Competence Centre Thin-Film- and Nanotechnology for Photovoltaics Berlin

Practical Considerations in Quantitative Dark and Illuminated Lock-In Thermography Analyses of Shunts in Silicon Thin-Film Modules

Felice Friedrich[1,*], Karolina Mack[1], Nandha Krishnan[1], Sven Kühnapfel[1,2], Bernd Stannowski[2], Christof Schultz[3], Rutger Schlatmann[2,3], and Christian Boit[1]

[1]PVcomB/Technische Universität Berlin, Germany; [2]PVcomB/Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany; [3]PVcomB/University of Applied Sciences (HTW) Berlin, Germany

*Corresponding author: felice.friedrich@pvcomb.de

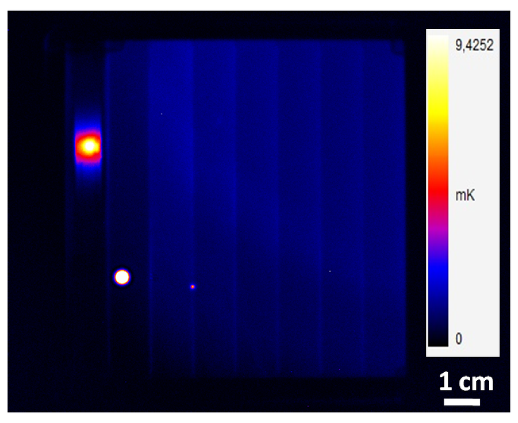
Motivation

- **Hot spots** in photovoltaic modules deteriorate the performance and may finally cause breakdown, even fire.
- Method of choice for **localization** of hot spots/shunts in solar cells: Lock-In Thermography (LIT).
- Technological progress has reduced cost and time.
- Scientific research now focuses on an extension to **quantitative analyses** e.g. for shunt removal classification.

