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Electro-optical Characterization of Thin-film Solar Cells and Modules:

From nanophotonic cell characterization to macroscopic module characterization

14. Jan. 2016 | K. Bittkau, S. Lehnen, Z. Cao, A. Gerber, V. Huhn, Y. Augarten, A. Wrigley

Characterization Methods

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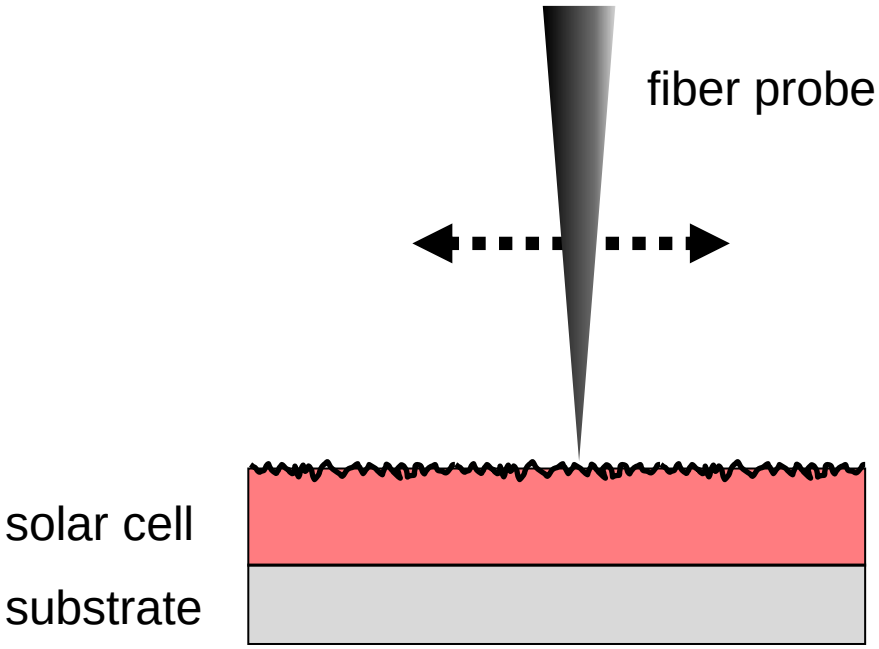
Nano-scale:

- Single-Probe Scanning Near-Field Optical Microscopy
- Dual-Probe Scanning Near-Field Optical Microscopy
- Near-Field Induced Photocurrent Measurement

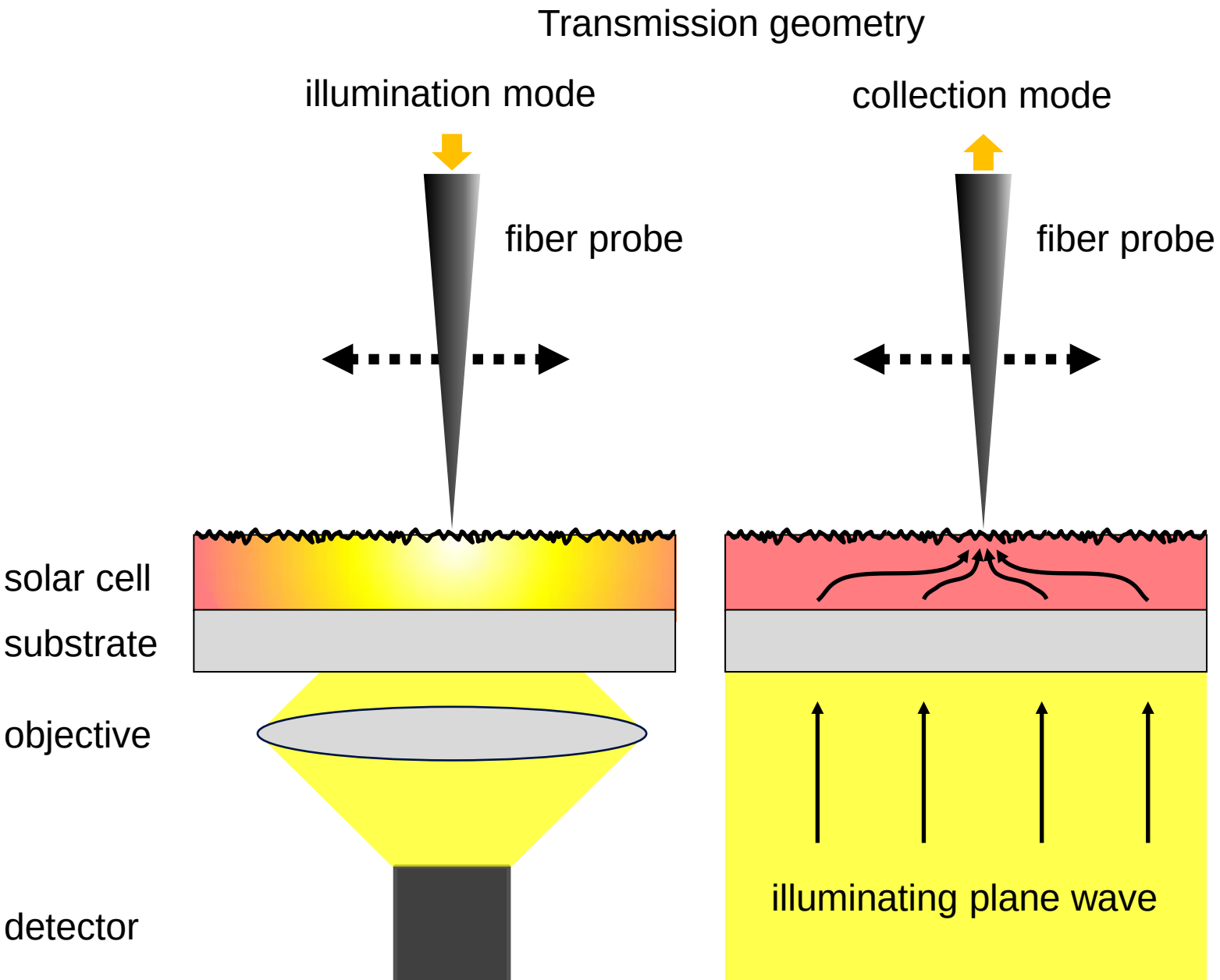
Macro-scale:

- Voltage-modulated Lock-In Thermography at MPP
- Differential Electroluminescence Analysis

