CROWM

Combined Ray-Optics / Wave-Optics Model

http://lpvo.fe.uni-lj.si/en/software/crowm/

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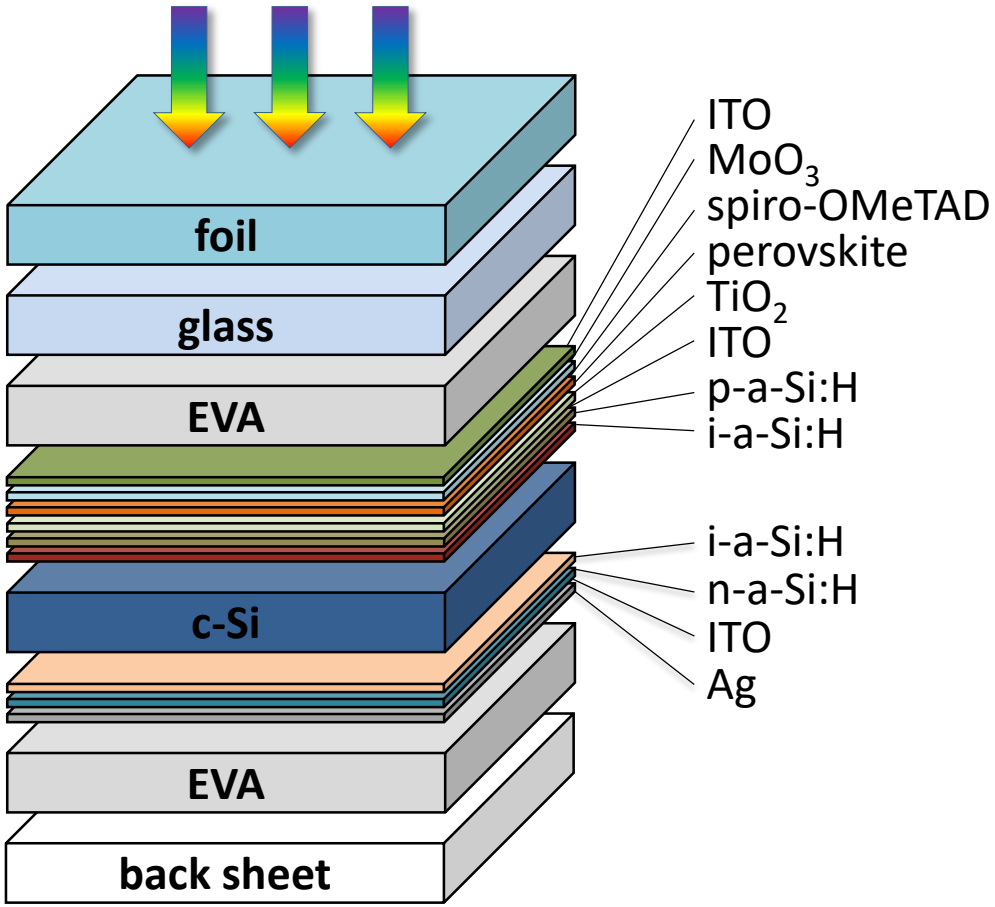
Optical modelling of modern PV devices



