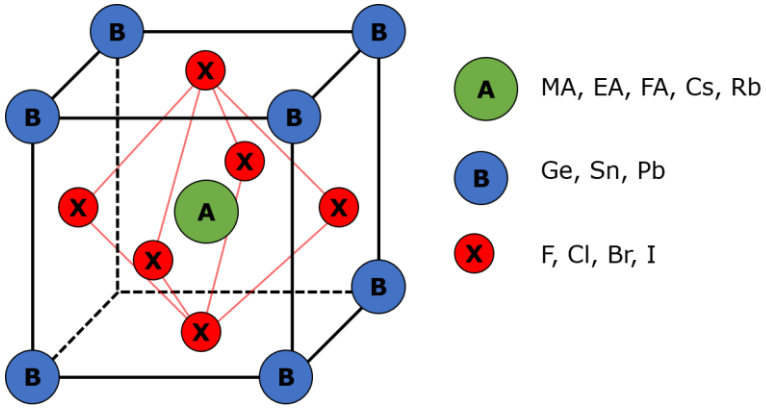


Higher Absorption

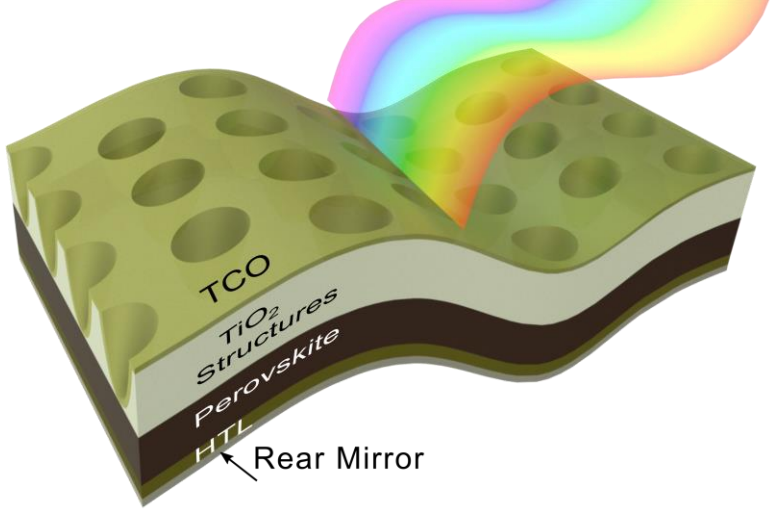
↓

Less material usage

↓

Lower solar cell cost

Perovskite **UV** Stability Problems



Deep trapping of electrons [1]

UV Radiation

TiO_2

e

Deep trap states

Recombination

e

Perovskite

Evaporation of Volatile Compounds [2]

UV Radiation

2e

$-2I$

I_2

$CH_3NH_3^+$

CH_3NH_2 (Volatile)

PbI_2 Photolysis [3]

UV Radiation

PbI_2

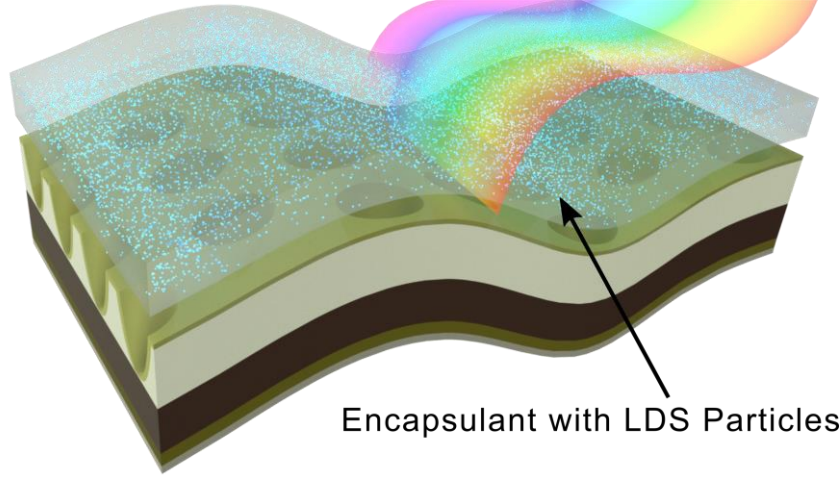
I_2

$CH_3NH_3^+$

CH_3NH_2 (Volatile)

[1] T. Leijtens et. al., *Nature Communications* (2013) [2] S. Ito et. al., *The Journal of Physical Chemistry C* (2014) [3] W.-A. Quitsch et.al., *The Journal of Physical Chemistry Letters* (2018)

UV→VIS Down-Shifting (DS)



UV Radiation

DS layer

TiO_2

e

Deep trap states

Recombination

e

Perovskite

UV Radiation

DS layer

2e

$2I^-$

I_2

$CH_3NH_3^+$

CH_3NH_2 (Volatile)

