Bernhard Kubicek Daniel Mayrhofer

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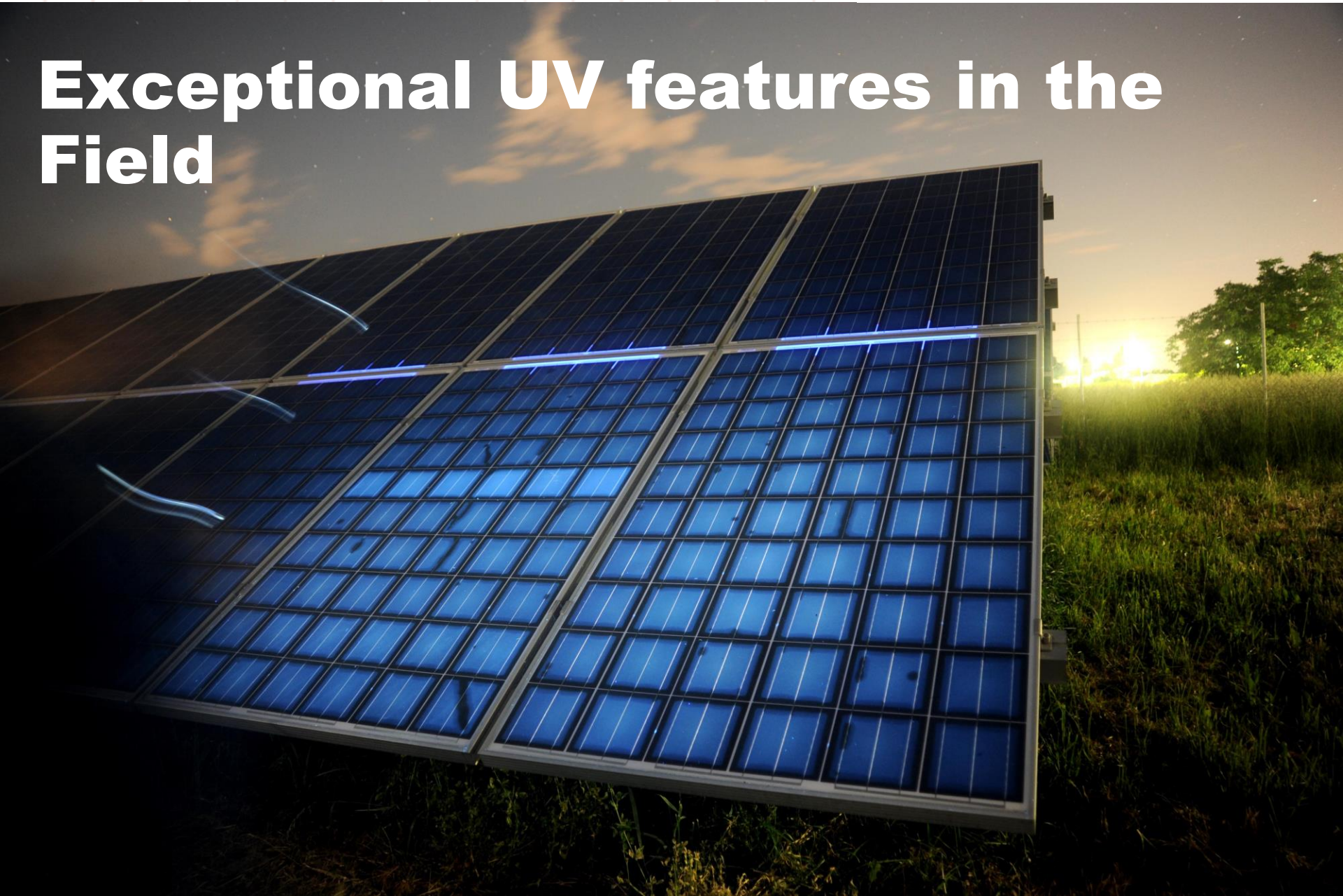
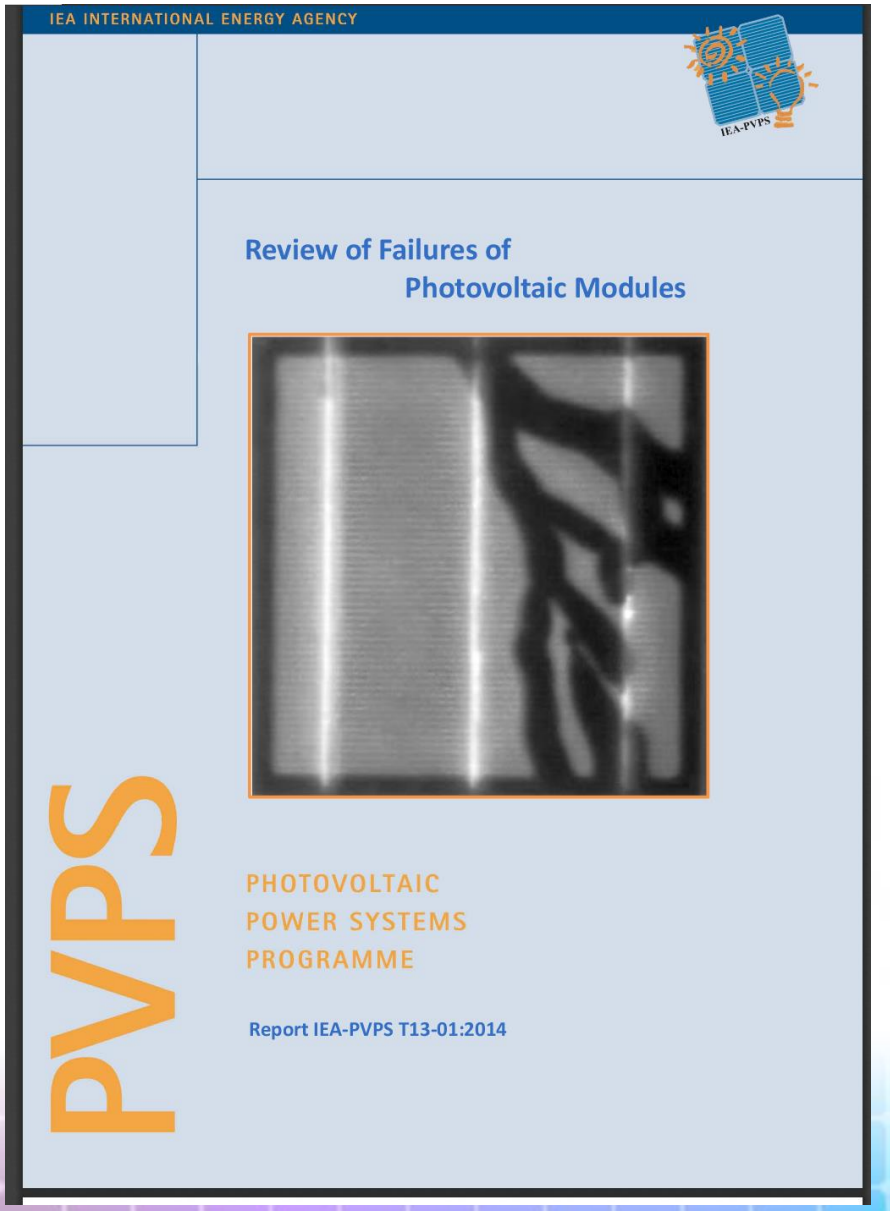
Exceptional UV features in the Field



PVPS T13: Exceptional UV



Our Timeline:

- Task 13 Report with UV-Chapter
- Fall 2014, first Trials
- 2015: Staffelstein, first Publication with UV
- … many improvements of lamp
- Since 2016 selling mobile lamp
  - And training