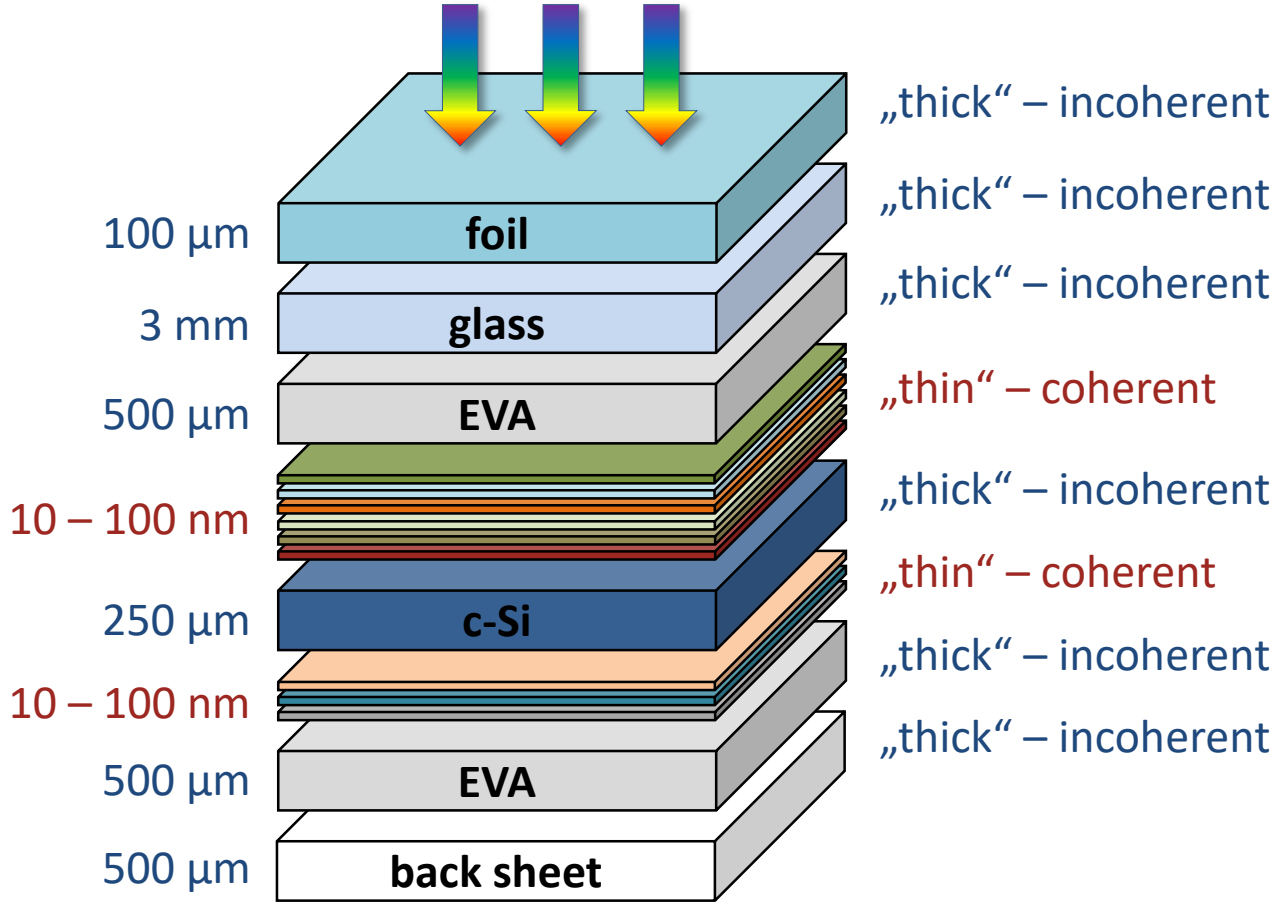
Example:

tandem
perovskite / c-Si
heterojunction
PV module

$R(\lambda)$
$A(\lambda)_{layer}$ = ?
$T(\lambda)$
...