LIT Experimental Results

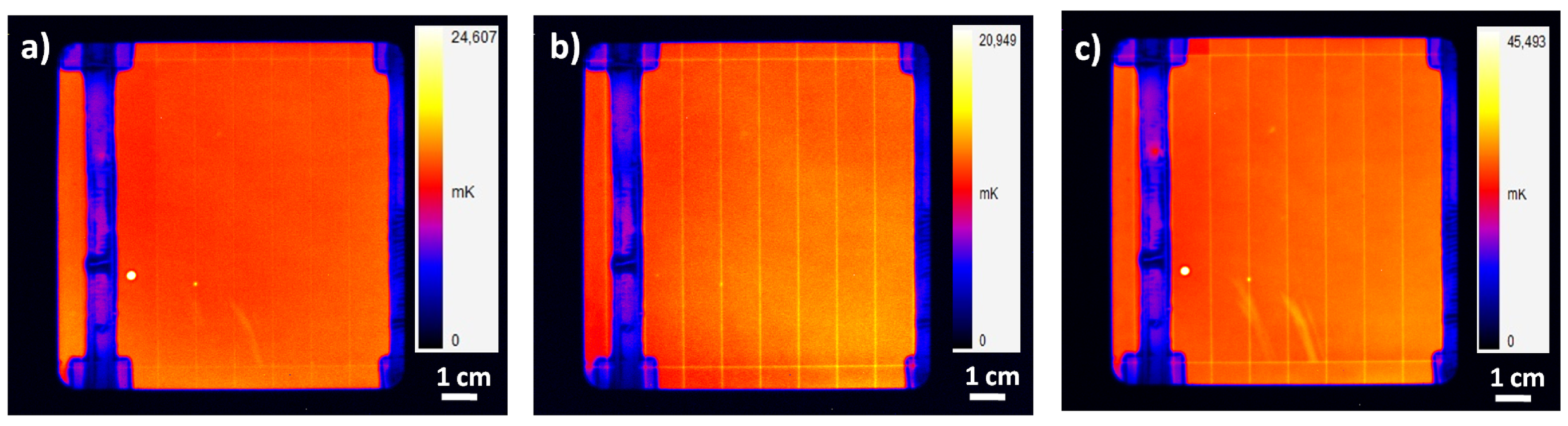
DLIT close to MPP

- V = 10 V, I = 5.2 mA, $f_{Lock\text{-}In}$ = 0.5 Hz, t = 1 min
- 3 visible shunts:
  - in cell 1 below the copper band (broadened)
  - in cell 2 in the material
  - laser scribe between cell 2&3
- Demonstrates excellent homogeneity of the material (apart from shunts, copper and isolation tape)
- Shunts not visible in thermograph taken at reverse bias (V = –10 V)



V_{OC}-ILIT

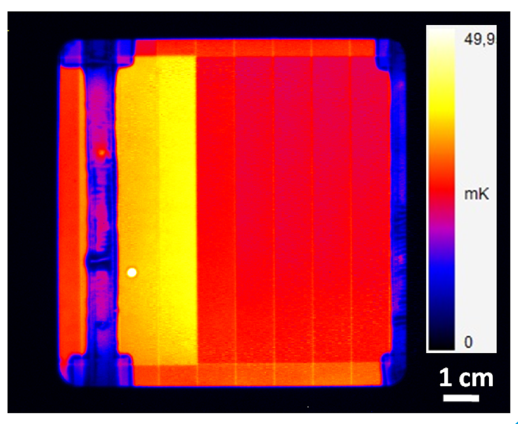
- No current flow, taken at different wavelength
  - a) green for selective excitation of a-Si:H subcell
  - b) red for selective excitation of µc-Si:H subcell
  - c) red&green at similar intensity for general optic excitation



- Shunt in cell 2 does not show under red illumination
- Interconnection shunt is reduced under red illumination
- Non-contacted regions at top&bottom show up with similar ΔT

J_{SC}-ILIT

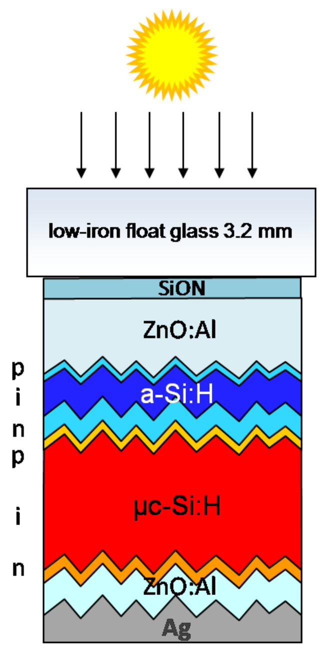
- Full photocurrent current is allowed to flow
- Cells 1-3 show higher temperature (relates to R_S)
- Cells 5-8 show lower average temperature than non-contacted regions at top&bottom