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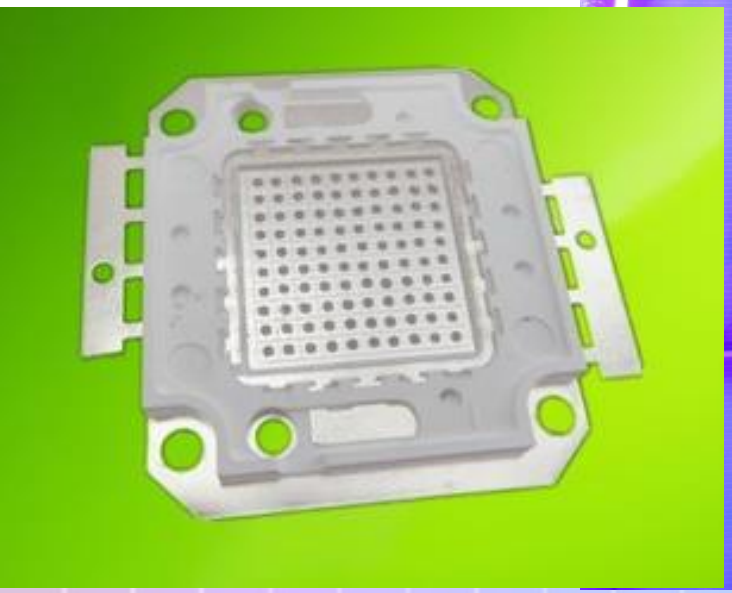
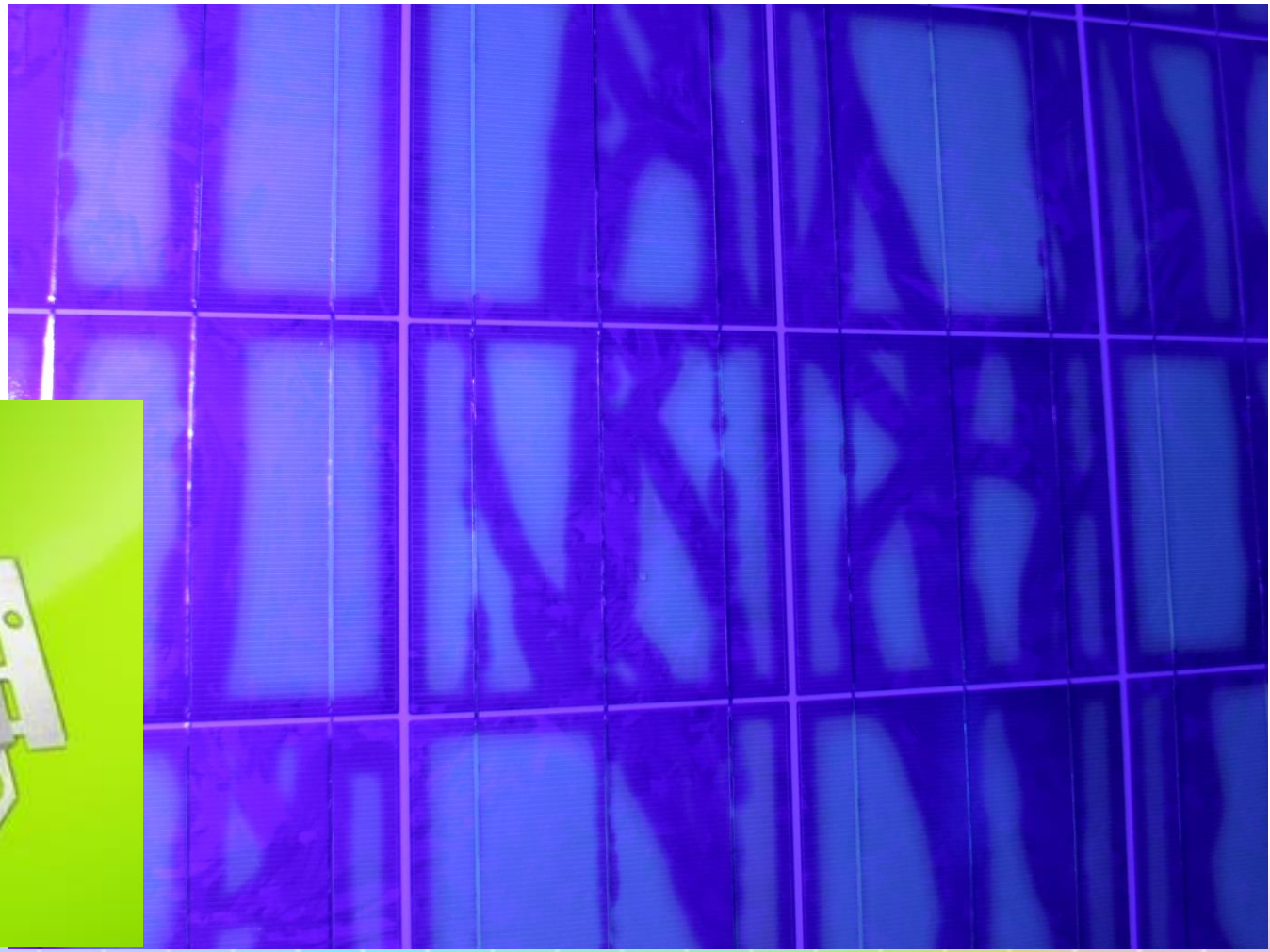
First trials: Contrast Problems





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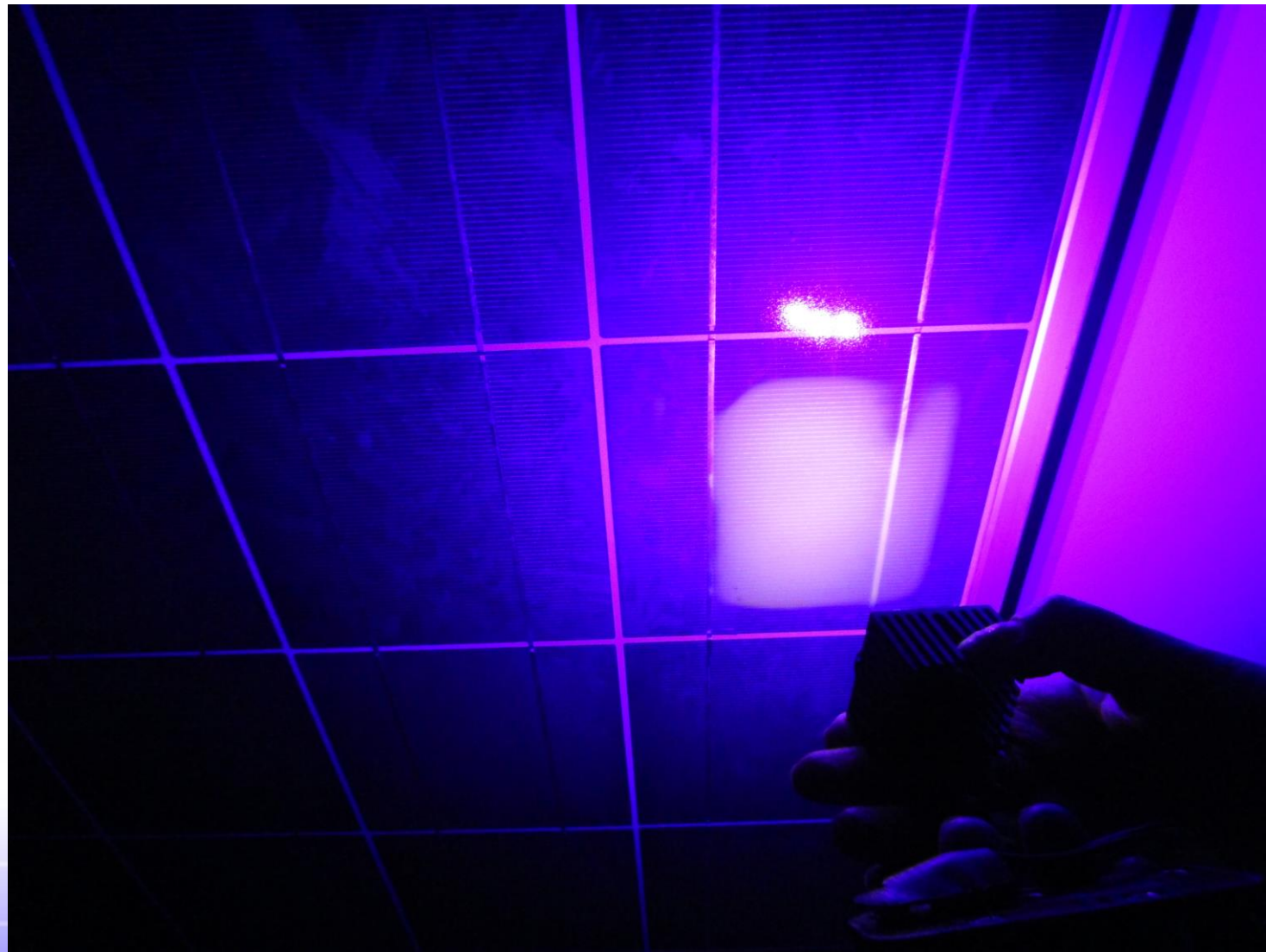
2nd Problem: homogenity



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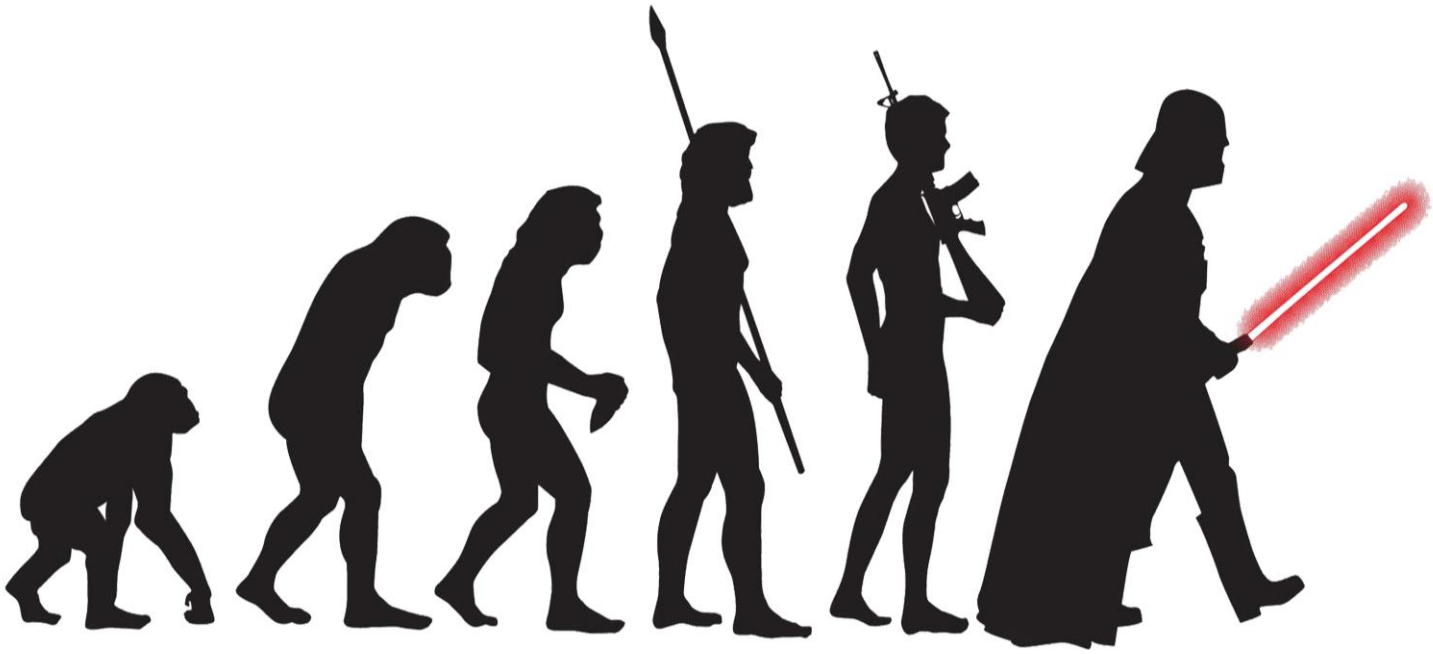
Many evolutionary steps later...