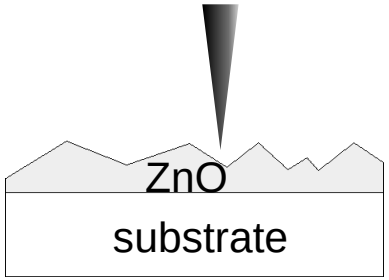
Scanning Near-Field Optical Microscopy

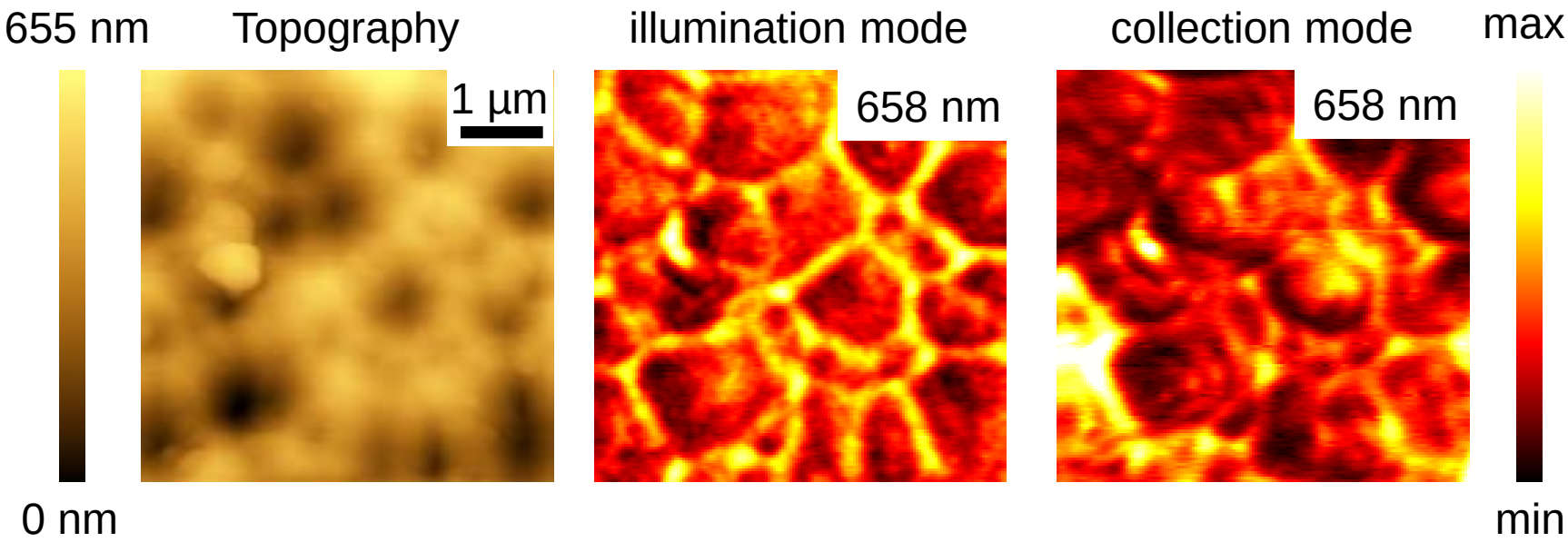


Single-Probe SNOM



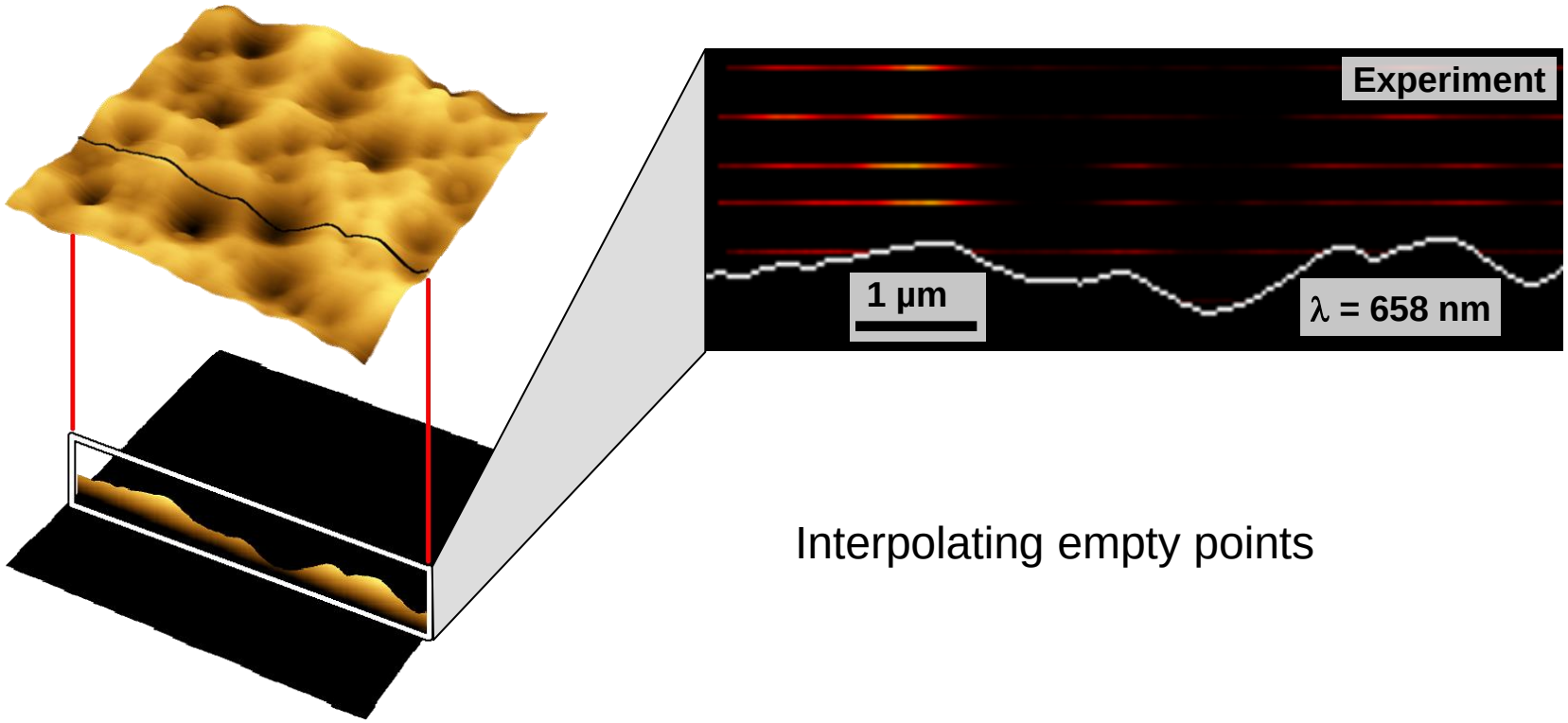
Light Scattering at Textured TCOs





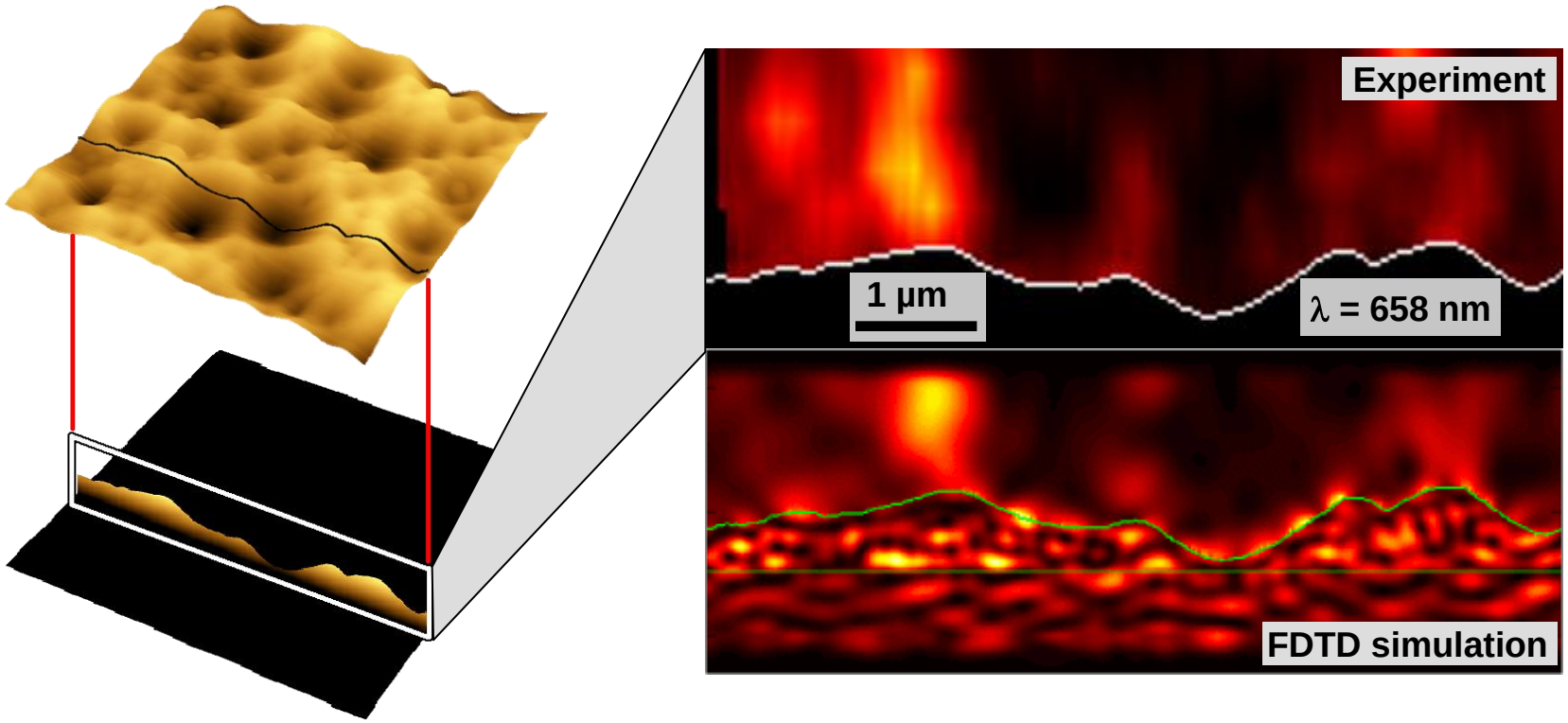
Optical properties with sub-wavelength resolution