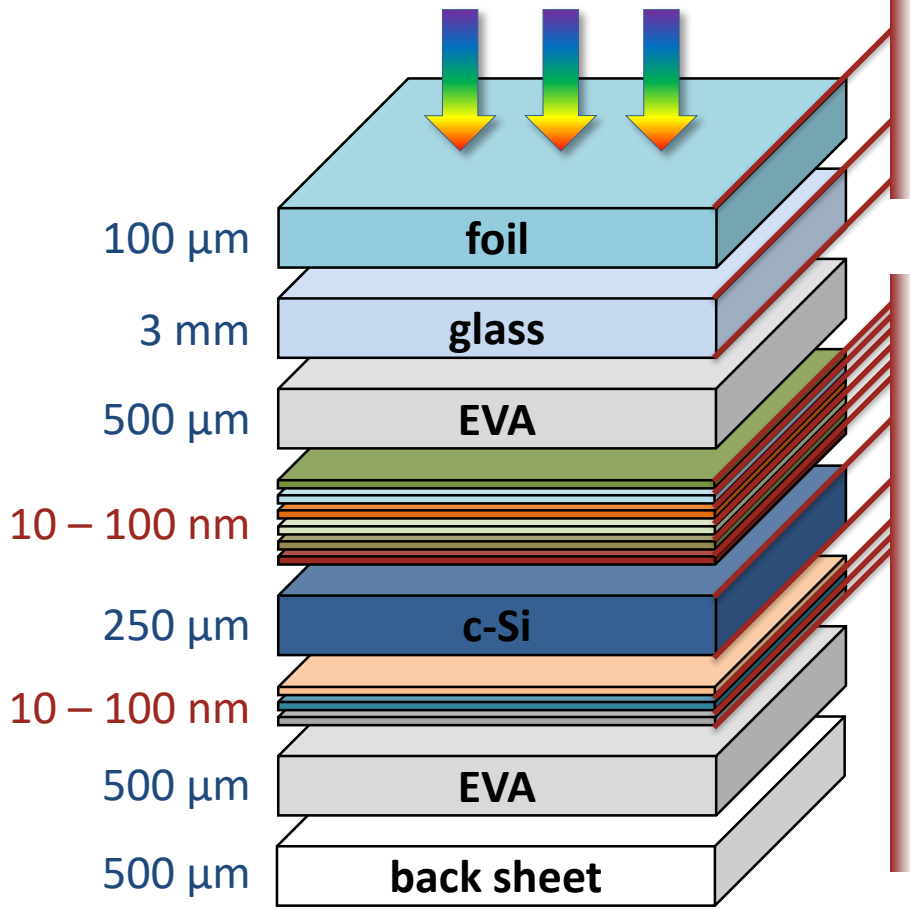
Optical modelling of modern PV devices

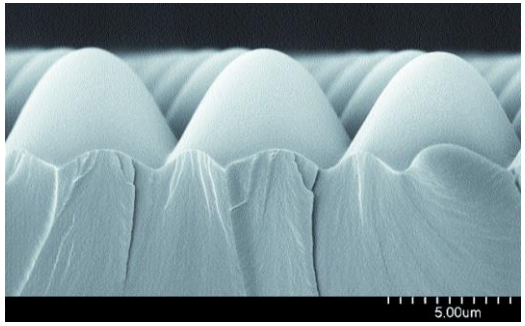
- Layer thicknesses / coherence conditions



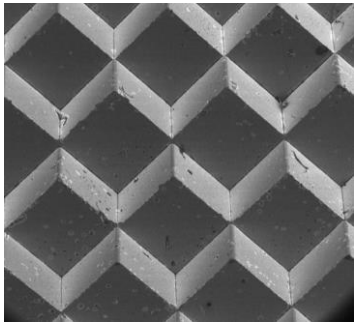
Optical modelling of modern PV devices

- Interface textures

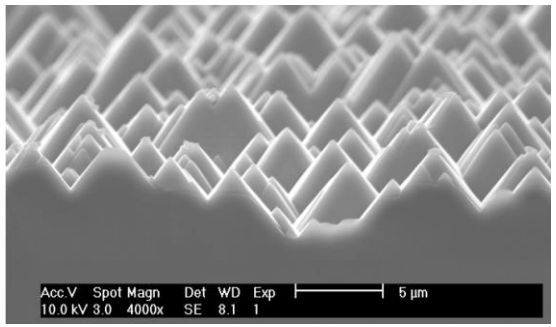


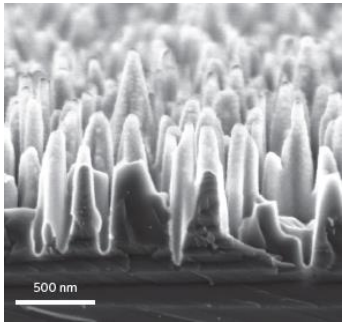


[HT-MLA-09, Holotools, Germany]

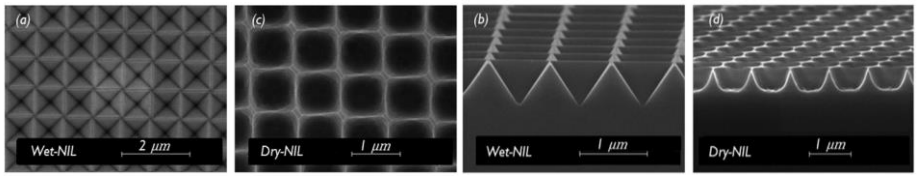


[C. Ulbrich et al., PIP, 2012]





[H. Savin et al., Nature Nanotechnology, 2015]