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Improved design

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Other commercial options:

- ISFH: Tent+Lamp+Camera
  - Daytime
- MBJ: Smart UV light
  - 8W
- AIT system:
  - 60W
  - Evaluated according to radiation safety ICNIRP guidelines

Outdoor evaluation

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Measurements of multiple plants:

- Thermography:
  - under the day, of course
  - 30° Summer
- UV-F
  - At night
  - 9:30 (sundown+1h) -2am

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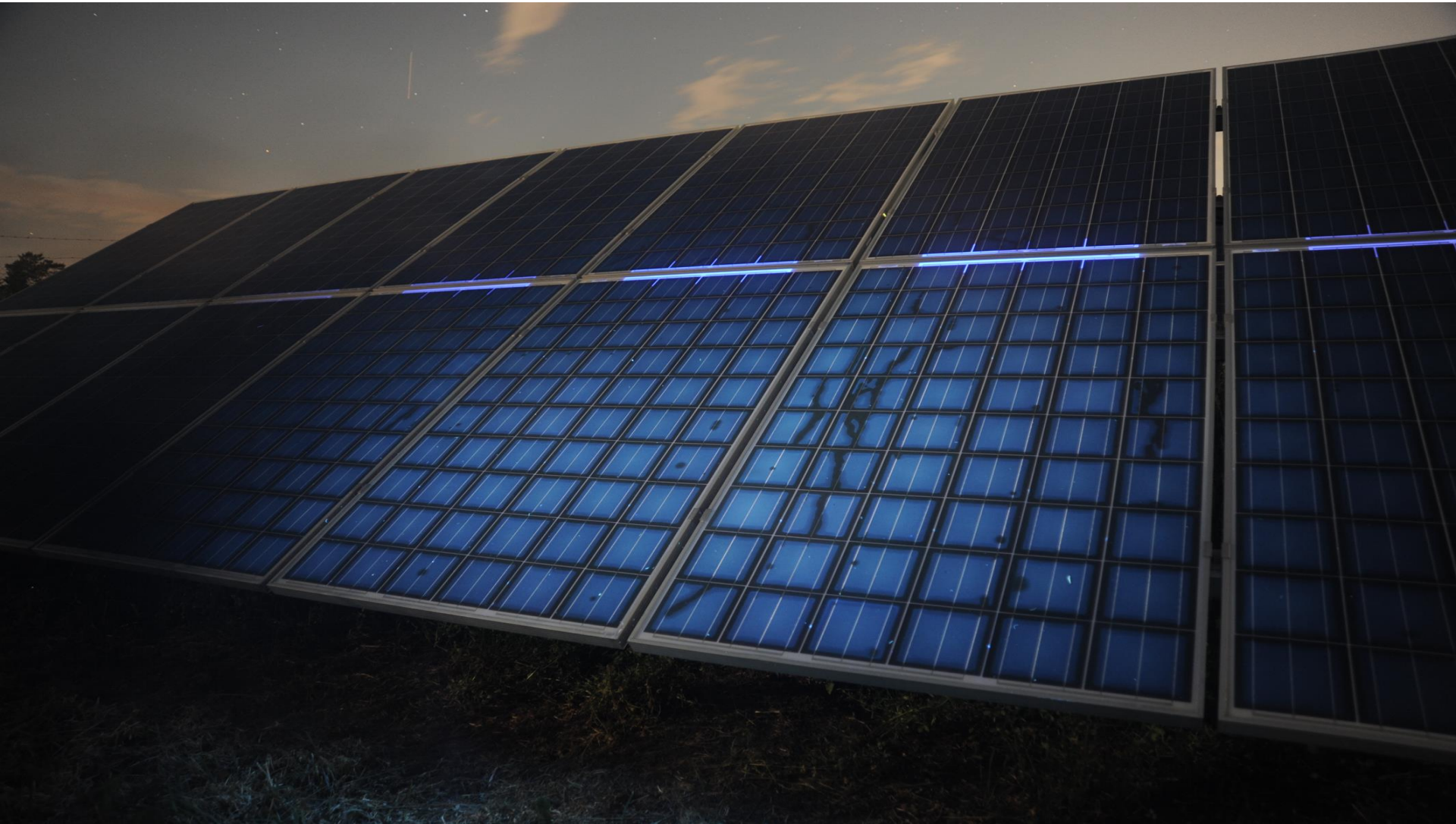
„Common“ Image:



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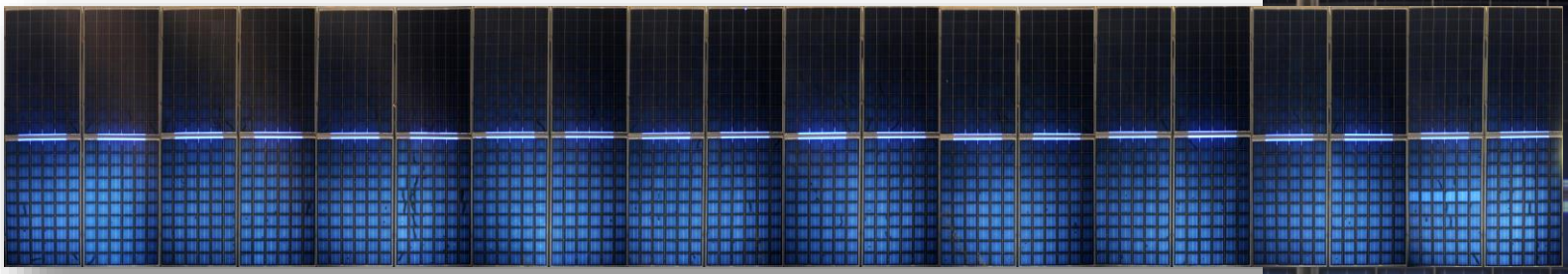
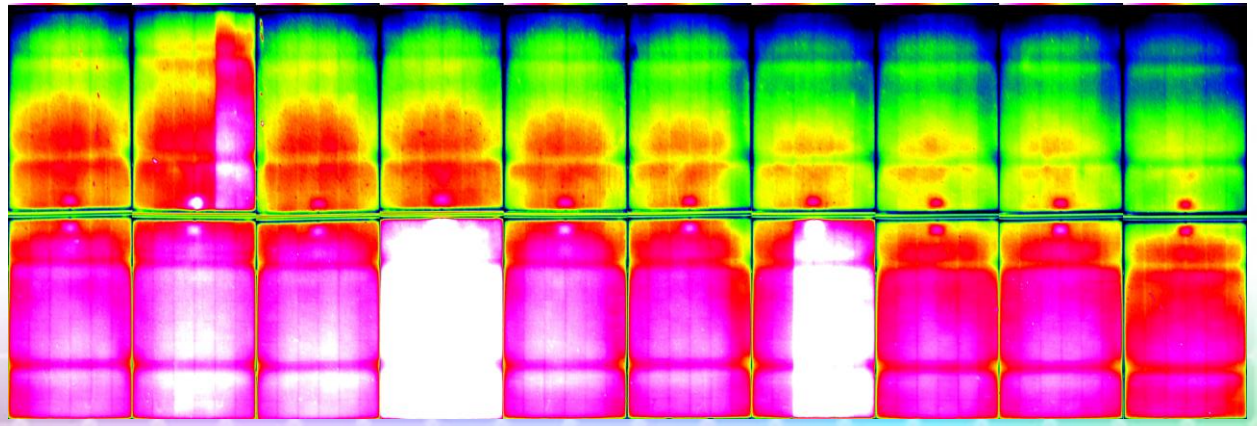
Next level: whole table

- Image resolution: 15000x2500 pixel
- Comparison with same data from thermography





When to perform UV-F ?