UV Radiation

DS layer

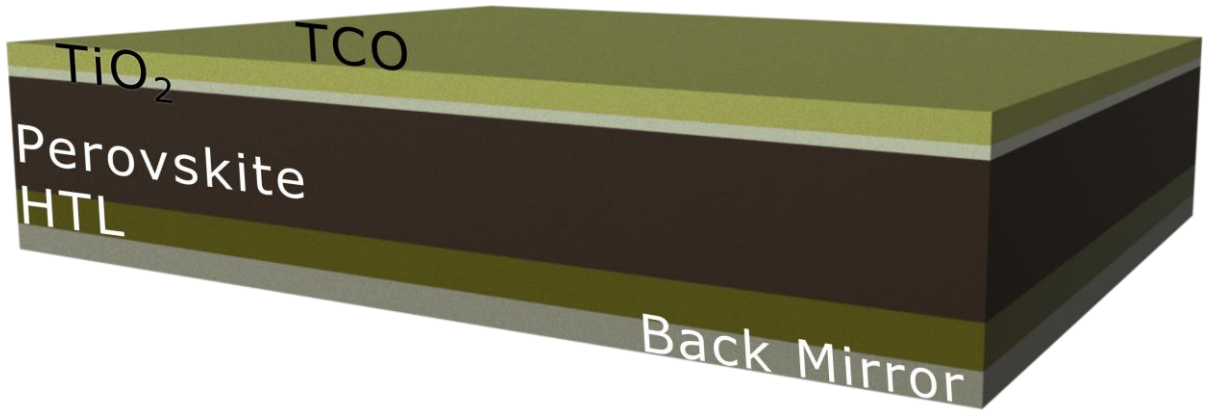
PbI_2

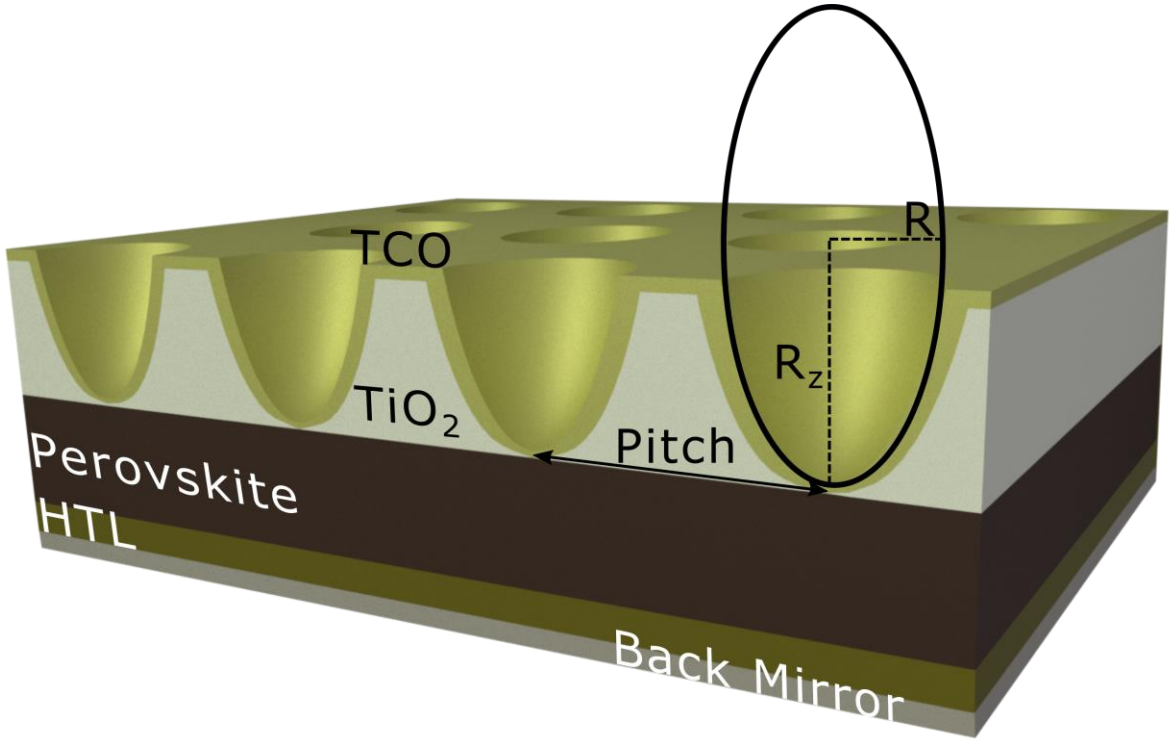
I_2

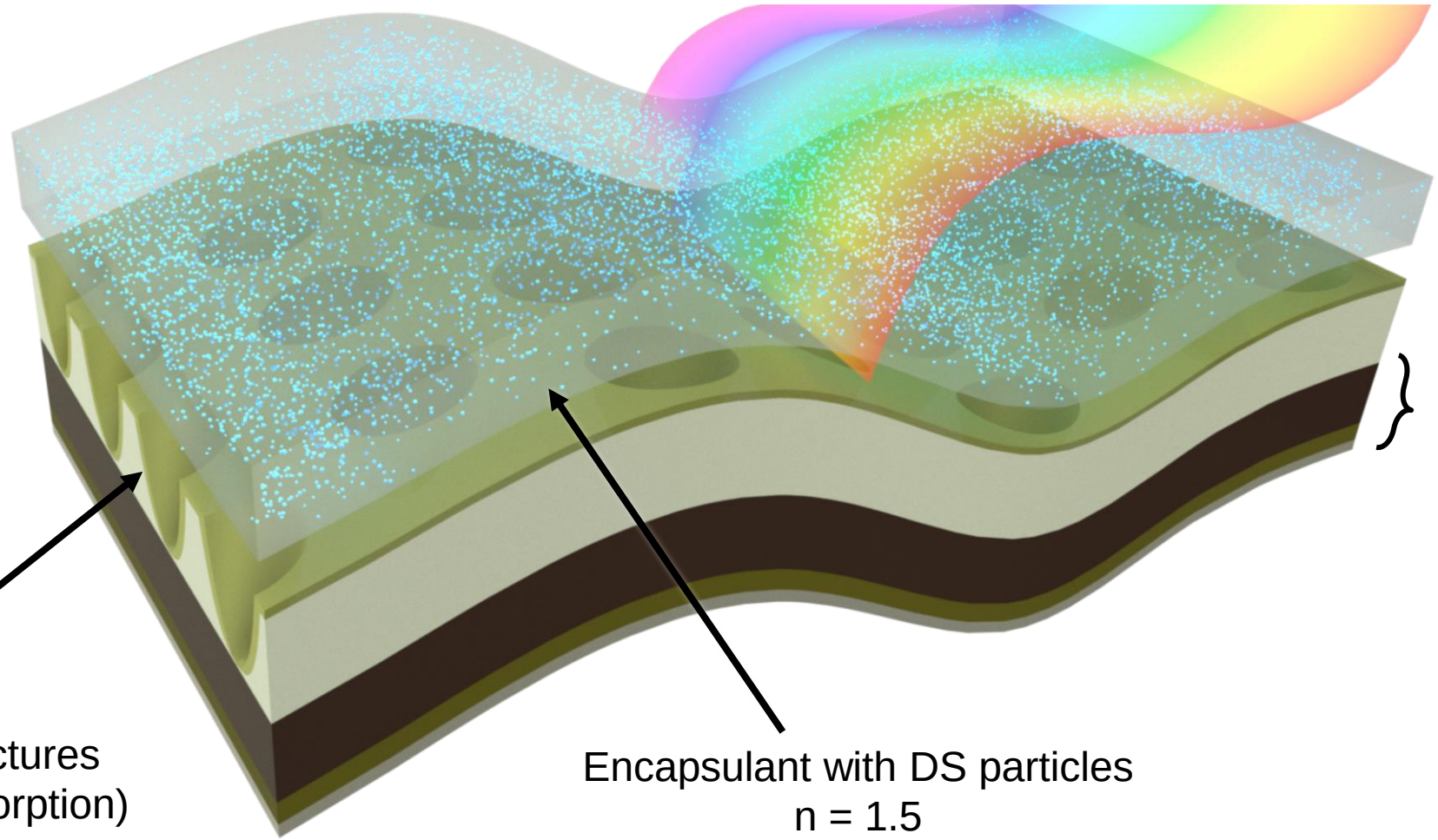
$CH_3NH_3^+$

CH_3NH_2 (Volatile)

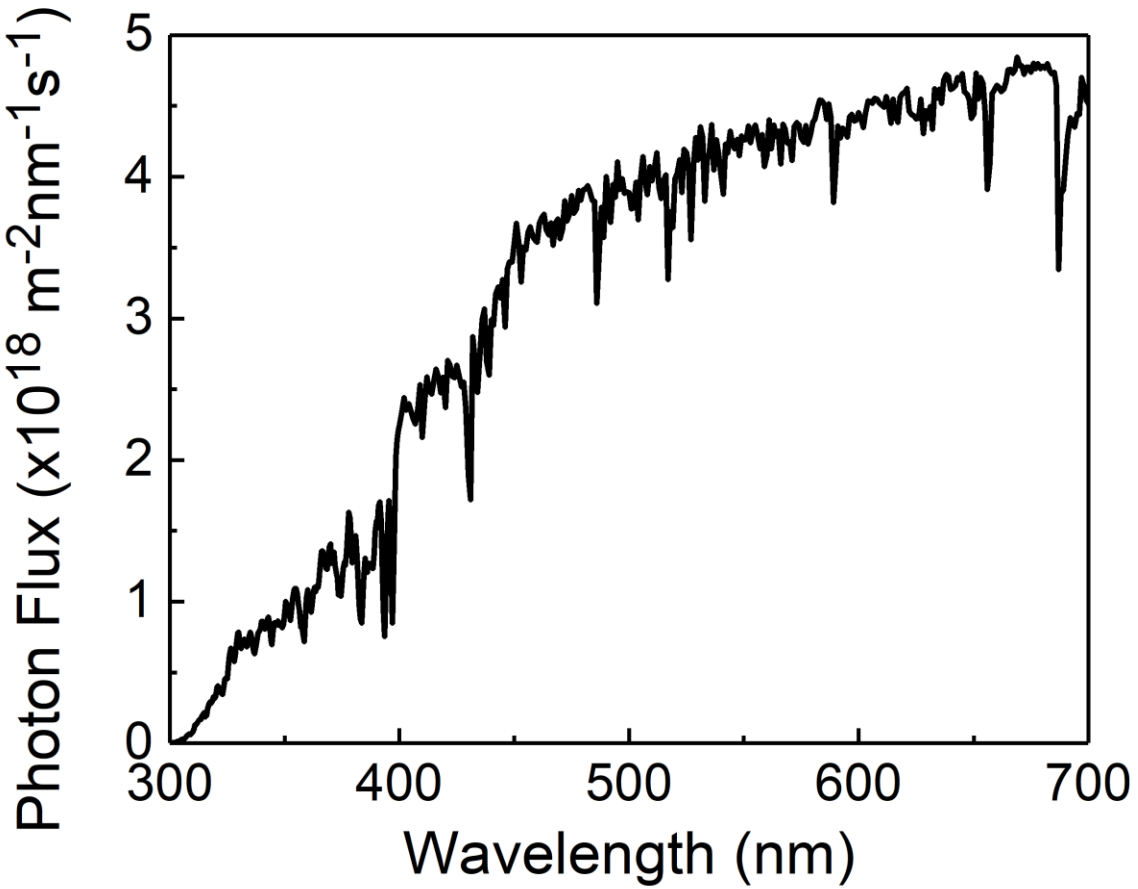
Solar Cell Structures






Perovskite Solar Cell
Light Trapping Structures
(Higher VIS-NIR Absorption)
Encapsulant with DS particles
n = 1.5