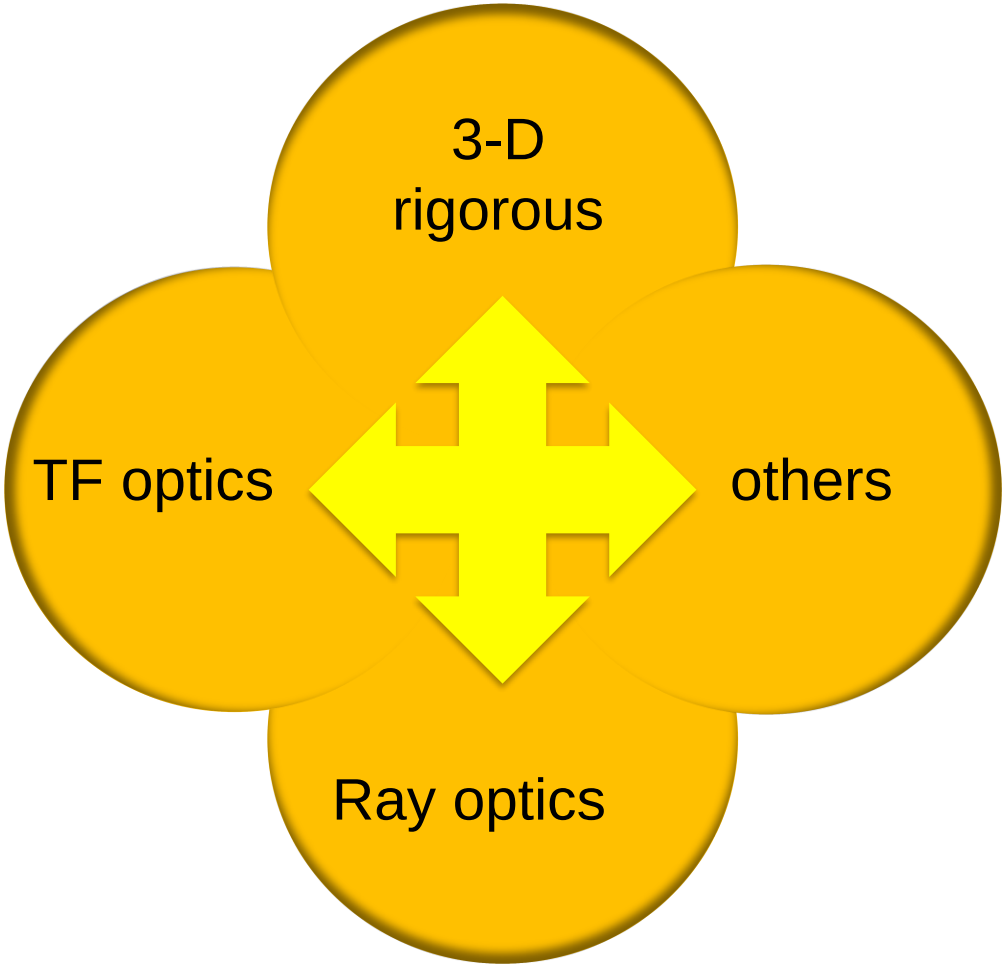
[C. Trompoukis et al., PIP, 2015]

Coupled modelling approach (CMA)

To **seize the advantages** of different models

and

couple them together via a standardized I/O interface



[M. Topič et al., Solar Energy Mat. and Solar Cells, 2014]