- At night.
  - Darkness can be planned for easier than >400W/m^2
  - Disadvantage: many roof-mounted systems not approachable
- In winter:
  - Early darkness
  - ~ 19:00 vs ~21:30 in summer

- To quickly spot strange modules
- To analyze the encapsulation material

- Spotting uncertified modules
  - Change of brand of encapsulation

UV-F findings

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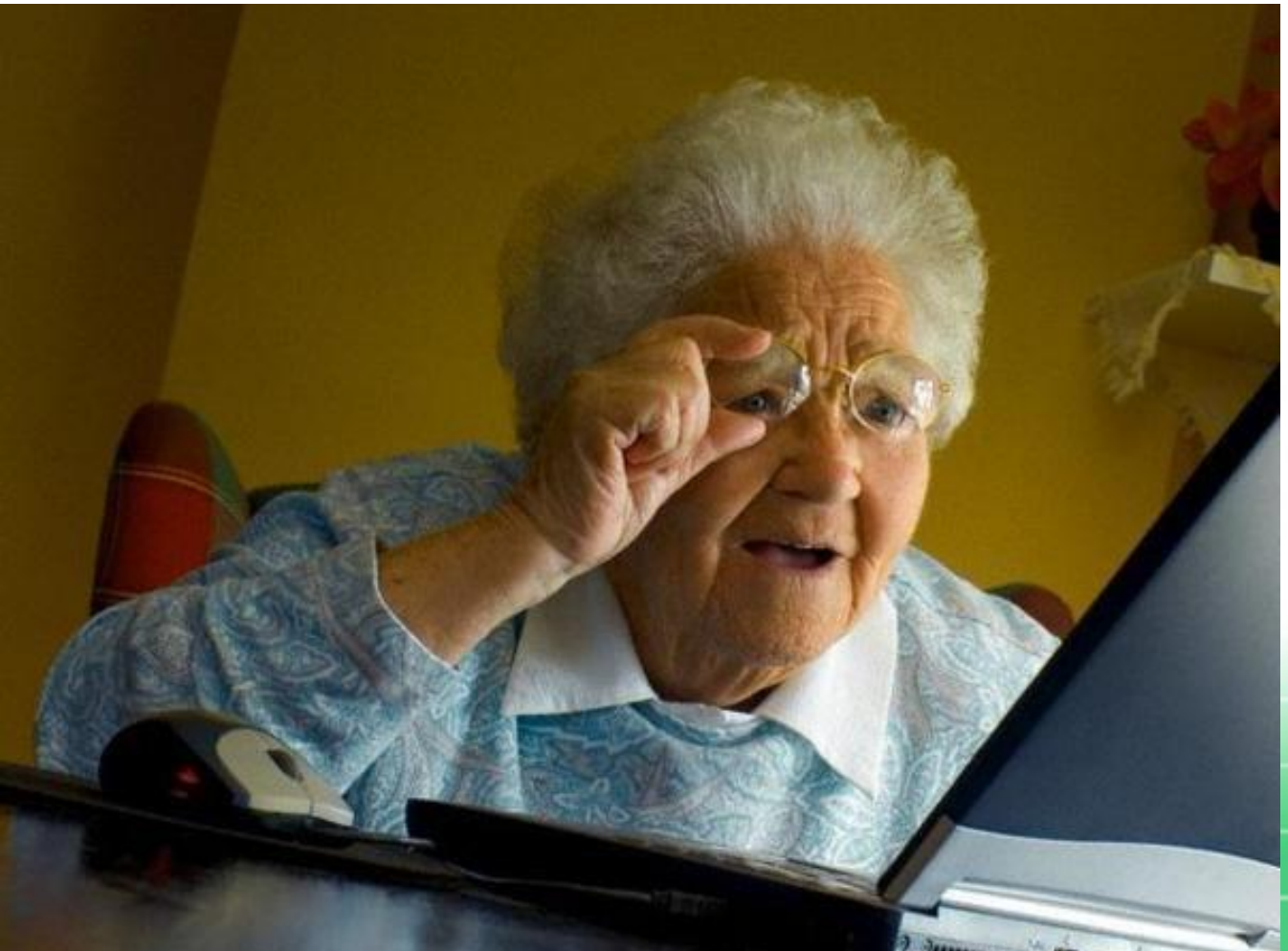

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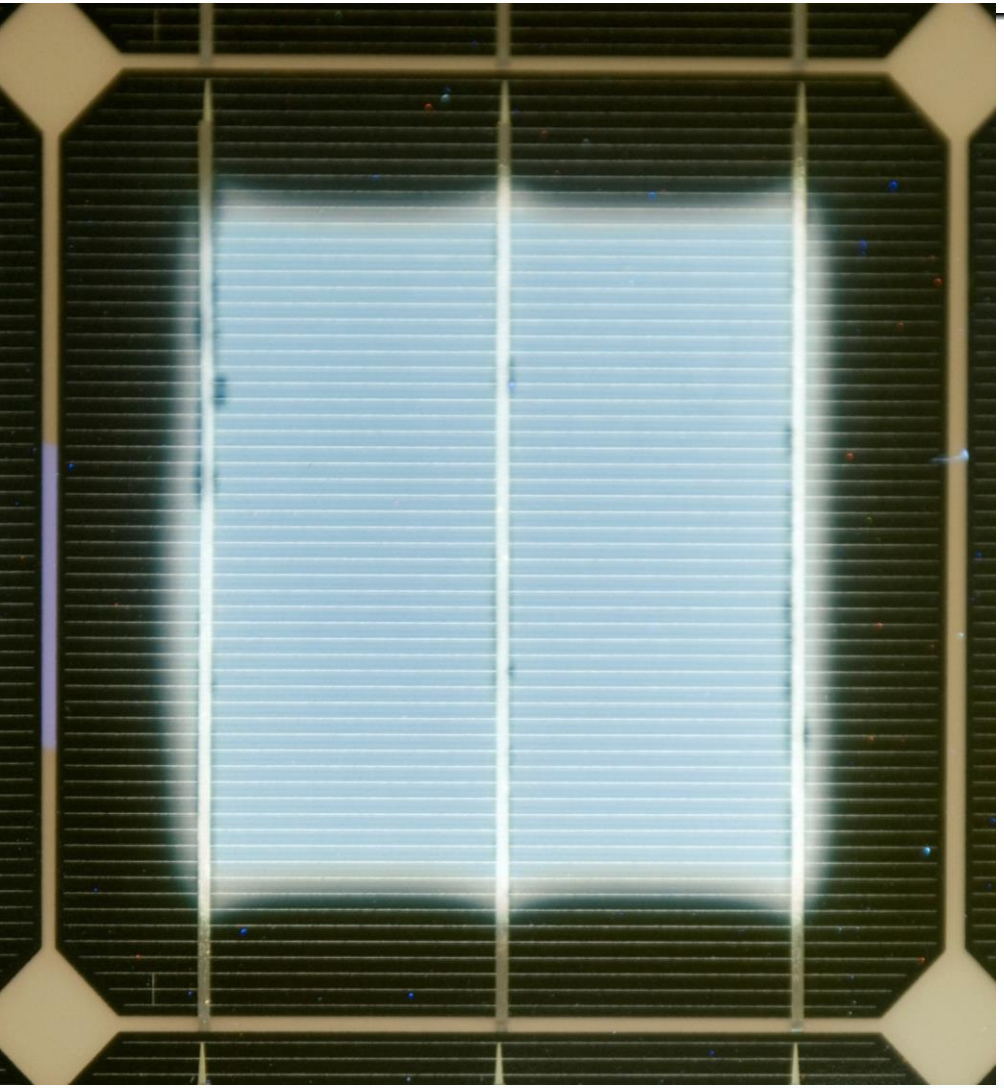
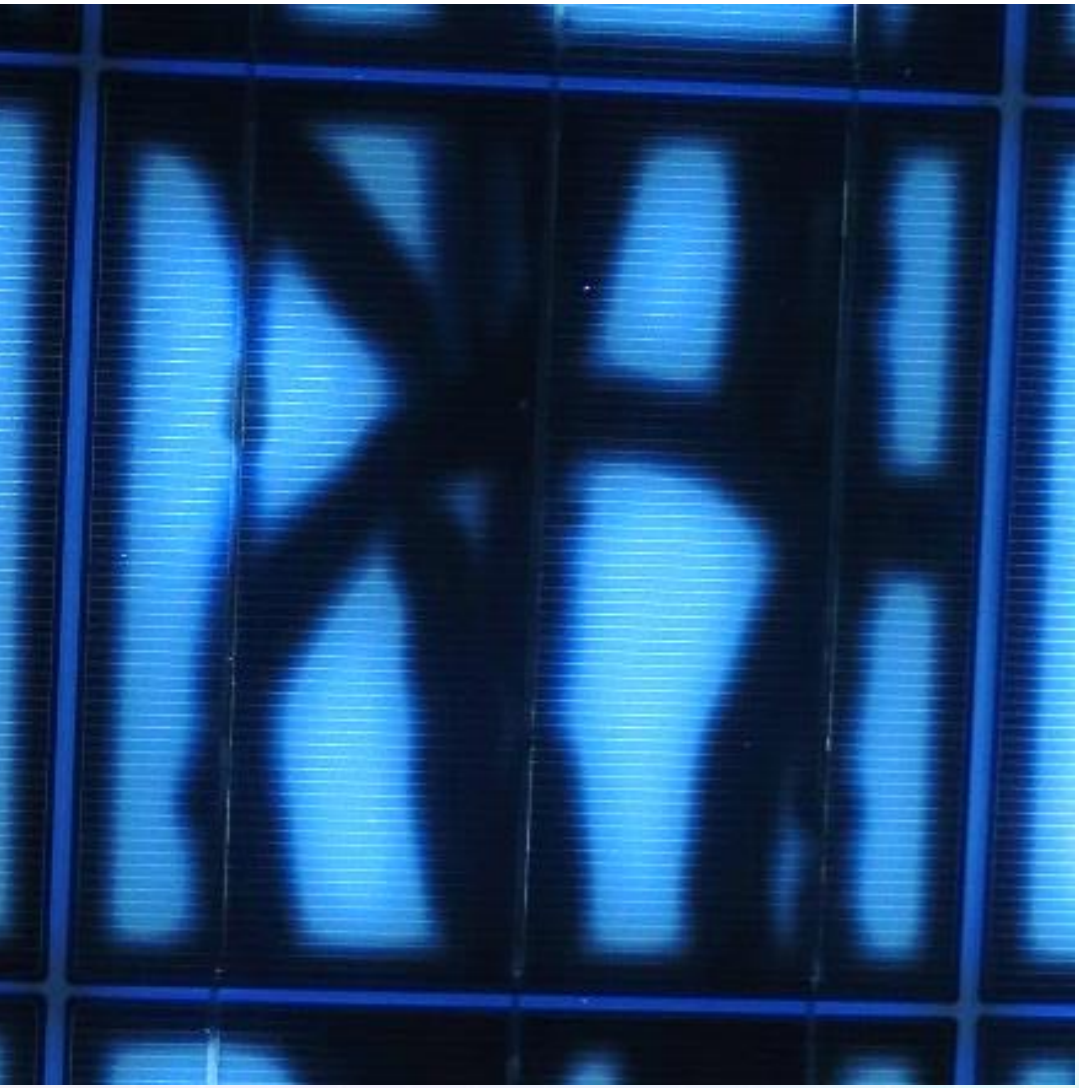