Down-Shifting (DS) Method

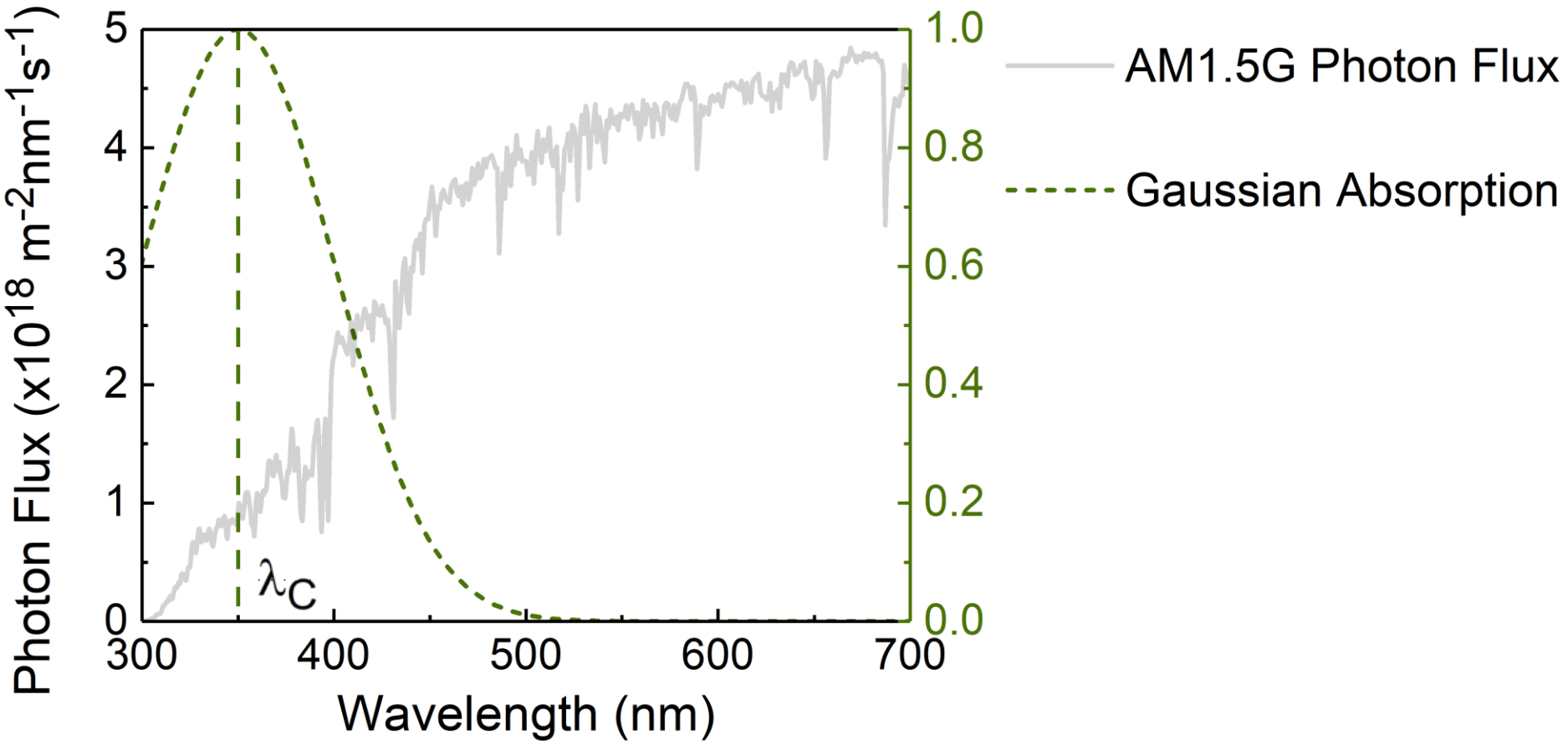


AM1.5G Photon Flux

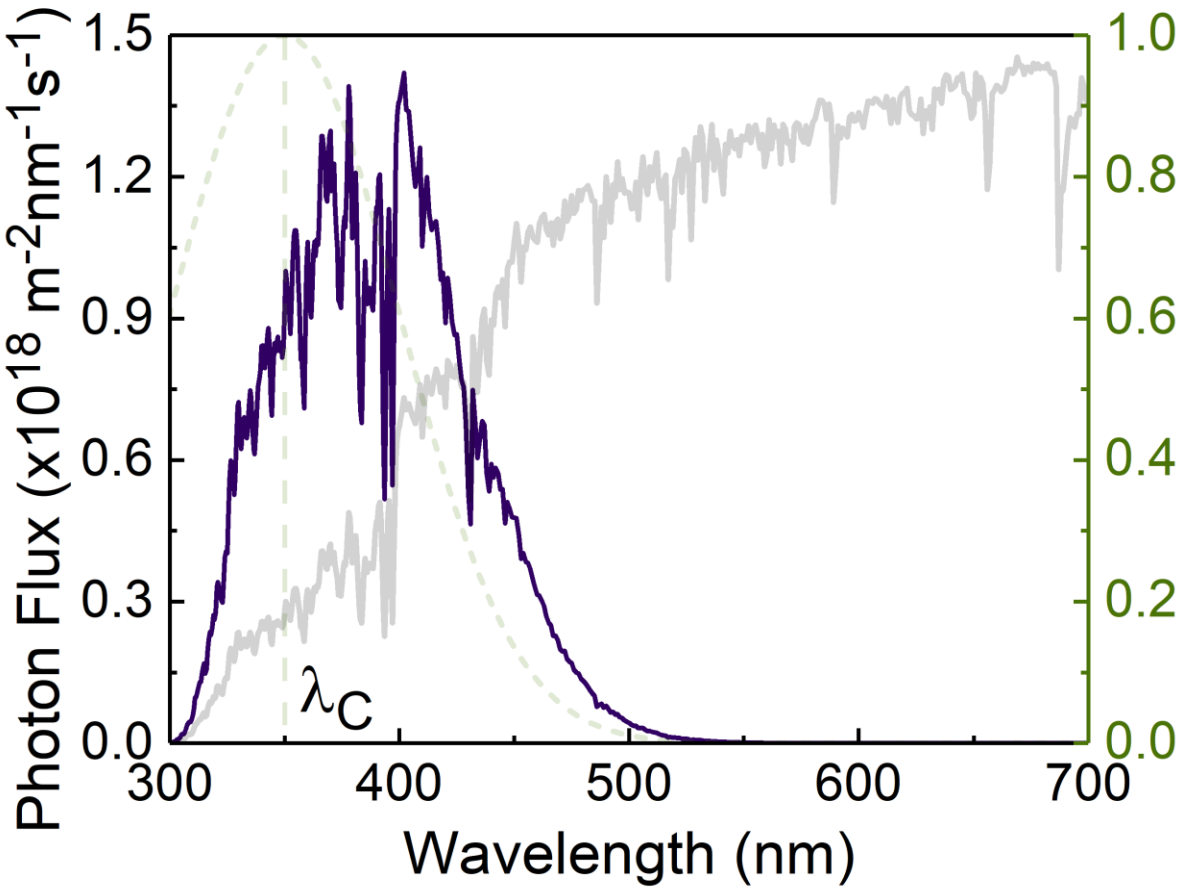
$$J_{ph} = \int A(\omega) AM_{1.5G} d\omega$$