- ➢ Not visible in the optical far-field

“Height Scans”



Interpolating empty points

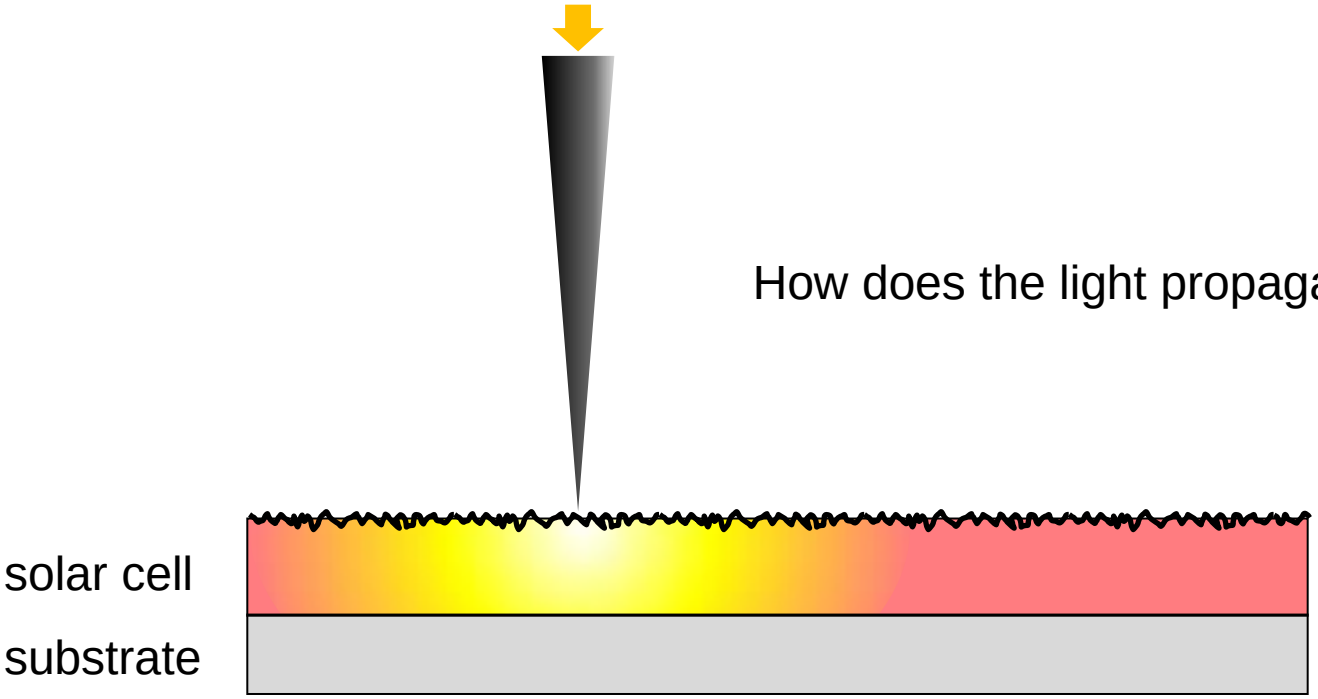
“Height Scans”



Excellent agreement between experiment and theory

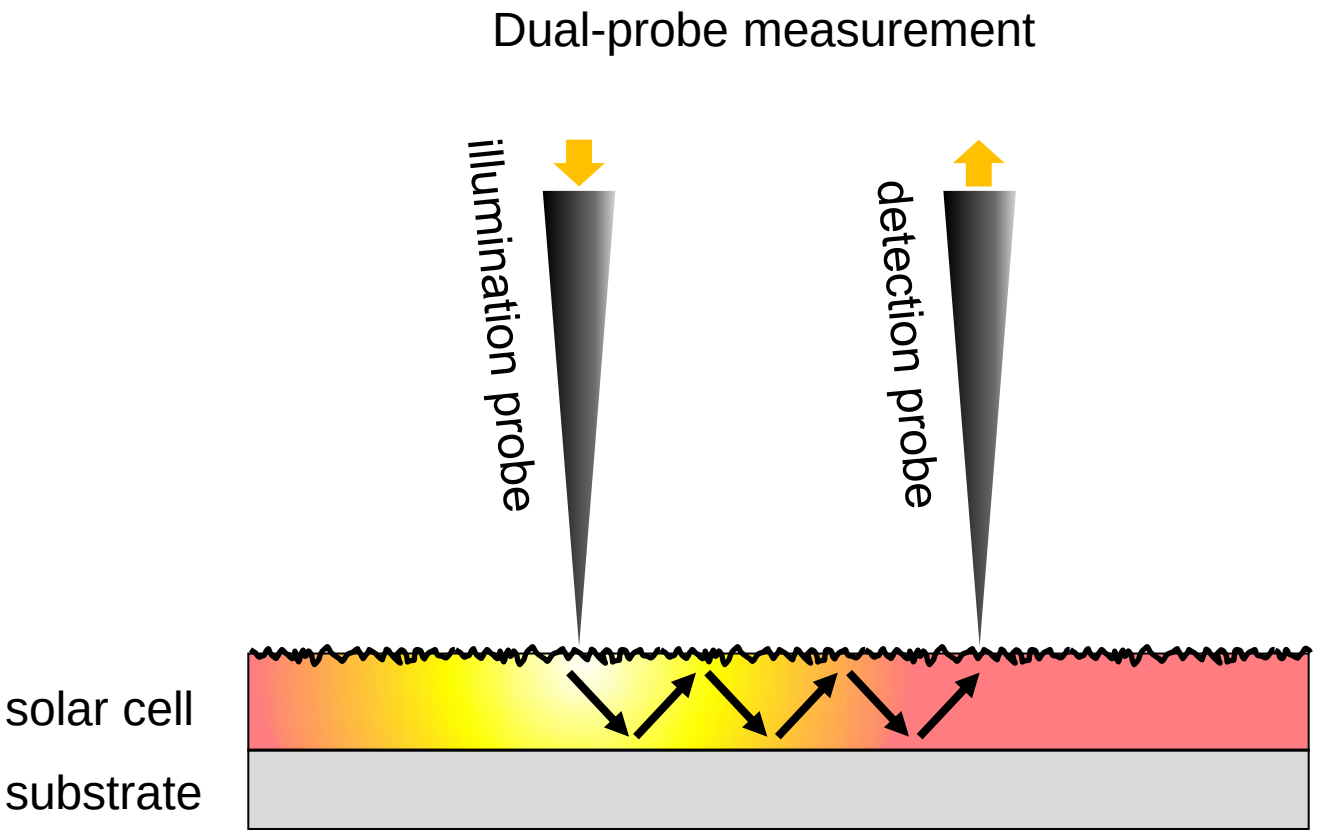
C. Rockstuhl et al., Appl. Phys. Lett. 91, 171104 (2007)