Perfect cell

- Center is bright
- Border with constant distance from cell sides
- Width of the dark borders depend on the outdoor exposure and the backsheet material's diffusion

PVPS T13: Exceptional UV



Cracked Cell

- Cell gaps and sides are brighter
- Hardly visible with naked eye (only on long exposure)

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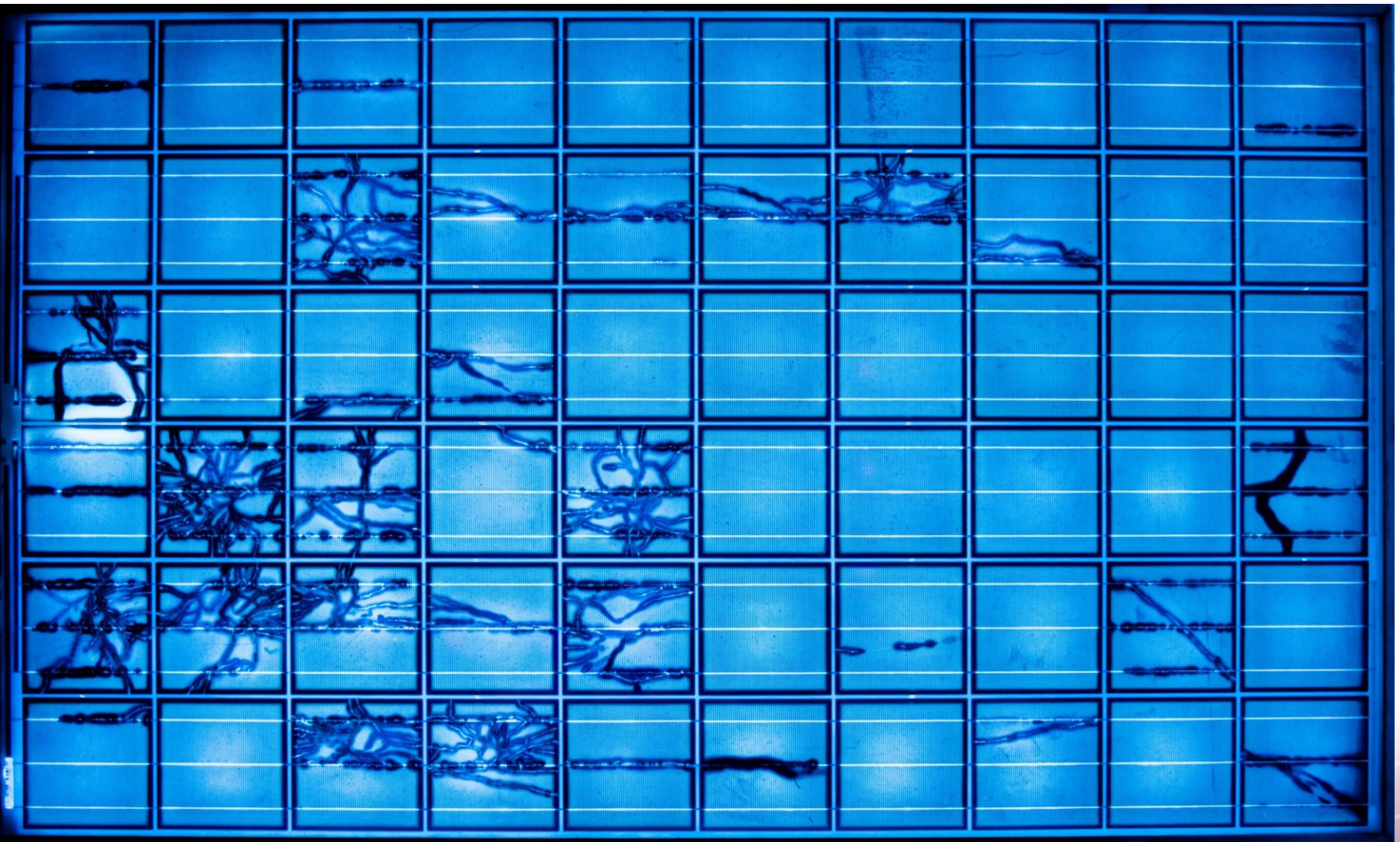
Hail corn impacts



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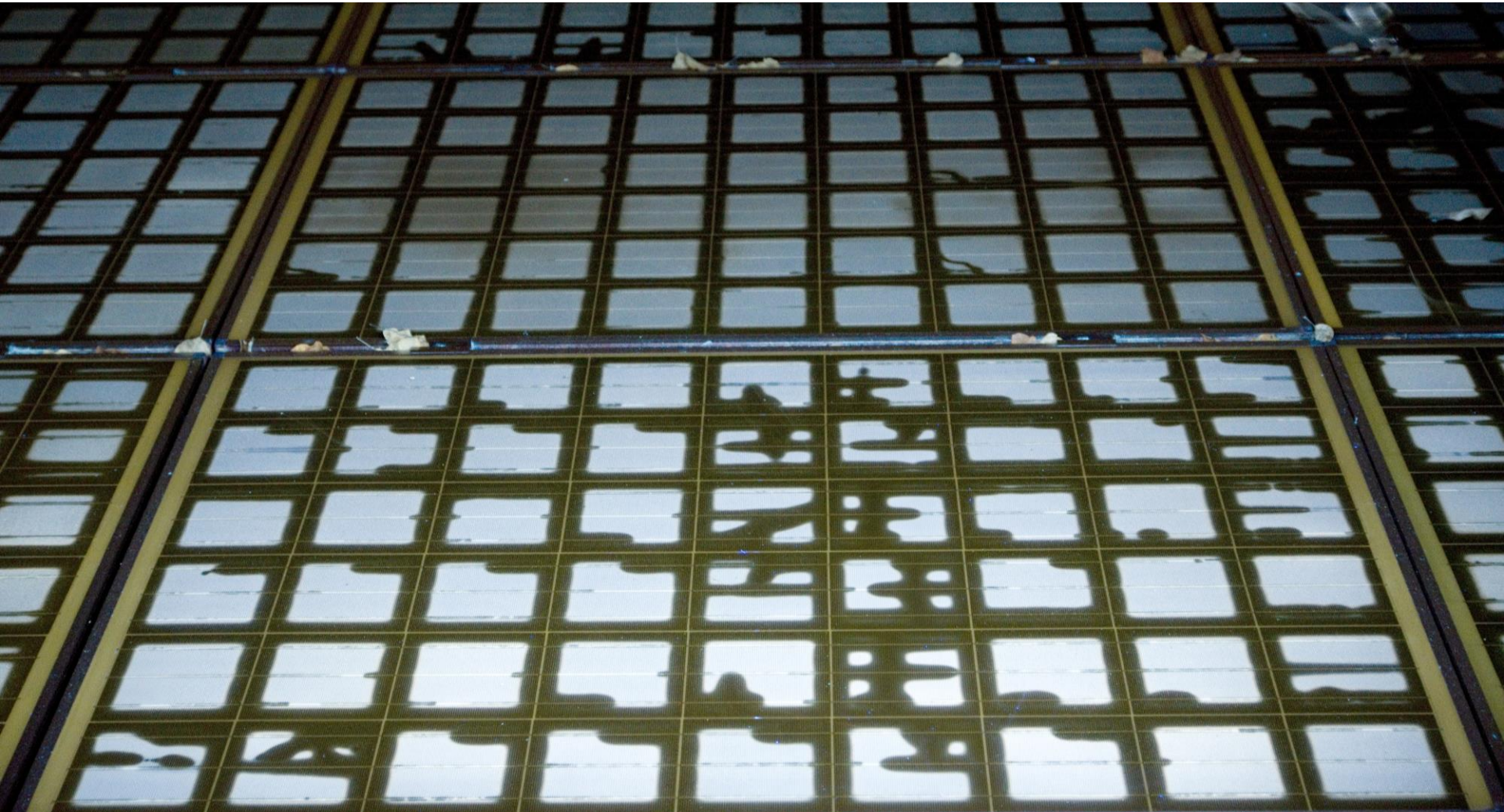
Extinction along edges, busbars and cracks



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Extreme Hot Spot Cell

- Much brighter than average cell
- Red/orange additional to blue UVF
- Browning is often visible even without UV