Experimental Details

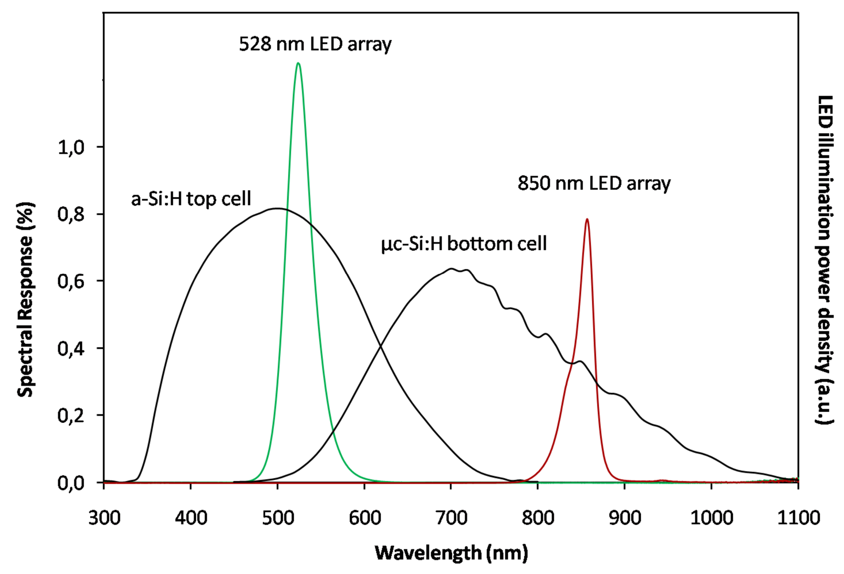
Samples

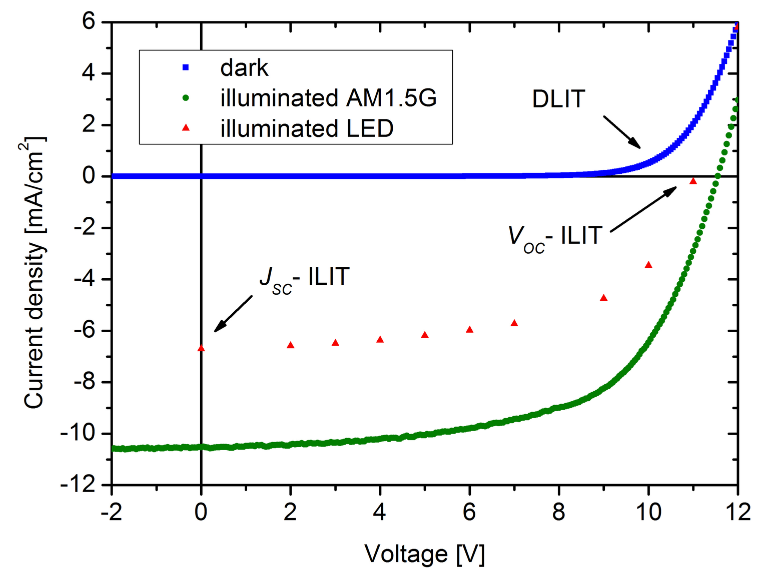
- State-of-the-art a-Si:H/µc-Si:H tandem minimodules [1]
- Total area of 8×8 cm^2 on 10×10 cm^2 glass substrate
- in this study: containing shunts



LIT setup

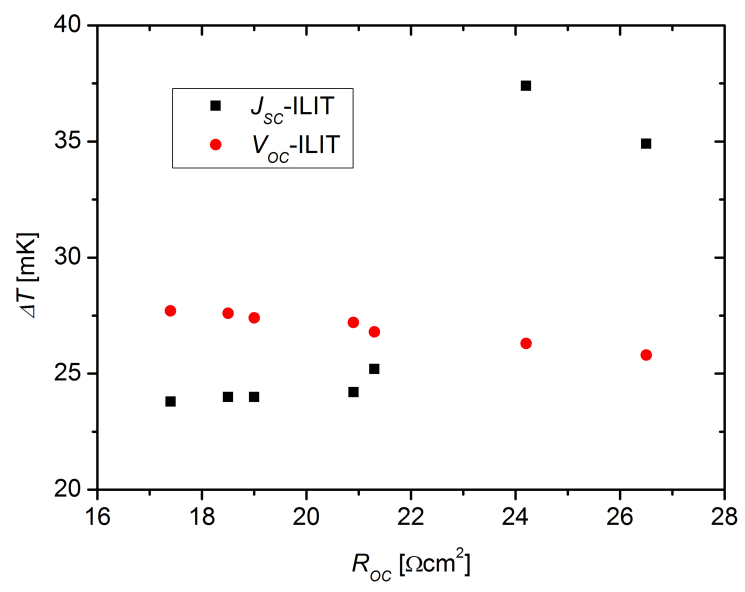
- Pulsed electric and optic excitation for application of DLIT and ILIT methods on solar cells and modules
- Red and green LED arrays for selective excitation of tandem cell layers [2] with 30×30 cm^2 uniform illumination (360 W/m^2)
- Contacting via copper stripes, black adhesive foil for homogeneous emissivity