Light Propagation in Solar Cells

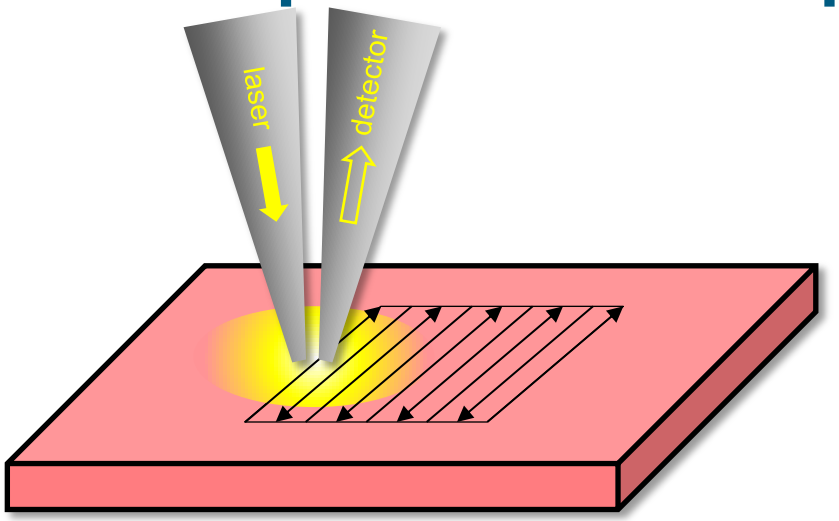


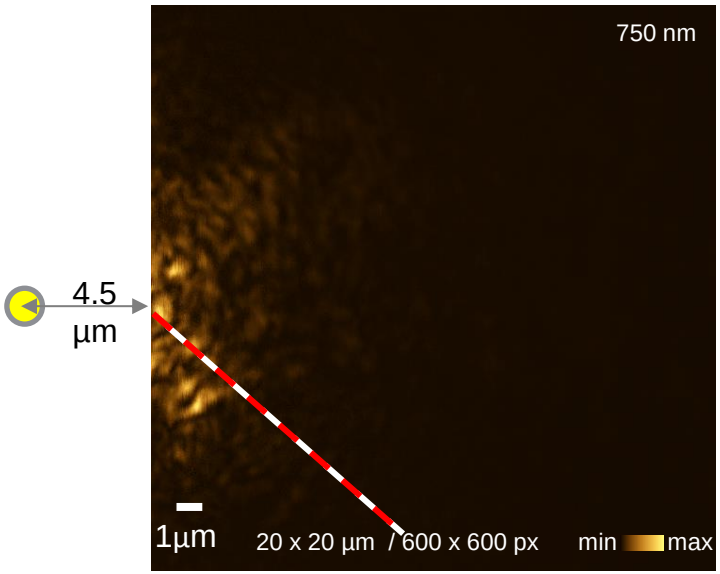
How does the light propagate laterally?