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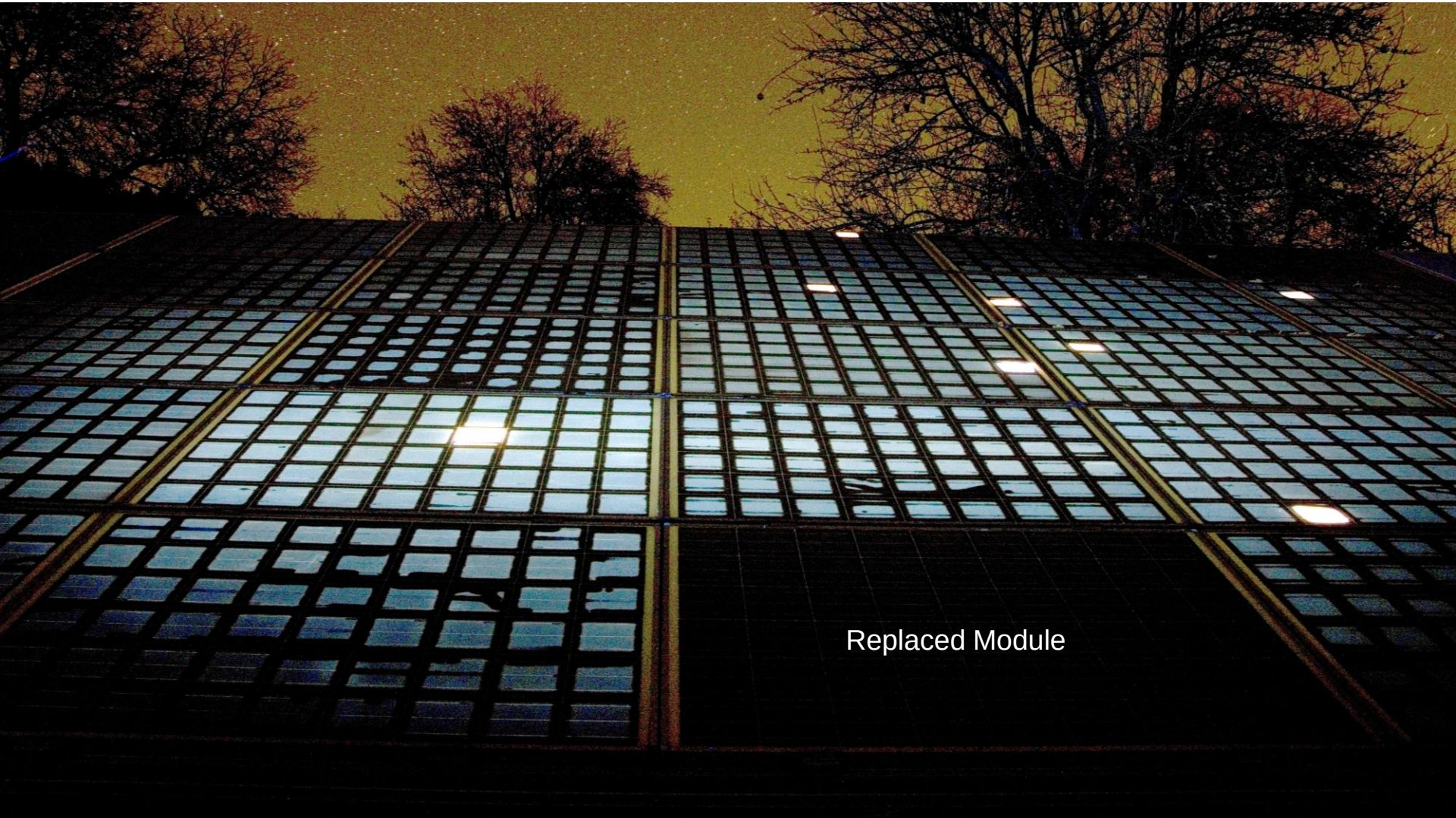
Hot cells + new module



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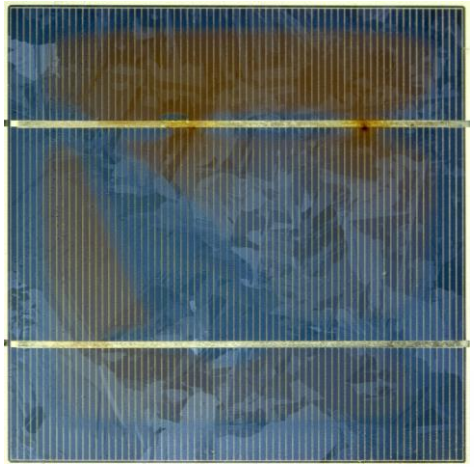
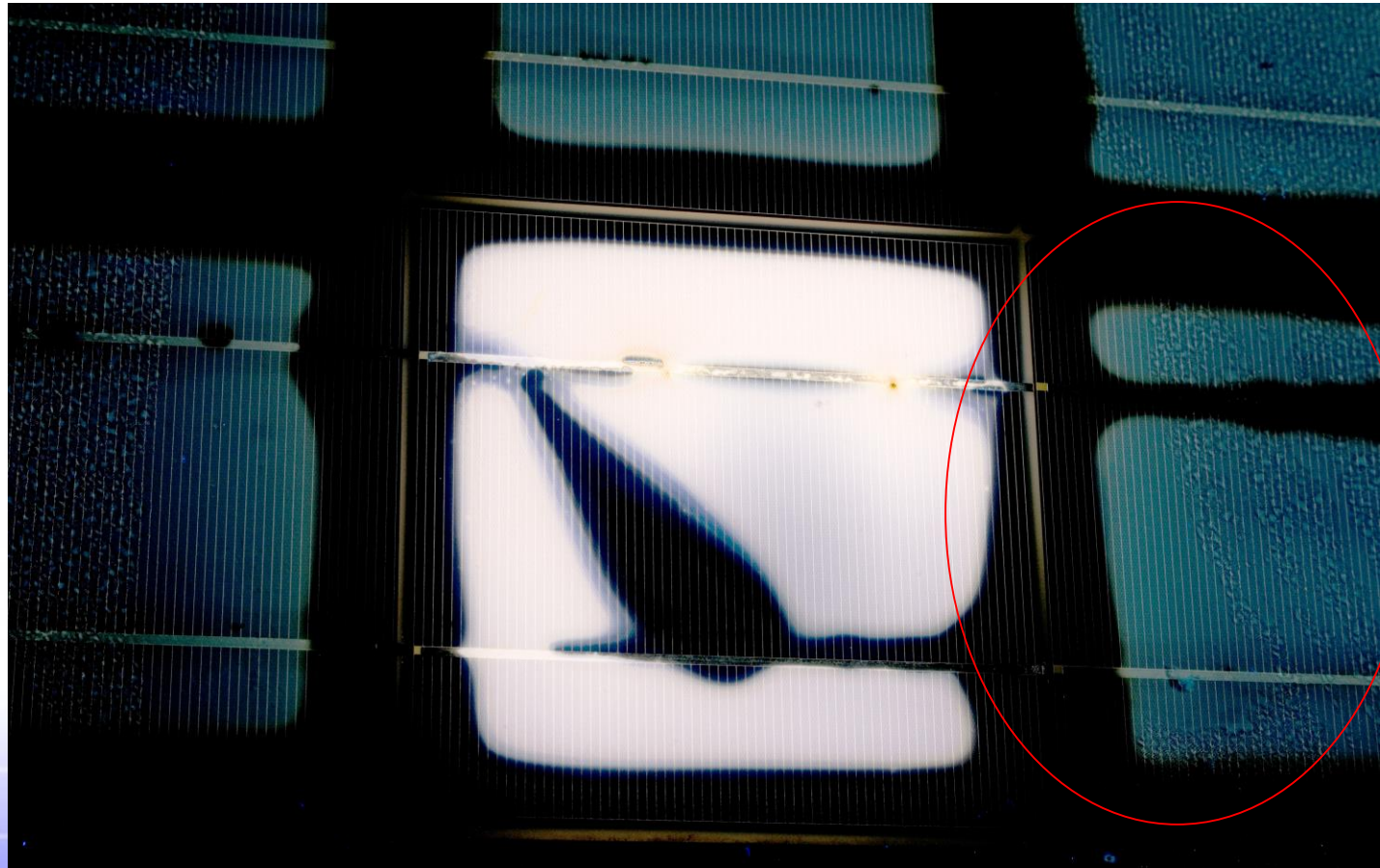
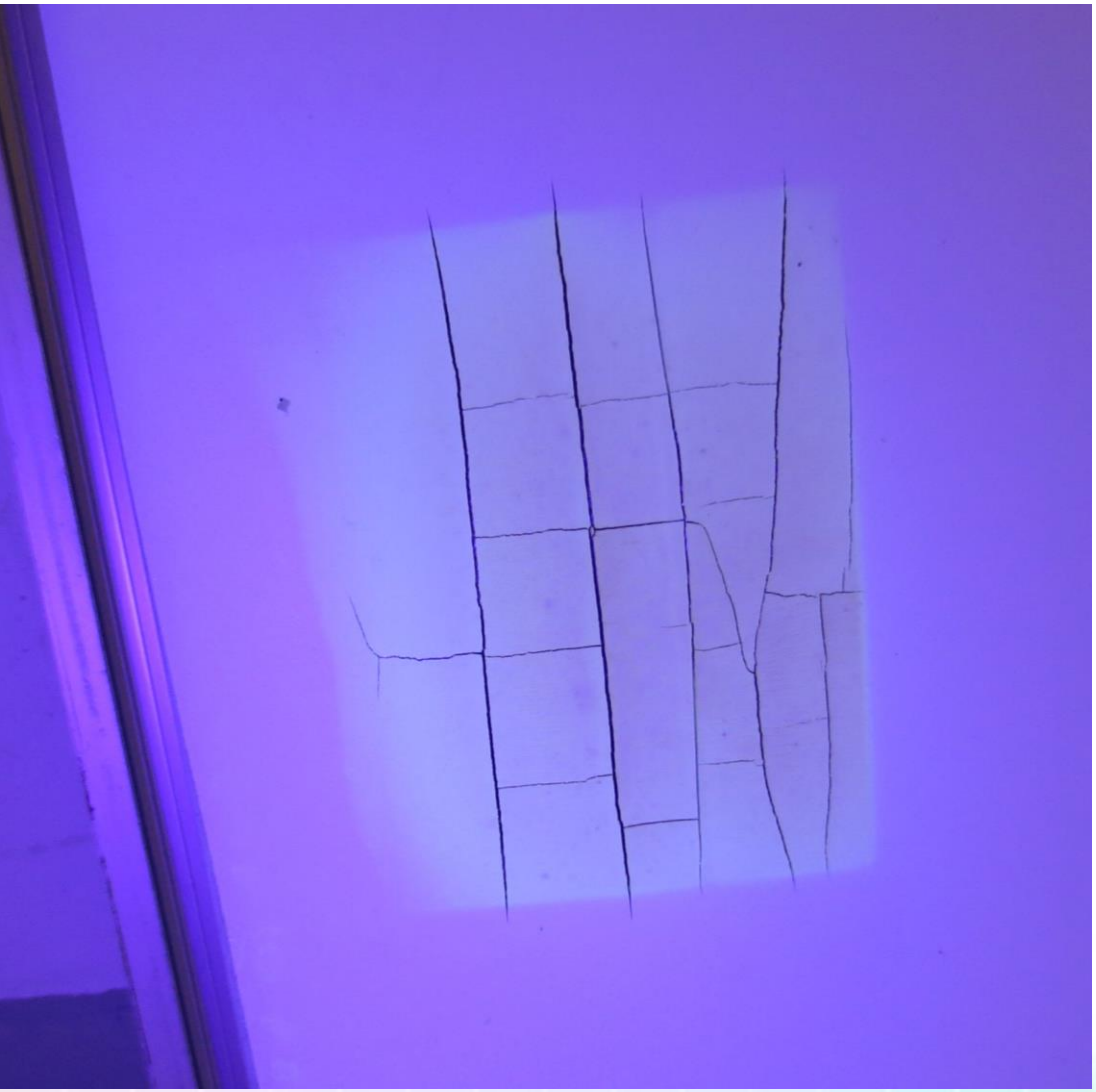
Temperature gradient ->Brightness gradient