Change to include DS effect

Down-Shifting (DS) Method



Down-Shifting (DS) Method



AM1.5G Photon Flux

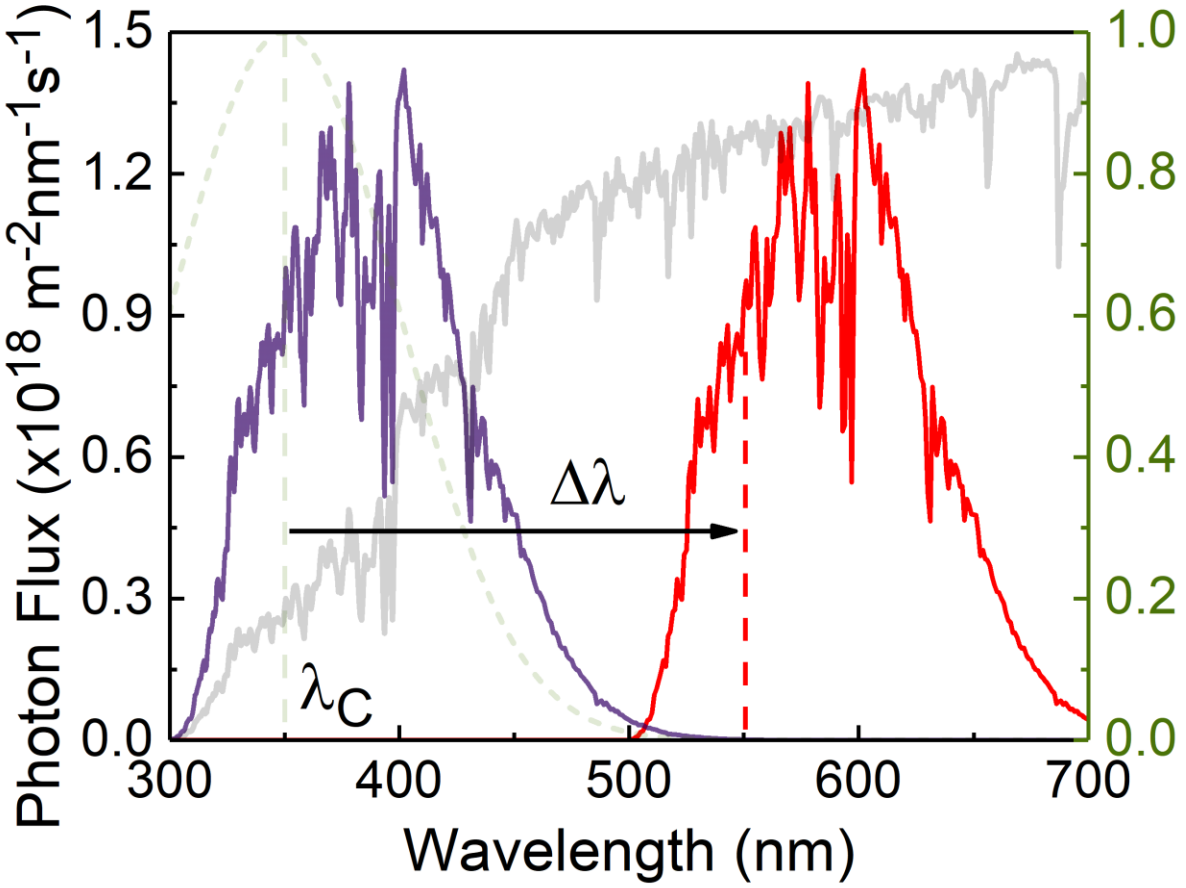
X

Gaussian Absorption

↓

Absorption Flux

Down-Shifting (DS) Method



AM1.5G Photon Flux

X

Gaussian Absorption

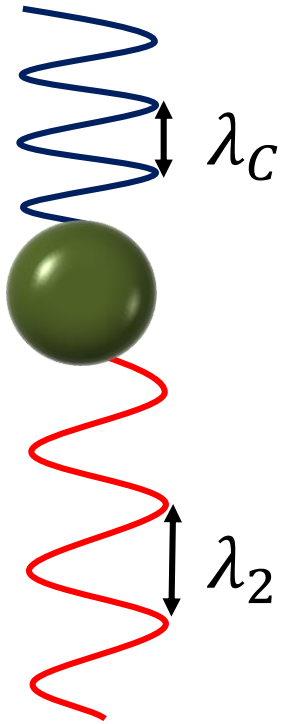