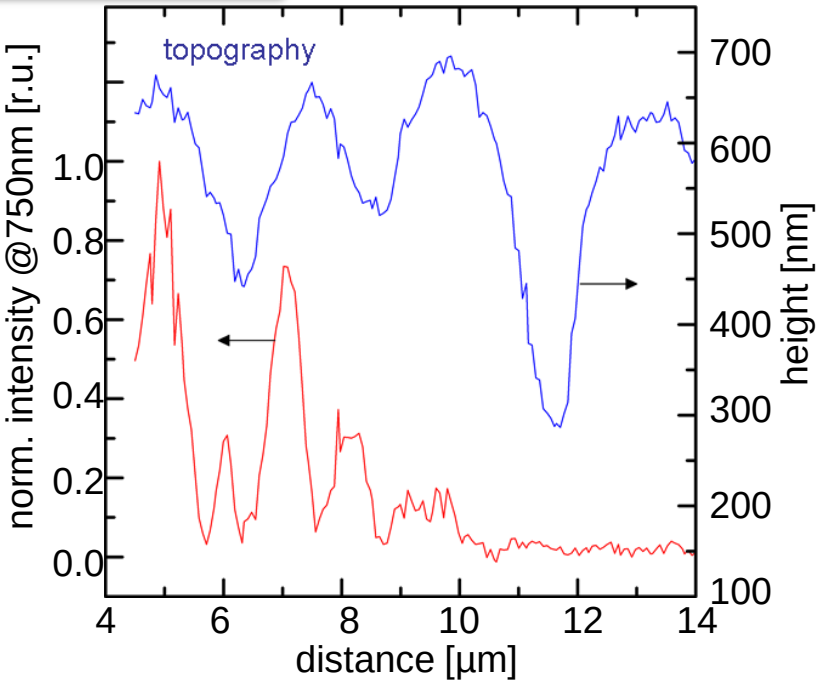
Dual-Probe SNOM



Scanning Near-Field Optical Microscopy



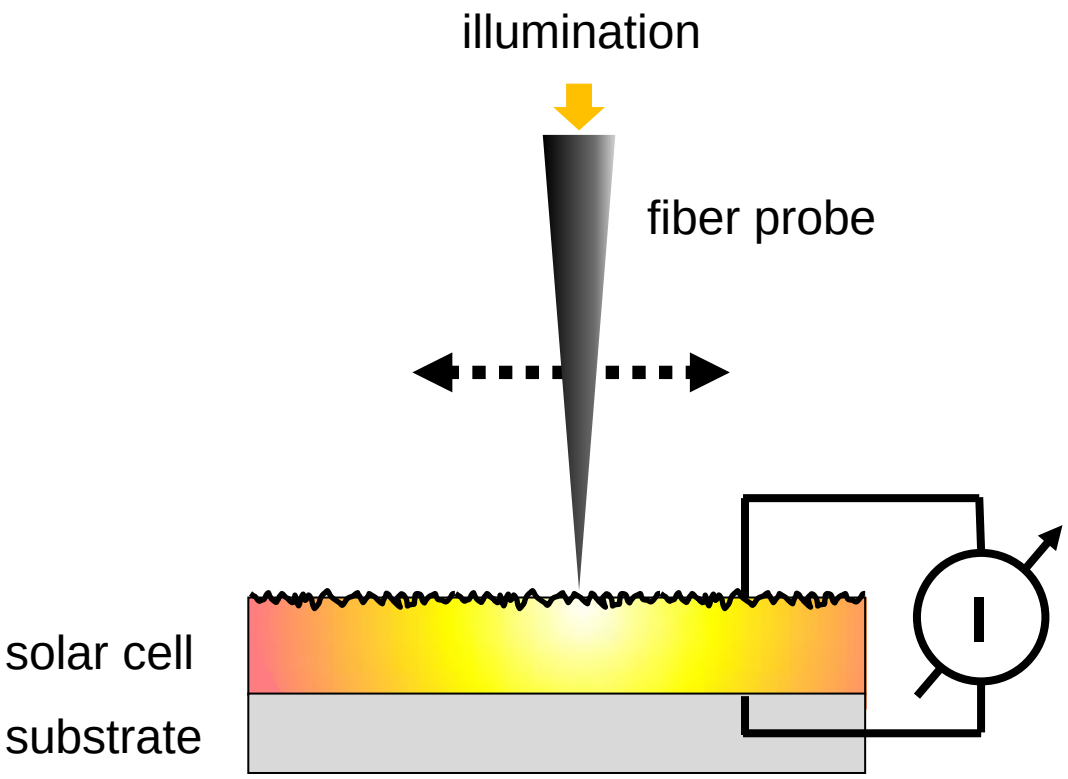




Intensity of guided mode correlates to surface structure

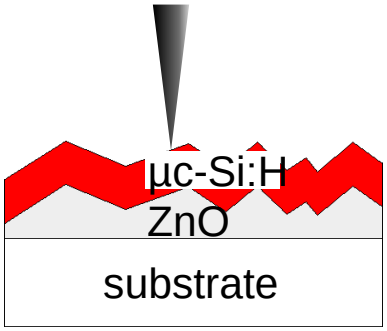
Lehnen et al., IEEE PVSC (2014)

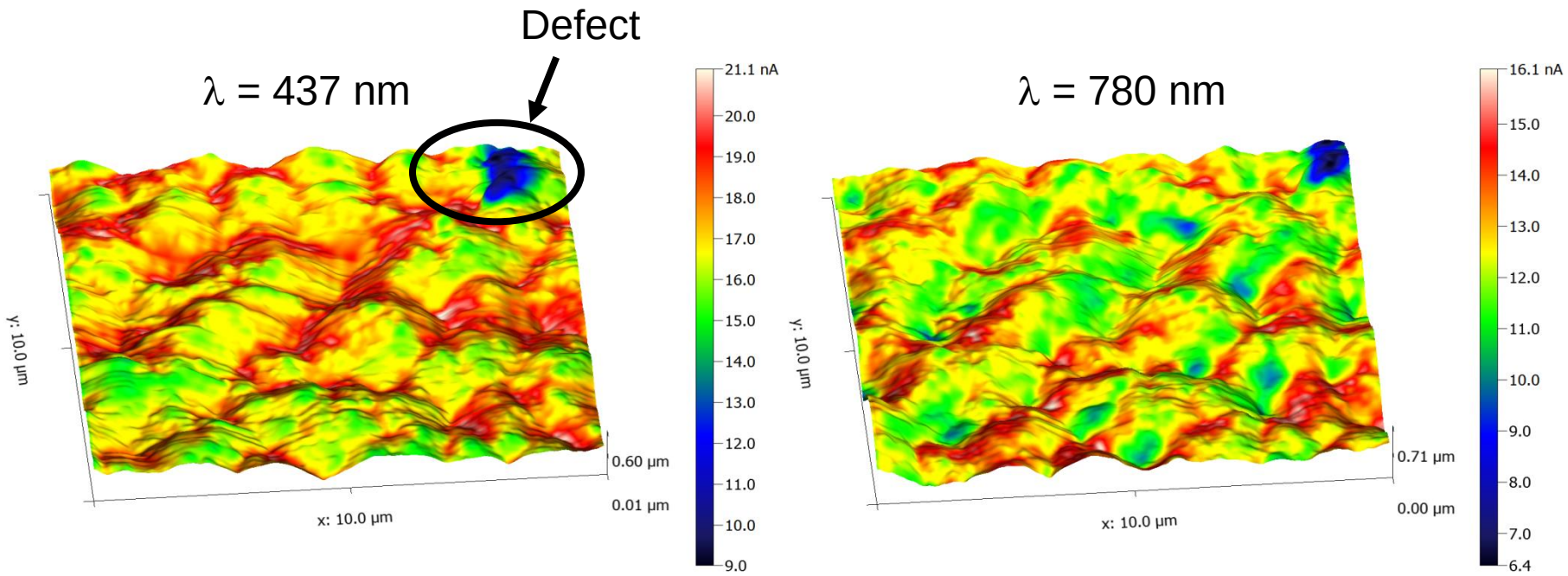
Near-field Induced Photocurrent



Use the sample (solar cell) as detector

Local Photocurrent in µc-Si:H Solar Cell





Local photocurrent depends on optical and electrical effects:

- Light coupling efficiency
- Recombination of charge carriers

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Luminescence vs. Thermography

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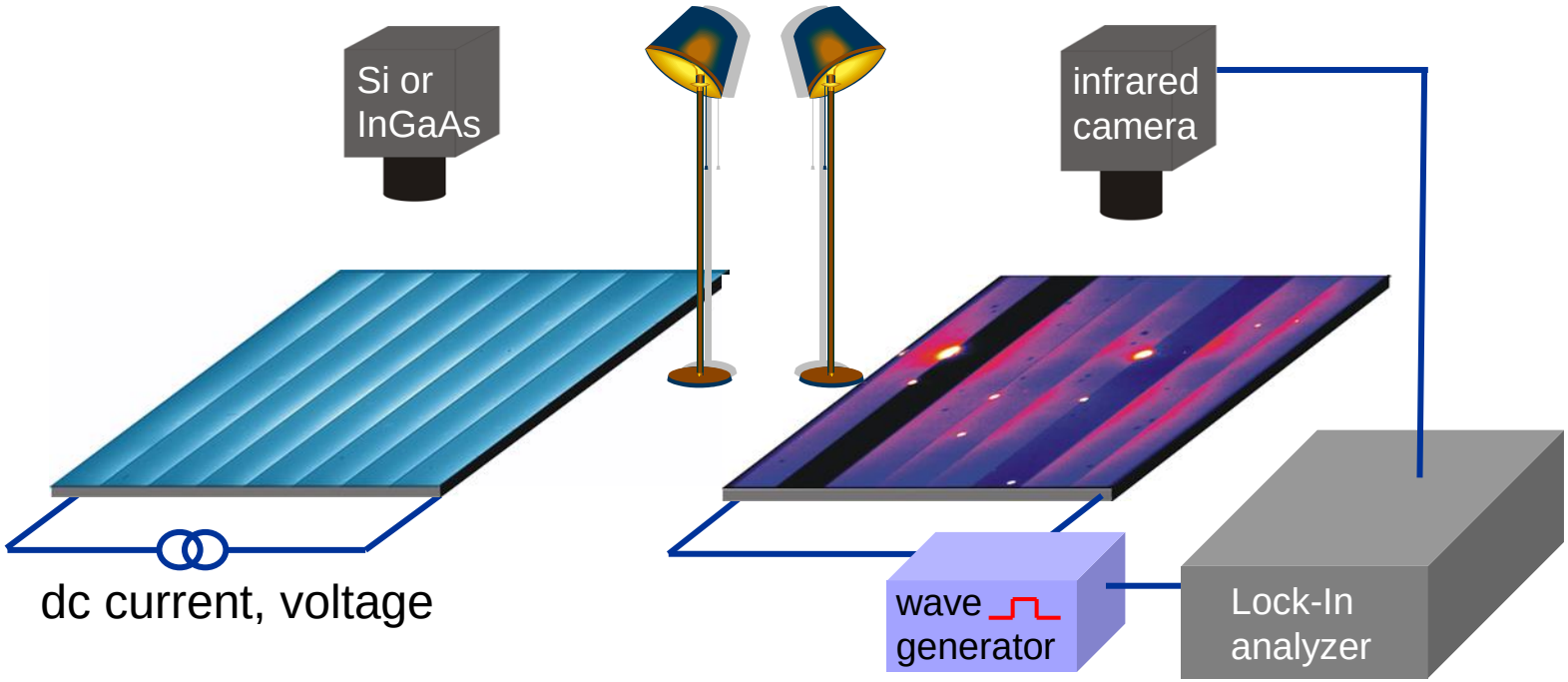
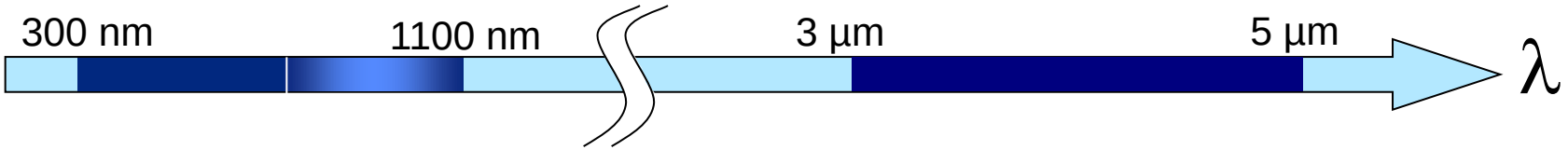
Electro(Photo-)luminescence