VIS-Photography



PVPS T13: Exceptional UV

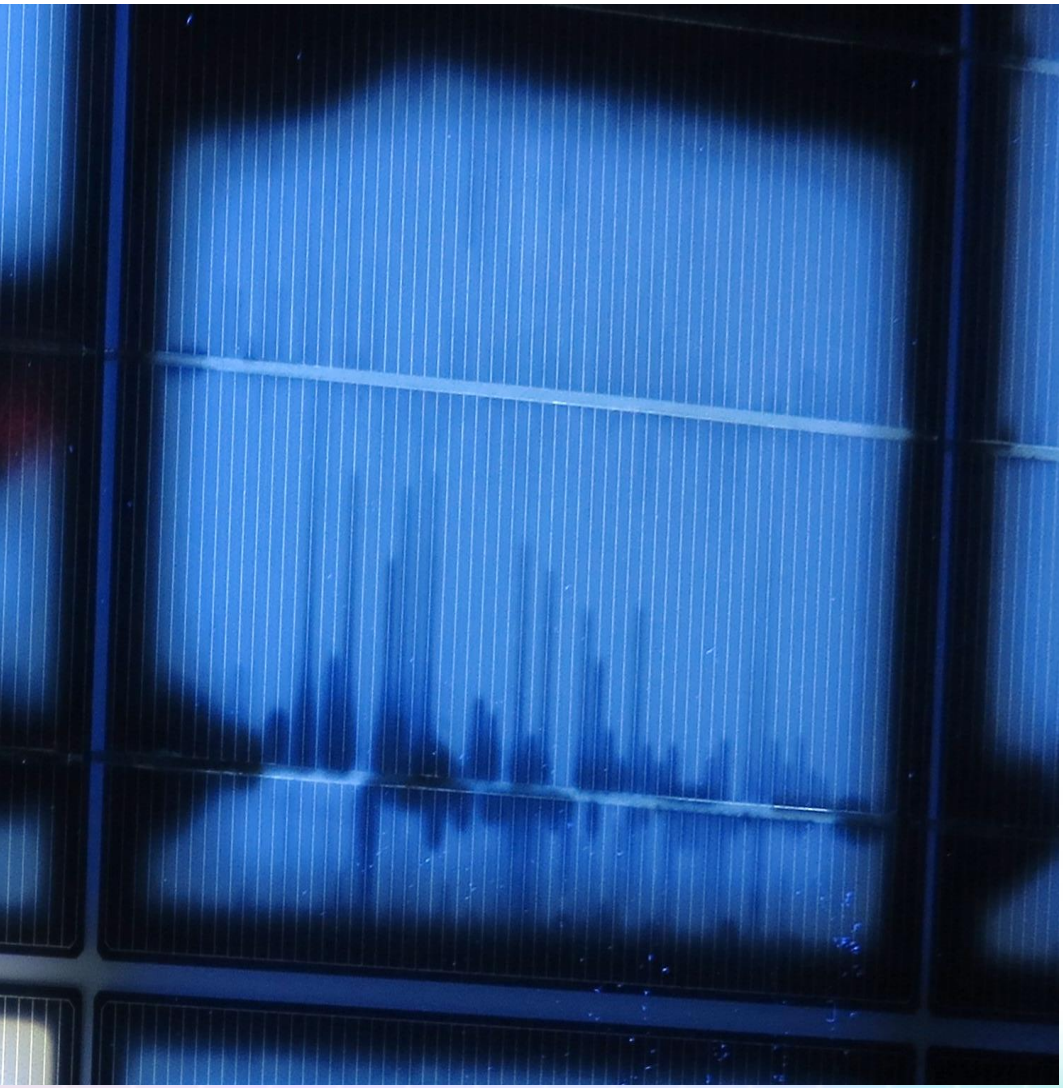


Fluorescenting backsheet

- In extreme hot spots, the backsheet has visible defects.
- If there is browning, it is also visible in the UV-F

- Probably not very useful

PVPS T13: Exceptional UV



Finger Soaking

- Dark region propagates along some fingers
- Unproven Hypothesis:
  - Solder flux is sucked along the rough surface of the fingers. While in-field the solder flux might destroy the UV-Fluoresence

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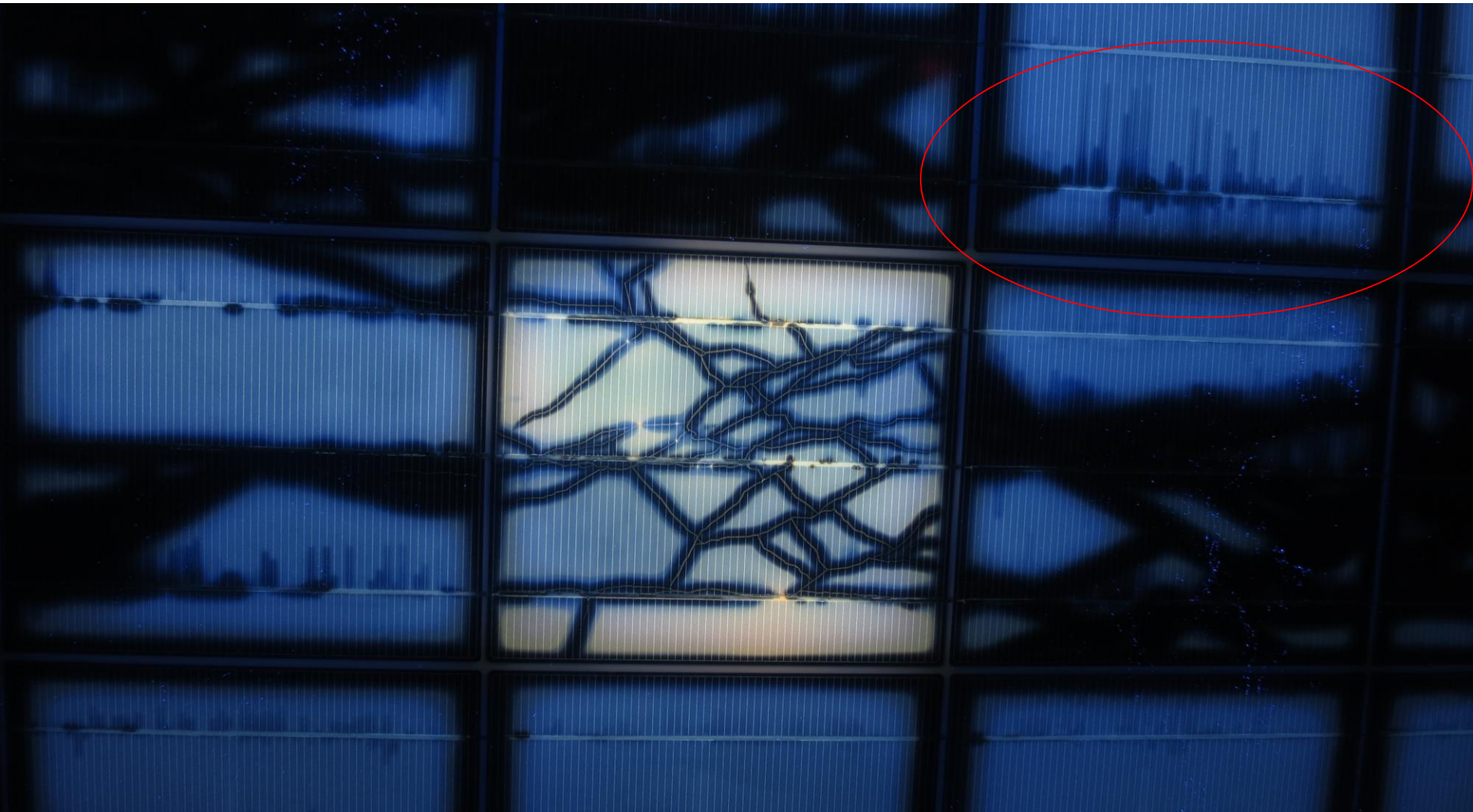
Diffusion along fingers