↓

Absorption Flux

↓ $+\Delta\lambda$

Emission Flux

$$\lambda_2 - \lambda_C = \Delta\lambda$$



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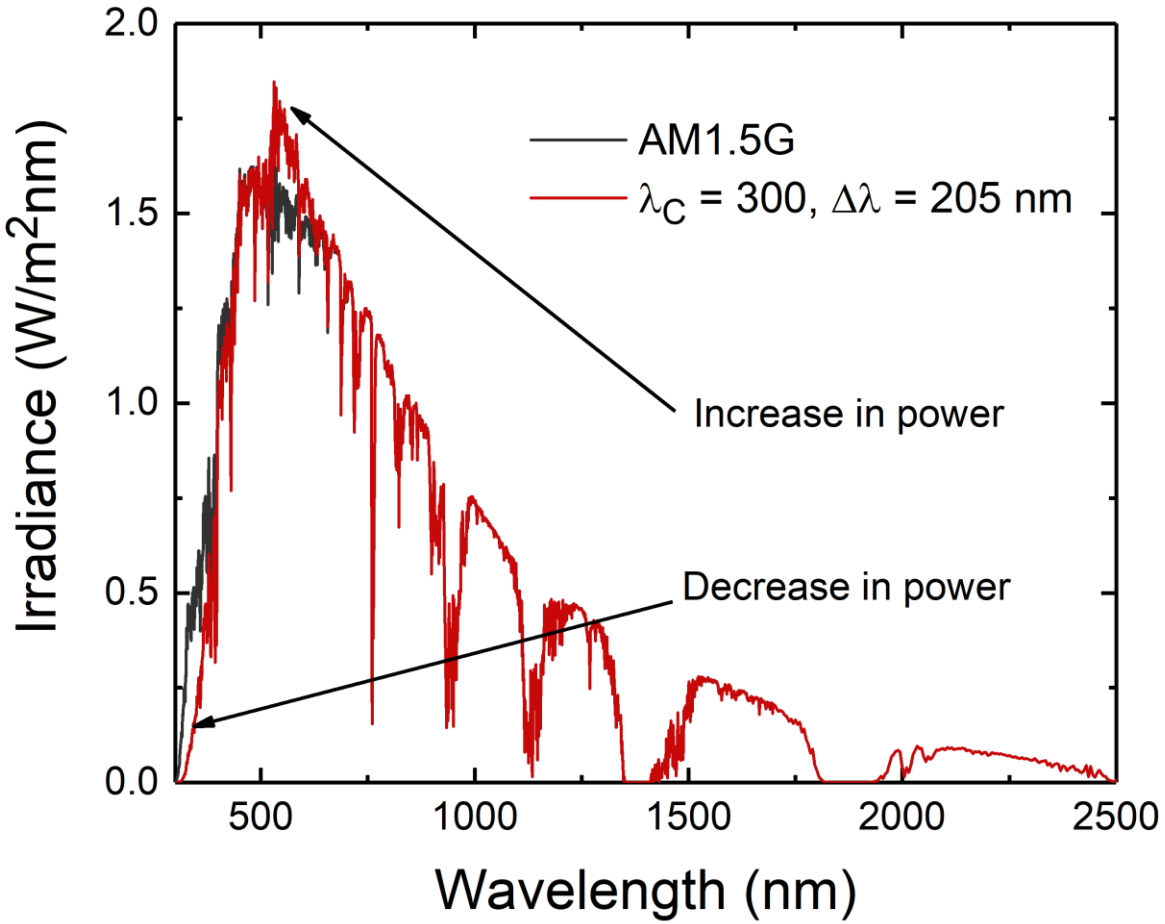
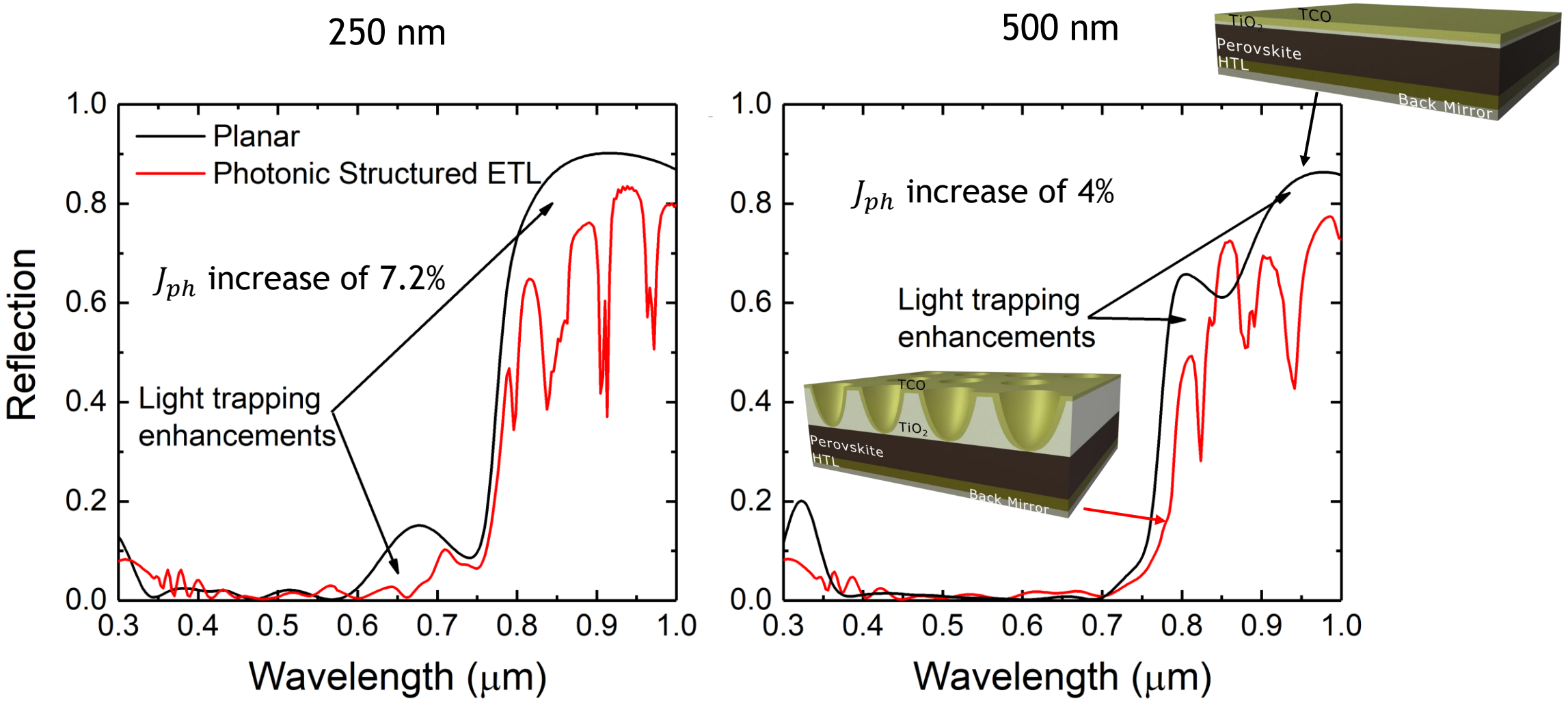
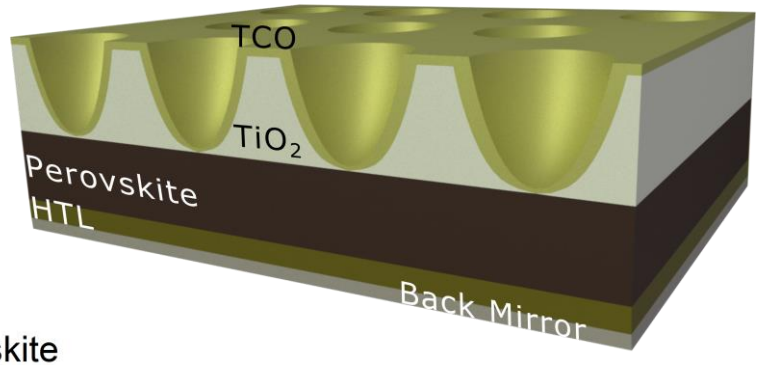
Down-Shifting Method