Lock-In thermography

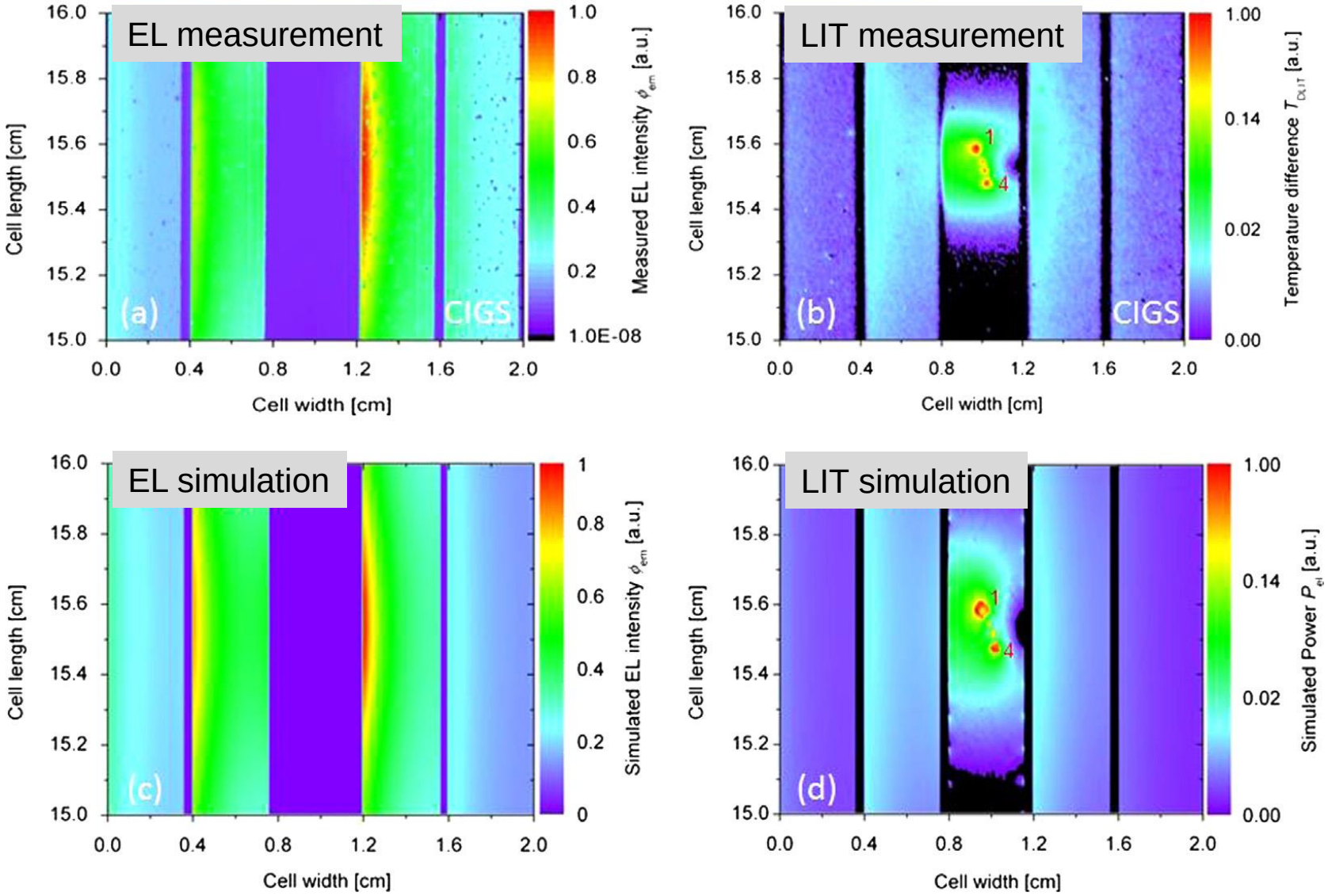


- electrical or light excitation
- radiative recombination
- Si based CCD camera
  - high resolution

- electrical/ light excitation
- heat radiation
- InSb-detectors:
  - low resolution