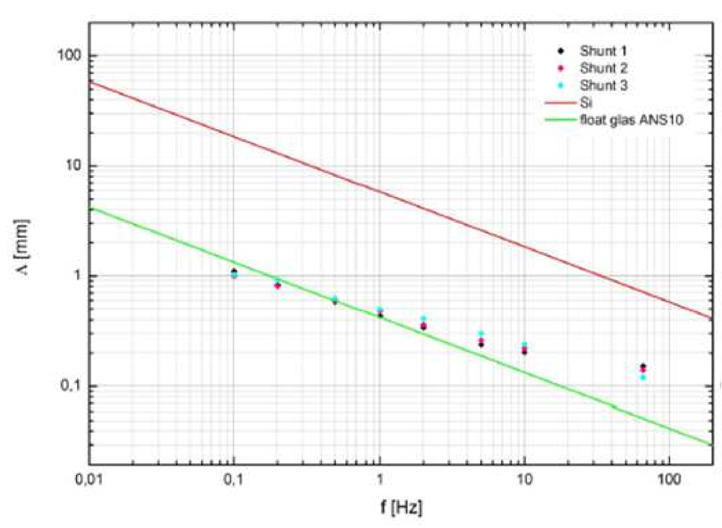


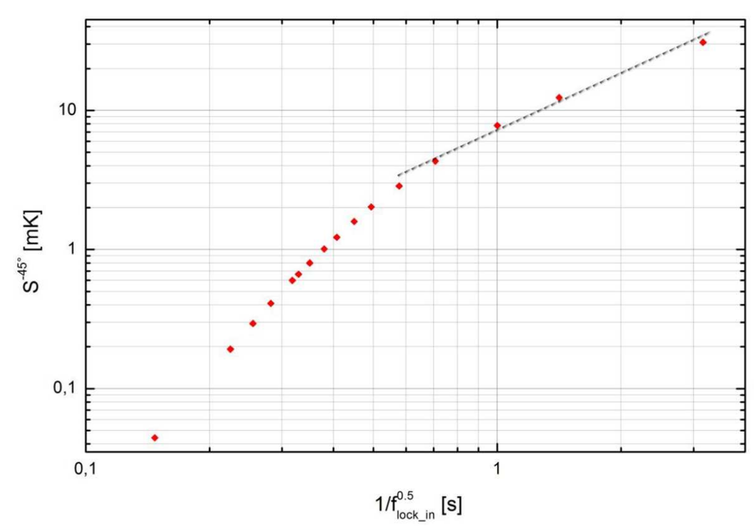


Discussion: Shunts and Quantitative Analysis

- Non-ohmic shunt in cell 2 is localized in the amorphous subcell (amounts to ~1% of I_{cell} based on image integration method [3])
- Series resistance correlates with temperature increase in J_{SC}-ILIT mode due to Joule heating
- Thermalization effect is observed in non-contacted regions in V_{OC}-ILIT mode
- Peltier effect is observed in J_{SC}-ILIT due to heat transport by the lateral current
- Additional effects hindering quantitative analysis of shunts in LIT:
  - influence of glass substrate and layered sample structure on thermal diffusion length
  - influence of the emissivity foil on the signal phase shift







Conclusions

- Quantitative analysis of shunts in Si thin-film solar cells is feasible for DLIT under consideration of the correct measurement range.
- Illuminated LIT signal contains more information (like thermalization and Peltier) that nevertheless hinder a straightforward shunt analysis and call for support via thermo-opto-electronic device simulation.

References

[1] B. Rau et al., *Photovoltaics International*, 17 (2012) 99

[2] H. Straube et al., *physica status solidi (c)*, 8 (2011) 1339

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