Reflection Profiles

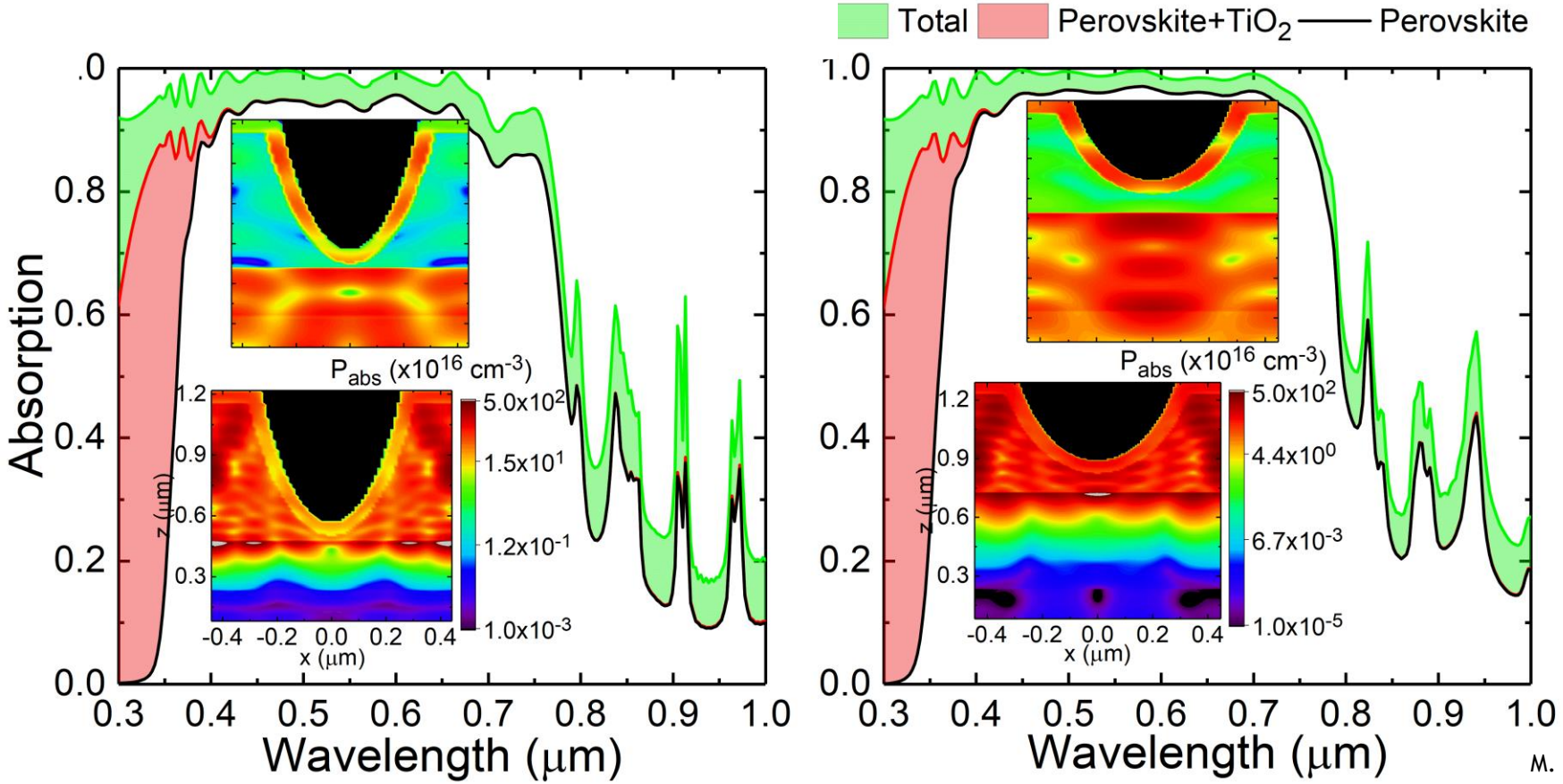


Absorption Profiles



250 nm

500 nm



- Excellent VIS Absorption
- Good VIS-IR Absorption
- TiO_2/ITO Absorption

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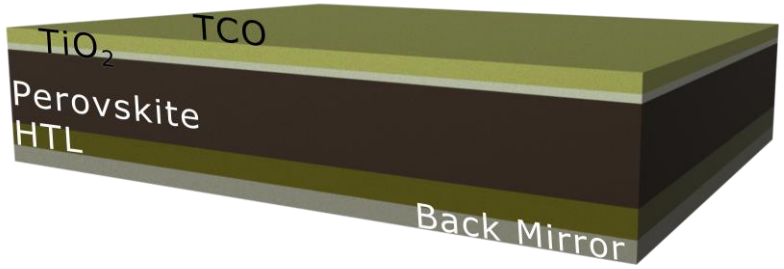
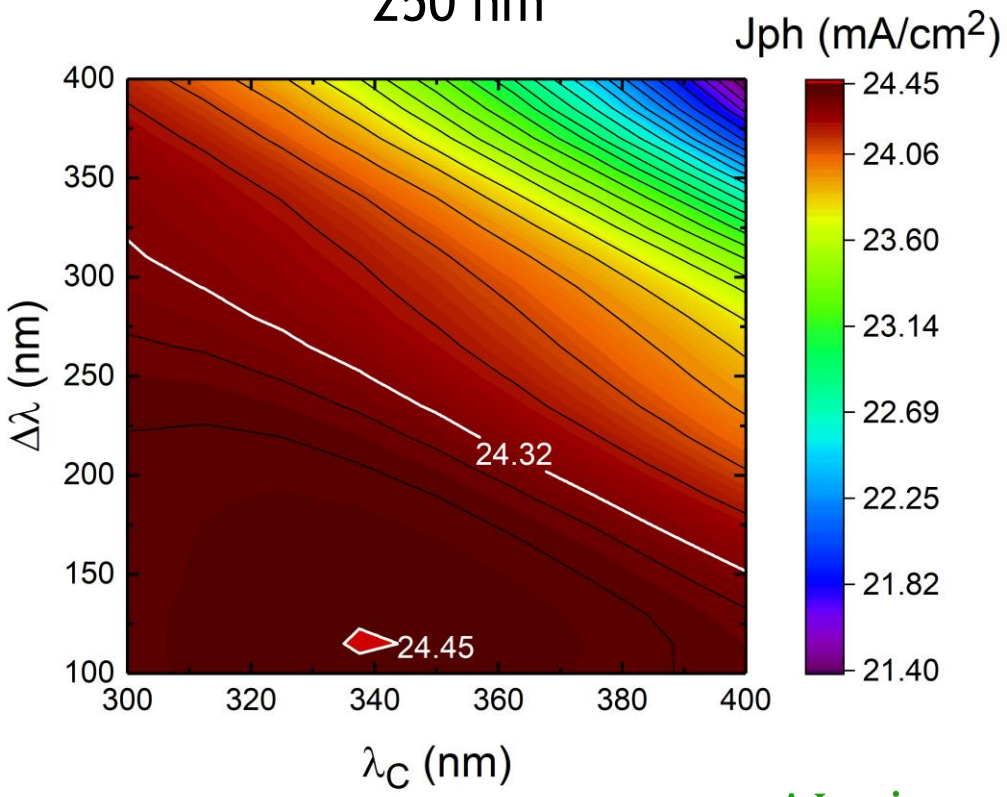
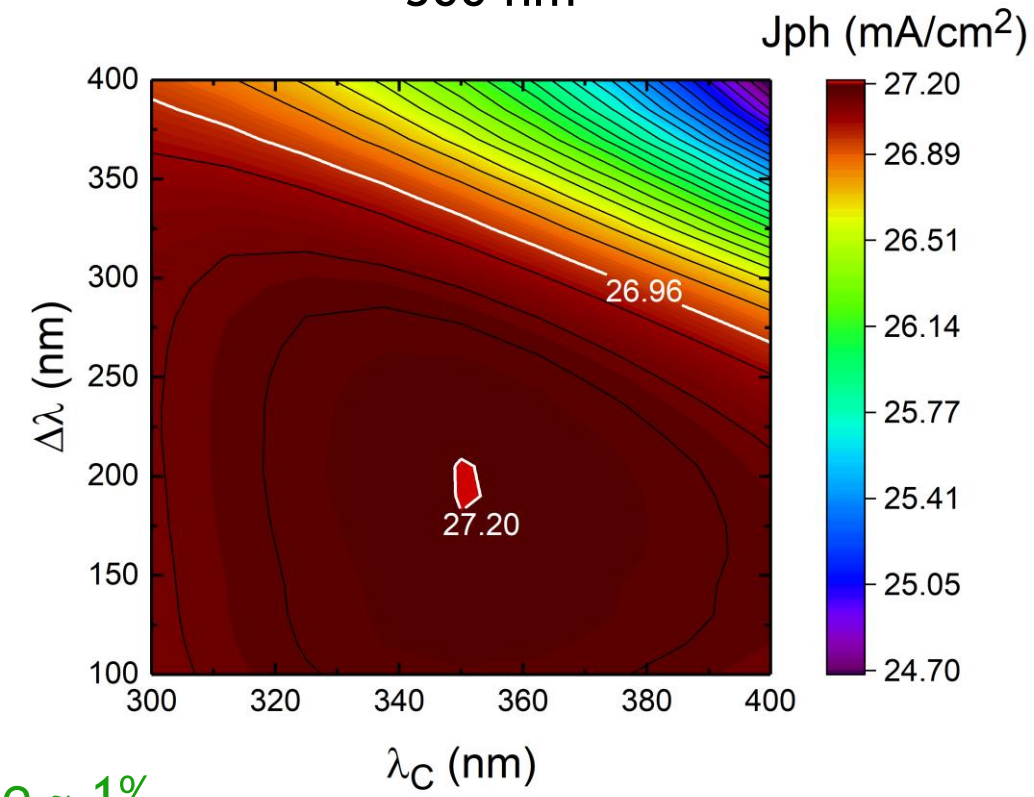
LDS Properties Sweeps

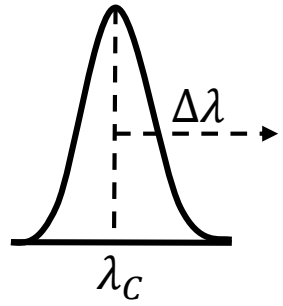


250 nm



500 nm





- ΔJ_{ph} increase ~ 1%
- $\lambda_C + \Delta\lambda$ sum ~ 500 nm
- J_{ph} reduction ~ 12% for unoptimized $\lambda_C + \Delta\lambda$