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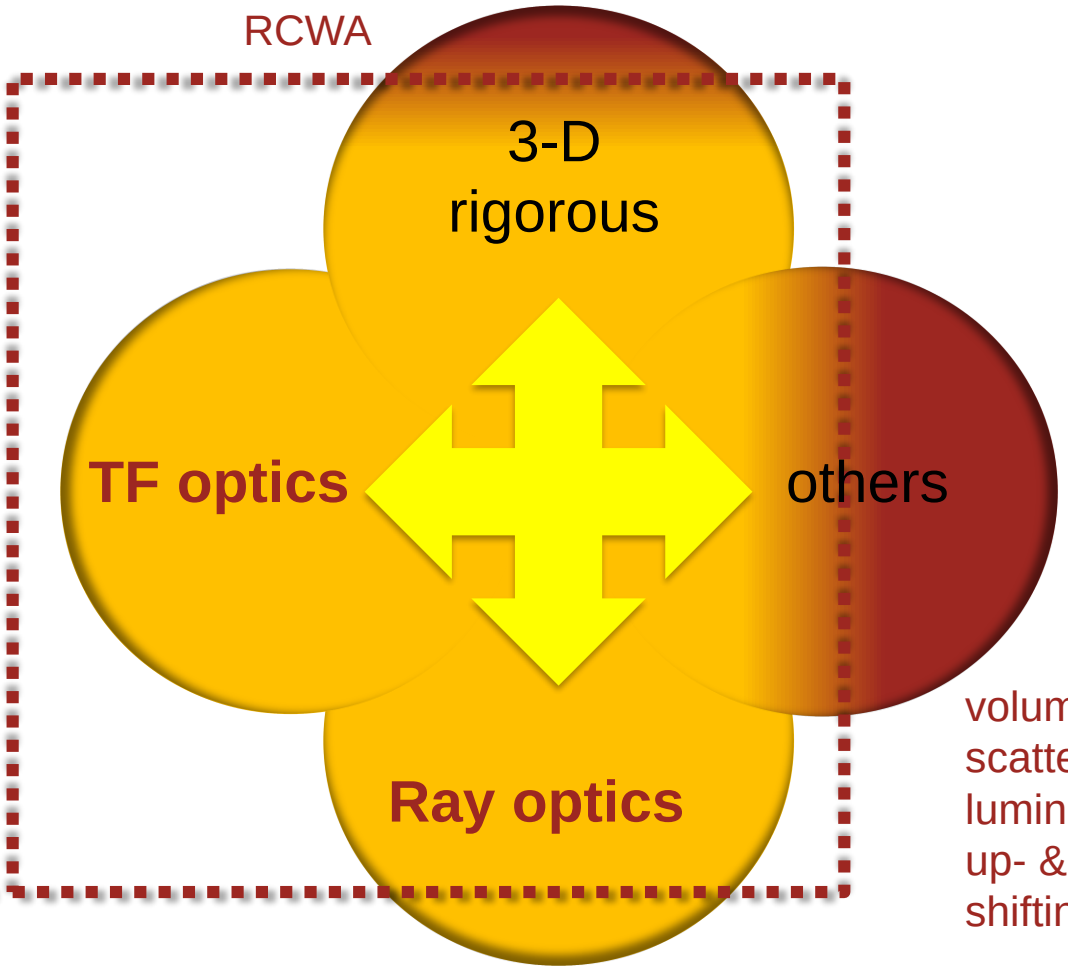

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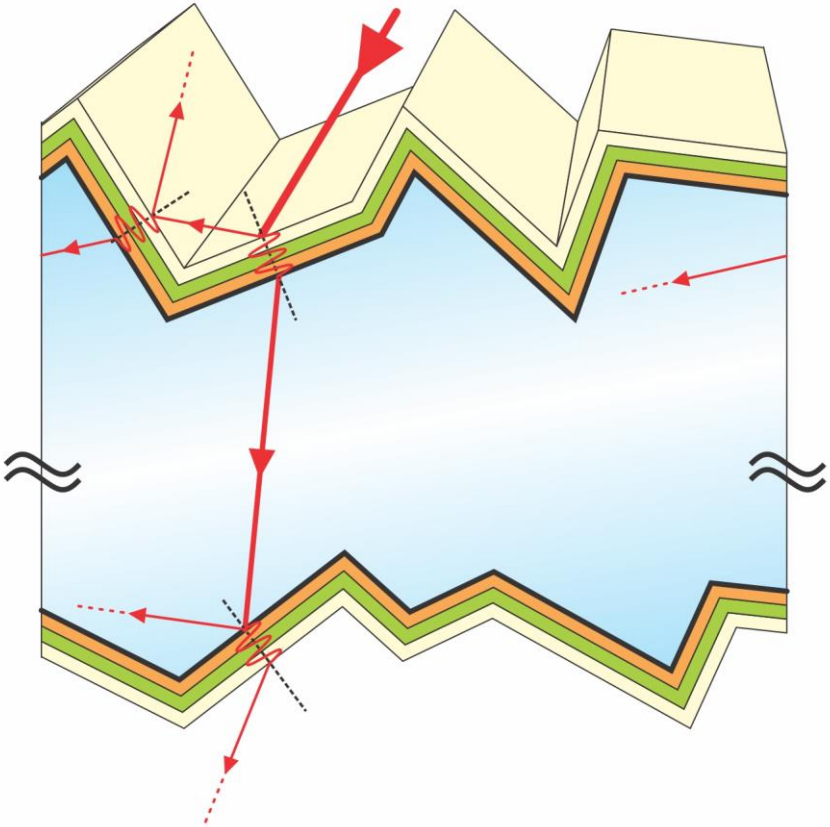