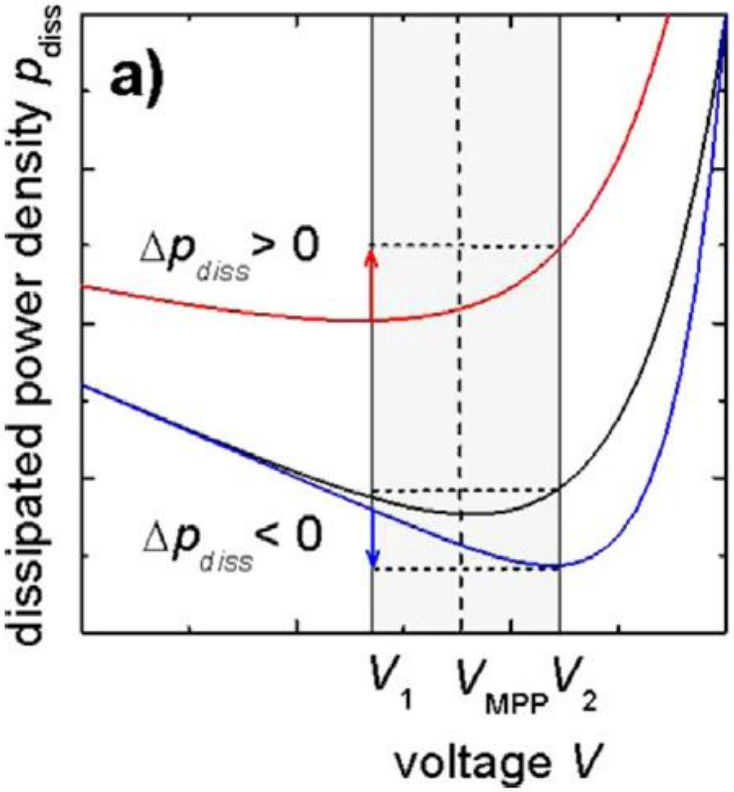
EL vs. LIT

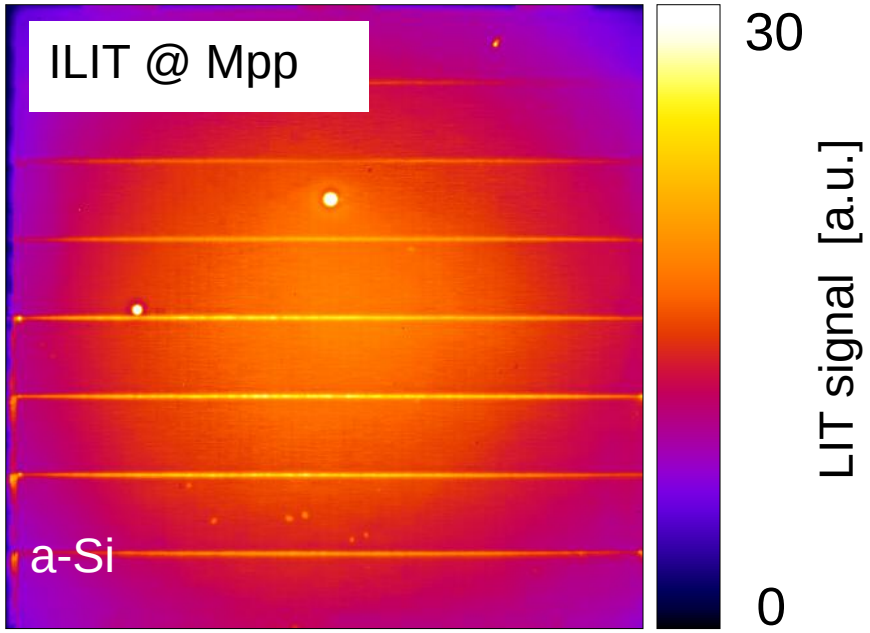


Excellent agreement between experiment and theory

A. Gerber et al., SOLMAT 135, 35-42 (2015)

Voltage-modulated LIT at MPP

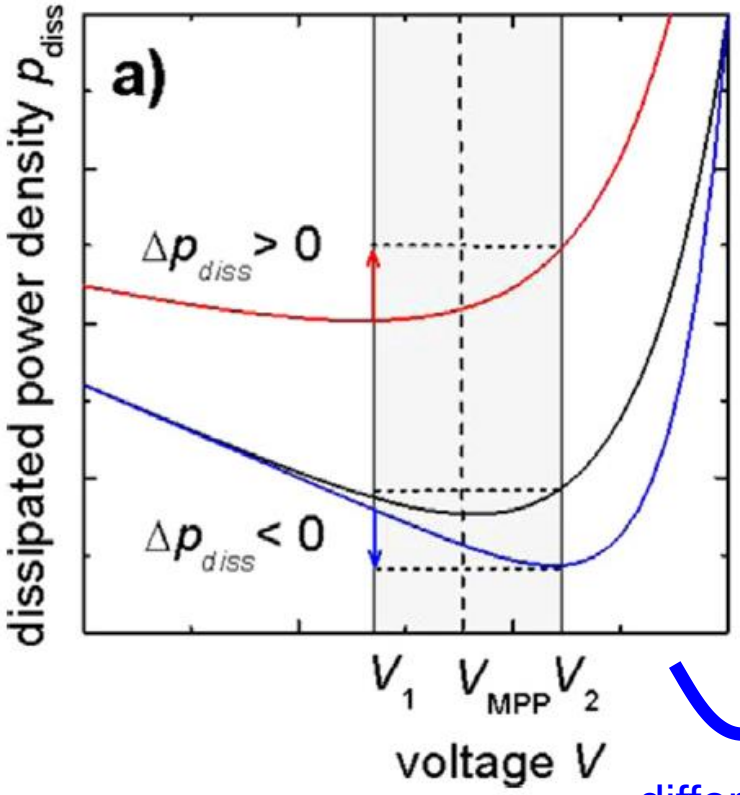


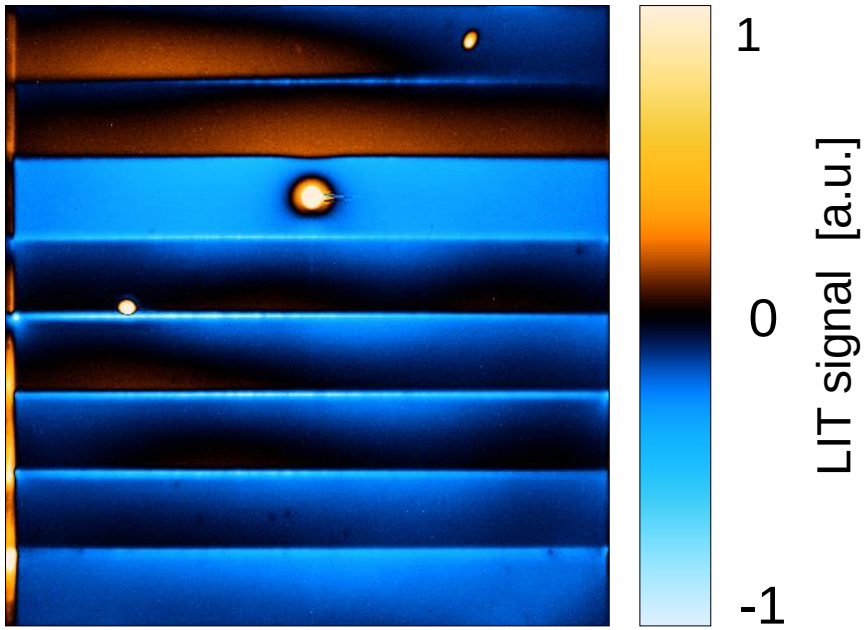


Signal contains a lot of background information
Shut is visible but the impact on the module is hard to see