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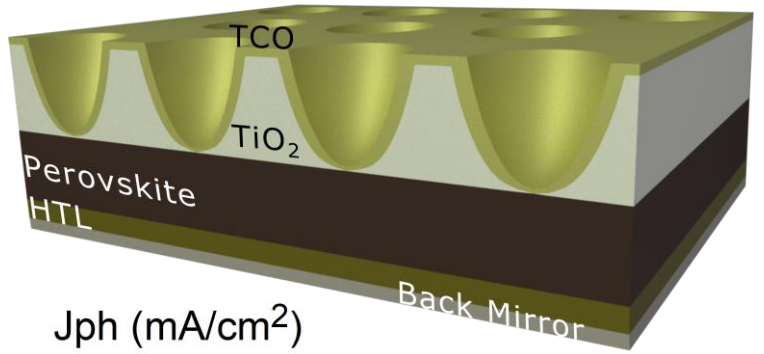
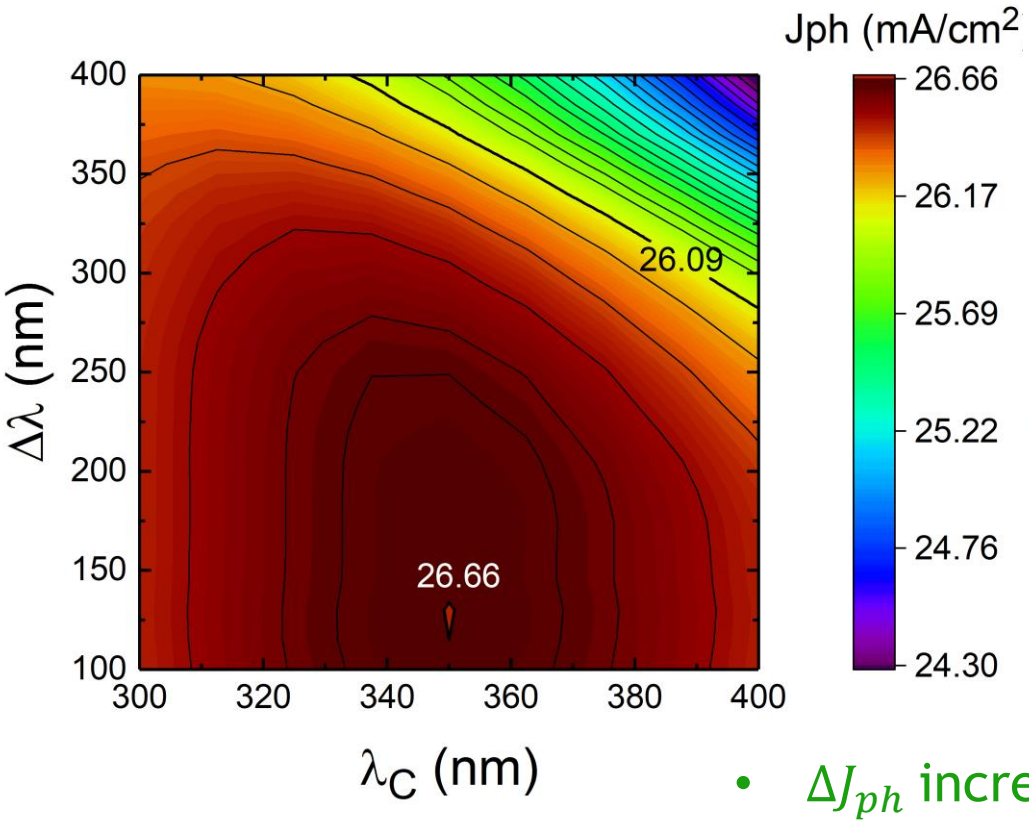
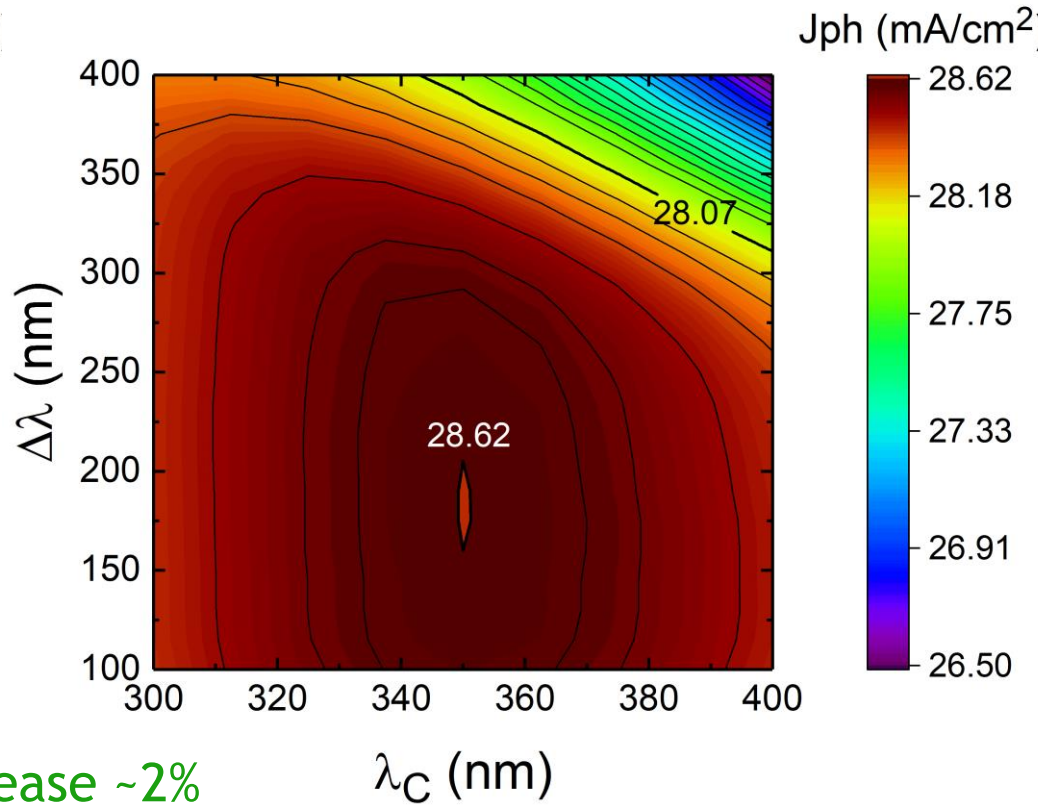
LDS Properties Sweeps

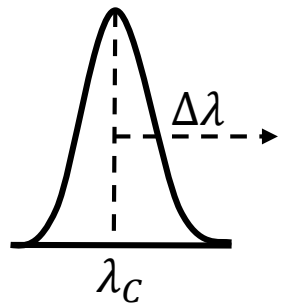


250 nm



500 nm





- ΔJ_{ph} increase ~2%
- $\lambda_C + \Delta\lambda$ sum ~ 500 nm
- J_{ph} reduction ~ 7% for unoptimized $\lambda_C + \Delta\lambda$

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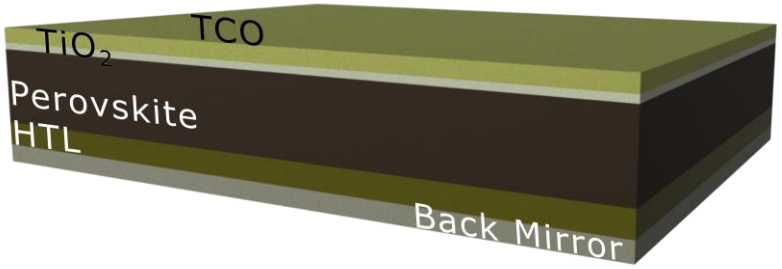
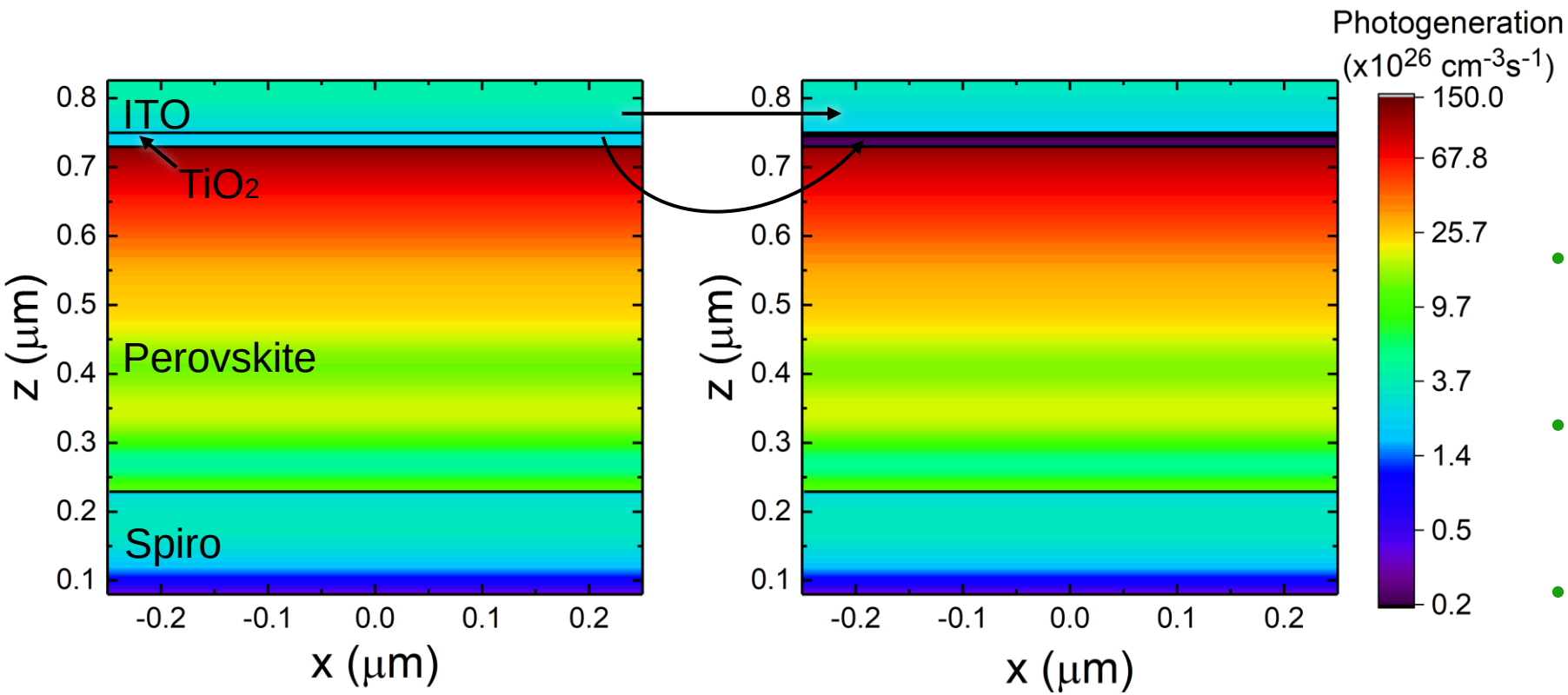
Generation Profiles and UV absorption



Pristine Spectrum

Shifted Spectrum



- **UV J_{ph} (300-400 nm) reduction ~80%**
- Lower TiO_2 photogeneration
- Increase in Perovskite bulk absorption