[B. Lipovšek et al., Informacije MIDEM, 2011]

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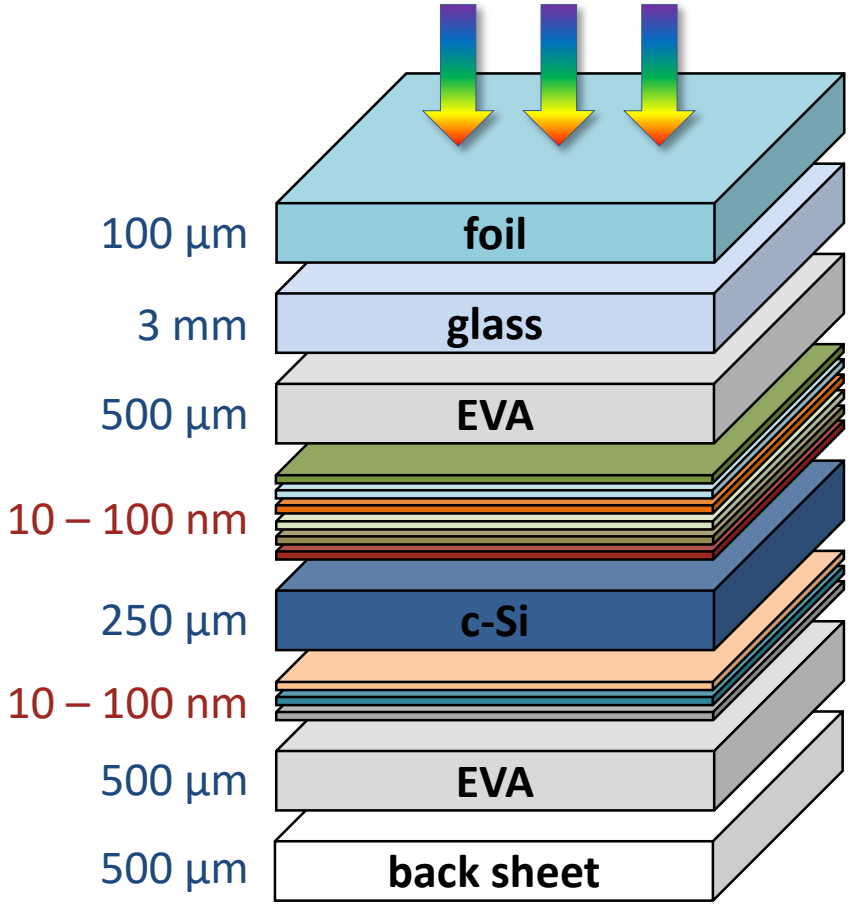

„thick“ – incoherent – **3D ray tracing**

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„thick“ – incoherent – **3D ray tracing**

„thin“ – coherent – **1D TMF**

„thick“ – incoherent – **3D ray tracing**

„thin“ – coherent – **1D TMF**

„thick“ – incoherent – **3D ray tracing**

„thick“ – incoherent – **3D ray tracing**

+ realistic (measured) 3D textures

CROWM highlights

- Optical simulation of thin-film structures combined with thick surface-textured layers (substrates, superstrates, thick absorbers)
- Arbitrary 1D or 2D periodic textures can be applied on each side of the thick layers
- Combination of 3D ray tracing (RT, incoherent geometric optics) and 1D transfer matrix formalism (TMF, coherent wave optics)
- Calculation of R_{tot}, T_{tot}, A in each layer, and ideal QE, and J_{sc} of solar cells