A. Gerber et al., SOLMAT 135, 35-42 (2015)

Voltage-modulated LIT at MPP



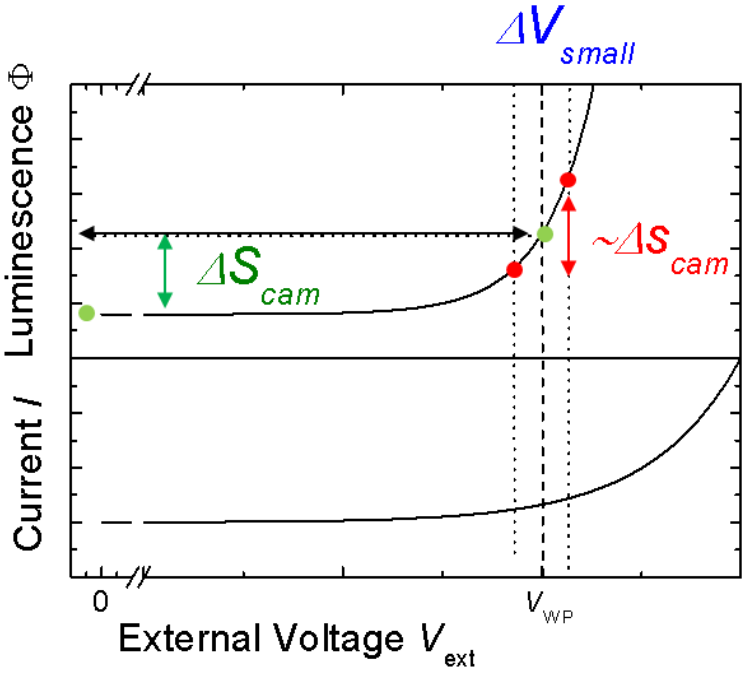


differential image
$LIT(V_2)-LIT(V_1)$

Shift of working points of individual cell stripes

A. Gerber et al., SOLMAT 135, 35-42 (2015)

Photocurrent Collection Efficiency

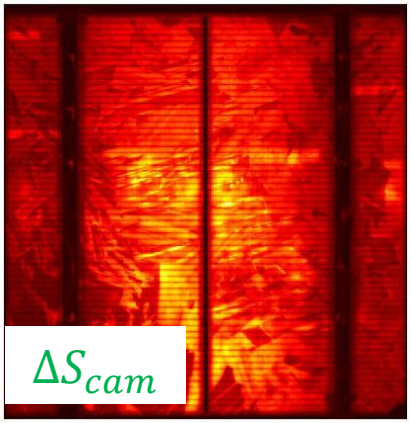


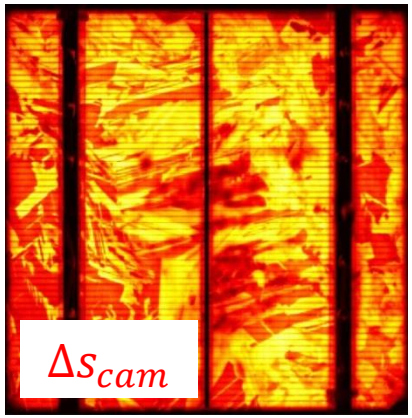
large signal difference image:

$$\Delta S_{cam} = S_{cam}(V_{WP}) - S_{cam}(0)$$

small signal difference image :

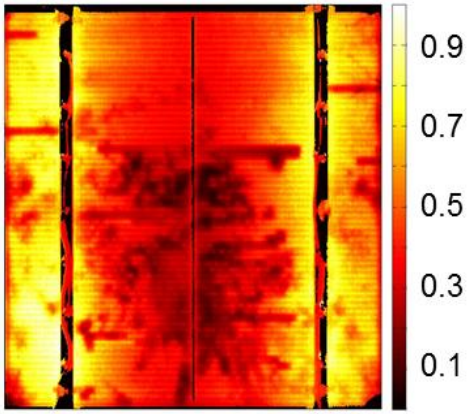
$$\Delta s_{cam} = \Delta S_{cam}(V_{WP} \pm \Delta V_{small})$$



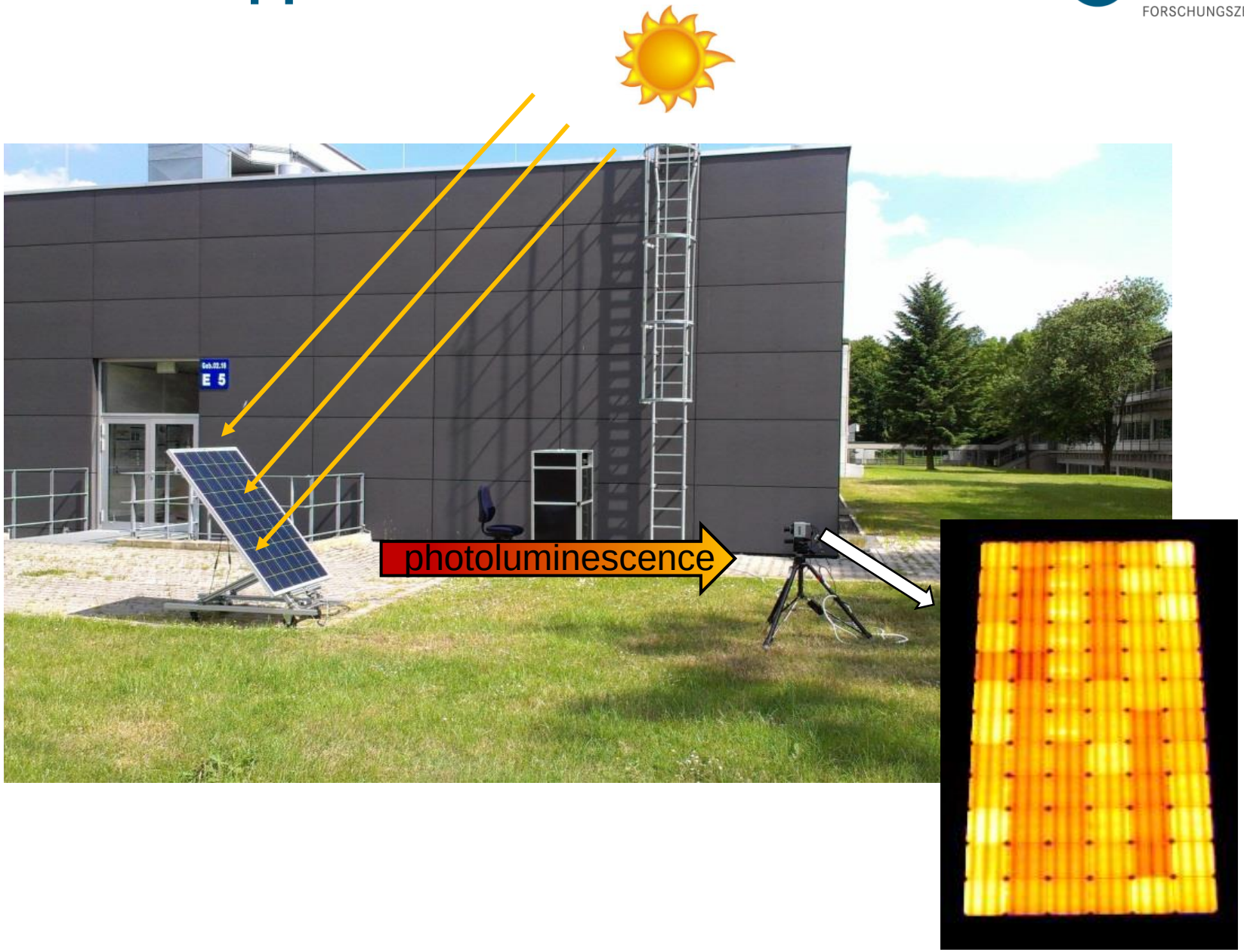


$$f = \frac{\Delta s_{cam}}{\Delta S_{cam}} \frac{V_{WP}}{\Delta V_{small}}$$

Photocurrent collection efficiency



Outdoor Application



Module photoluminescence Image

Conclusions

Visualization of light propagation in textured layer stacks in the near-field is a powerful tool to investigate light trapping in solar cells

Local photocurrent generation measured by SNOM allows to also access to electrical properties of the solar cell on a nanoscale

Differential lock-in thermography allows to study the local impact of defects on PV modules

Differential luminescence allows to study the local photocurrent collection efficiency

Methods applicable for outdoor characterization of cells/modules