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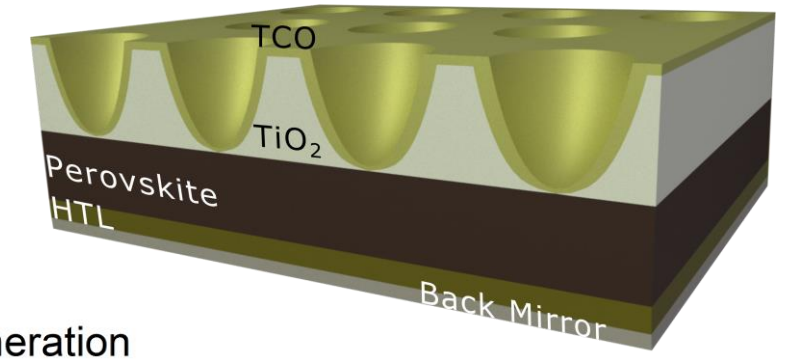
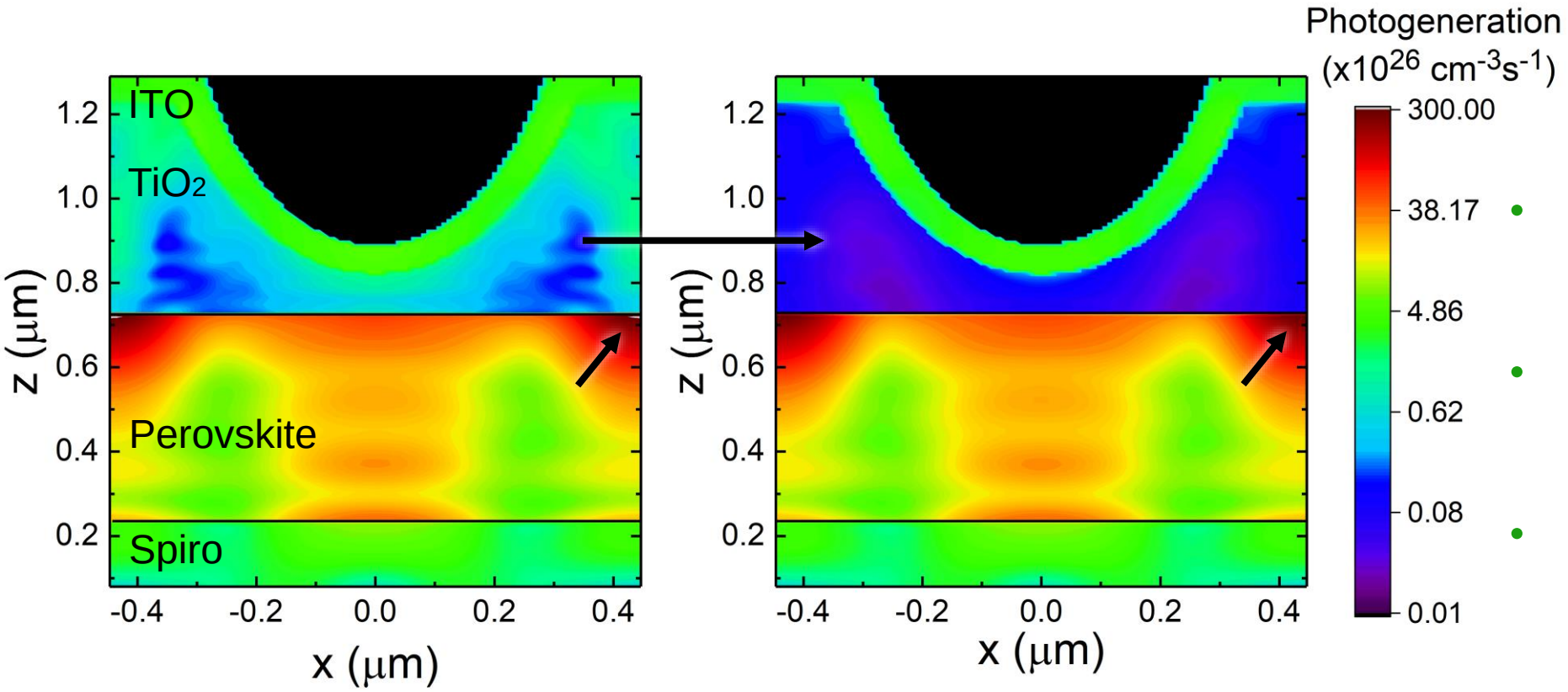
Generation Profiles and UV absorption



Pristine Spectrum

Shifted Spectrum



- UV J_{ph} (300-400 nm) reduction ~80%
- Lower TiO_2 photogeneration
- Increase in Perovskite bulk absorption

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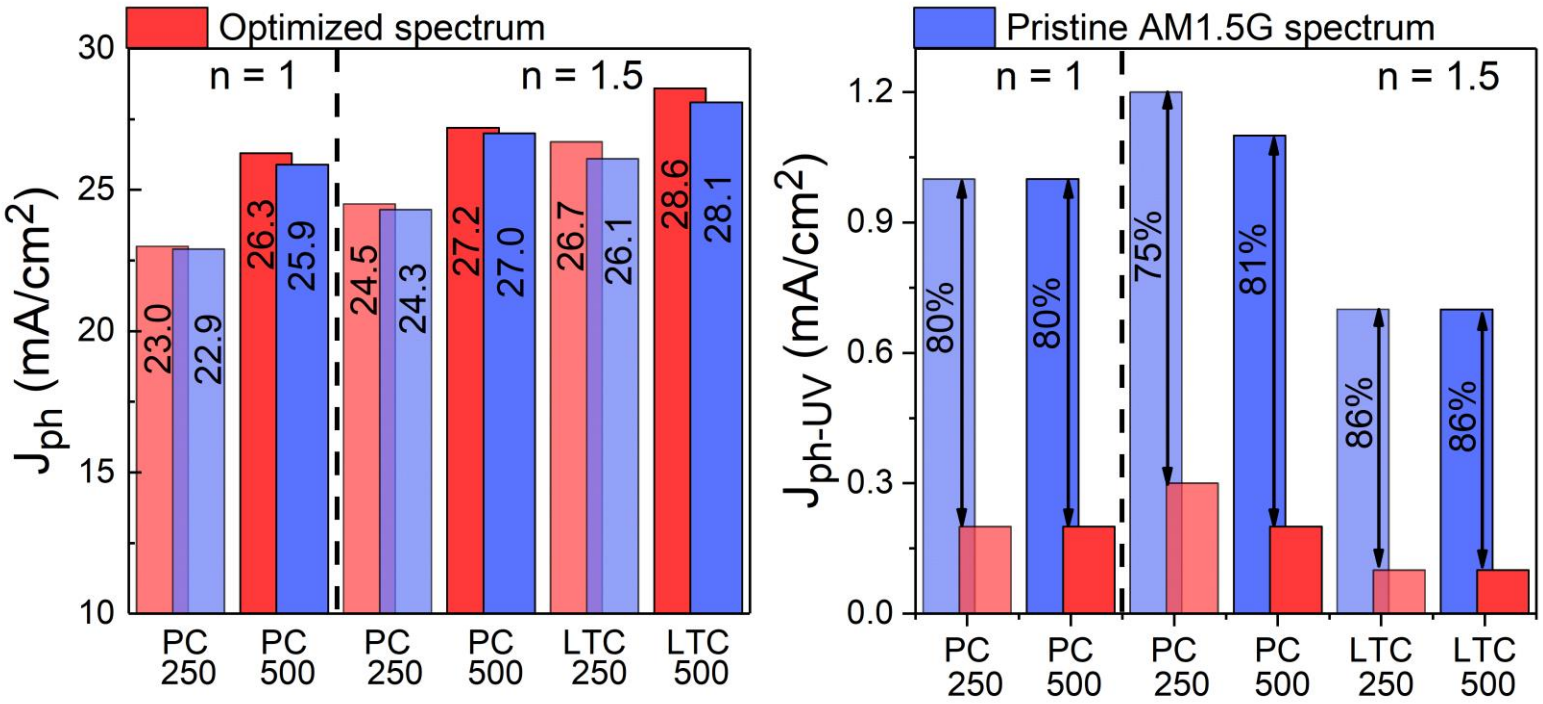
Final Thoughts



Max J_{ph} increase of 0.57 mA/cm^2

- ~60% of max gain possible

Reduction ~80% in UV absorption

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Thank you for your attention!

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