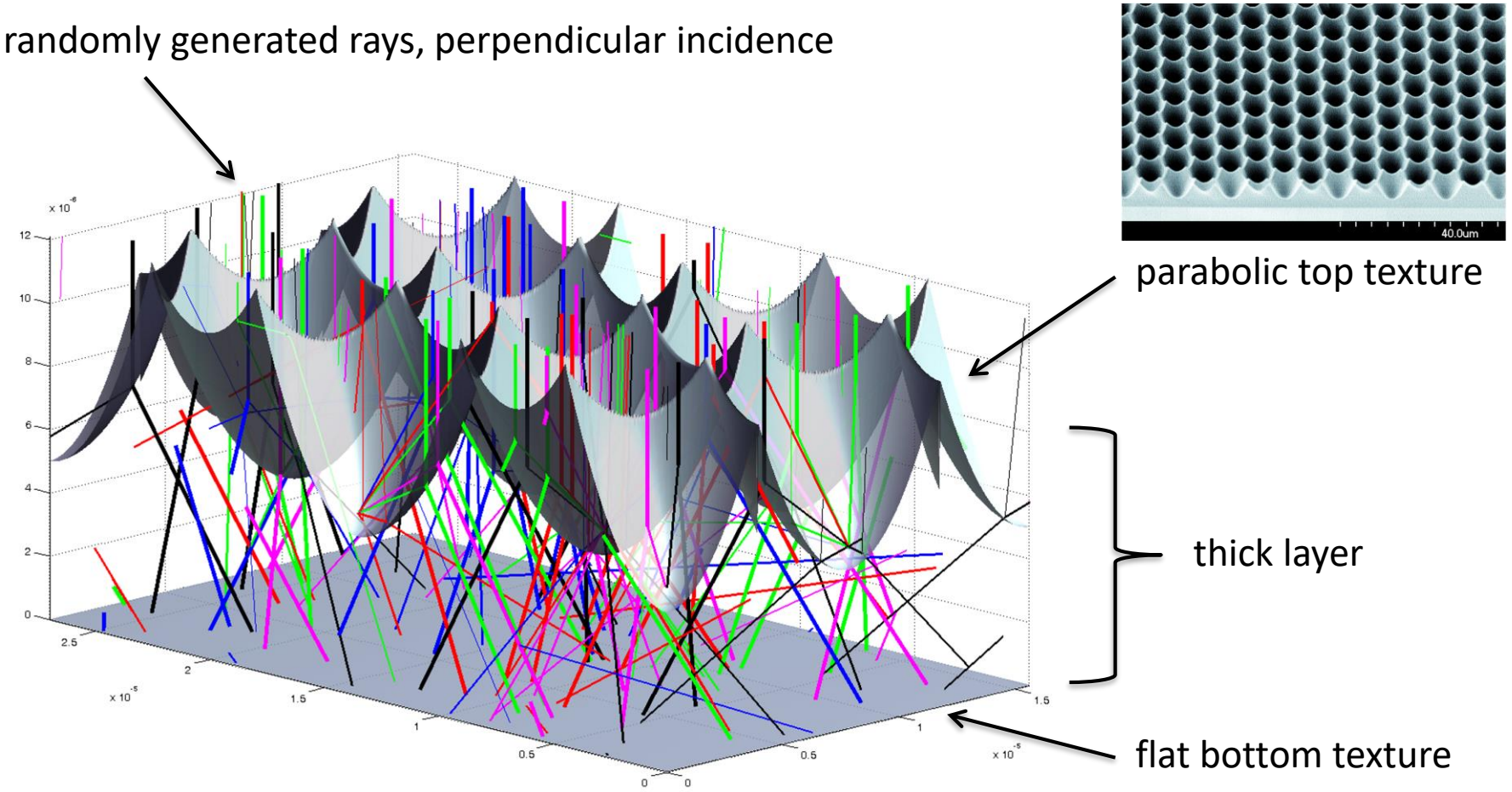
Basic input data

- Parameters of the simulated structure:
  - Layer thicknesses
  - $z(x,y)$ morphologies of the textures (one period in 1D or 2D)
  - Wavelength-dependent refractive indices ($N(\lambda) = n(\lambda) - j \cdot k(\lambda)$)
  - Illumination conditions (incident angle, spectral power density, polarisation)
- Simulation parameters:
  - Number and distribution (linear or random) of incident rays
  - Ray tracing precision settings (spatial resolution, minimum ray power, ...)
  - Additional settings for faster simulations (texture discretisation, incident angle discretisation, ...)

Output data

- Optical characteristics:
  - Total reflectance, $R_{tot}(\lambda)$
  - Total transmittance, $T_{tot}(\lambda)$
  - Absorptance within each layer of the simulated structure, $A(\lambda)$
- Solar cell characteristics (ideal):
  - Quantum efficiency, $QE(\lambda)$ (calculated from $A(\lambda)$ within the photoactive layer)
  - Short-circuit current density, J_{sc} (calculated from QE by applying the spectrum)
  - Short-circuit current density losses in all the supporting layers of the device

Example – 3D ray tracing



CROWM specifications

- Written and compiled in MATLAB
- Runs on 64bit Windows operating system
- Hardware protected with a USB security key
- Supports parallelization on multiple processor cores / clusters