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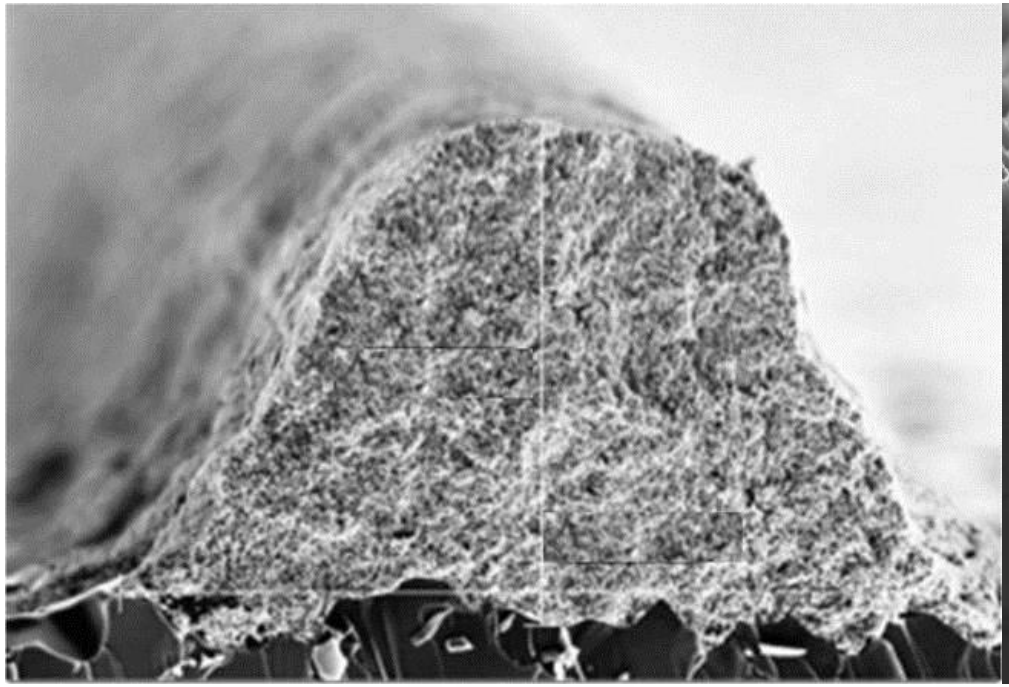
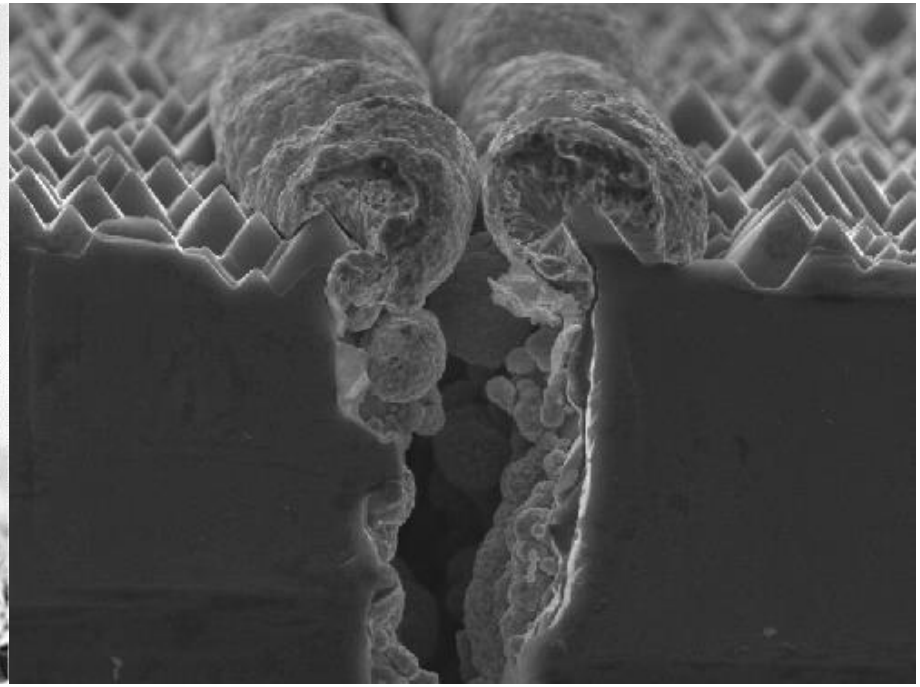
Rough Surface of fingers



Source: http://www.i2bf.com



Burried Contact Source: PVEducation.com

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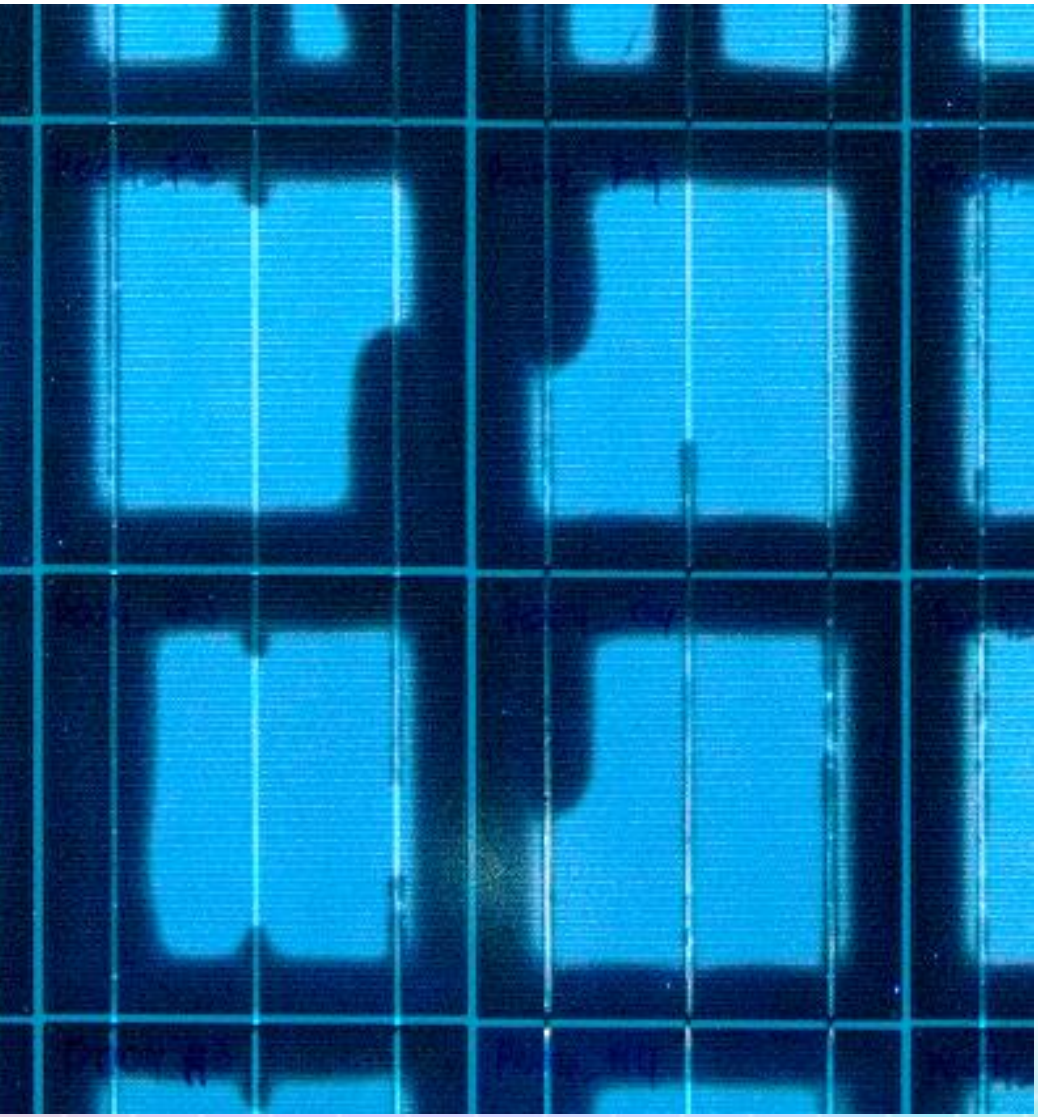

Busbar Conduction

- Dark region propagates along some busbars
- Unproven Hypothesis:
  - Airgap between busbar and cell
  - However measurements showed no soldering problems
- Alternative Hypothesis:
  - Cracks under the busbars due to soldering force

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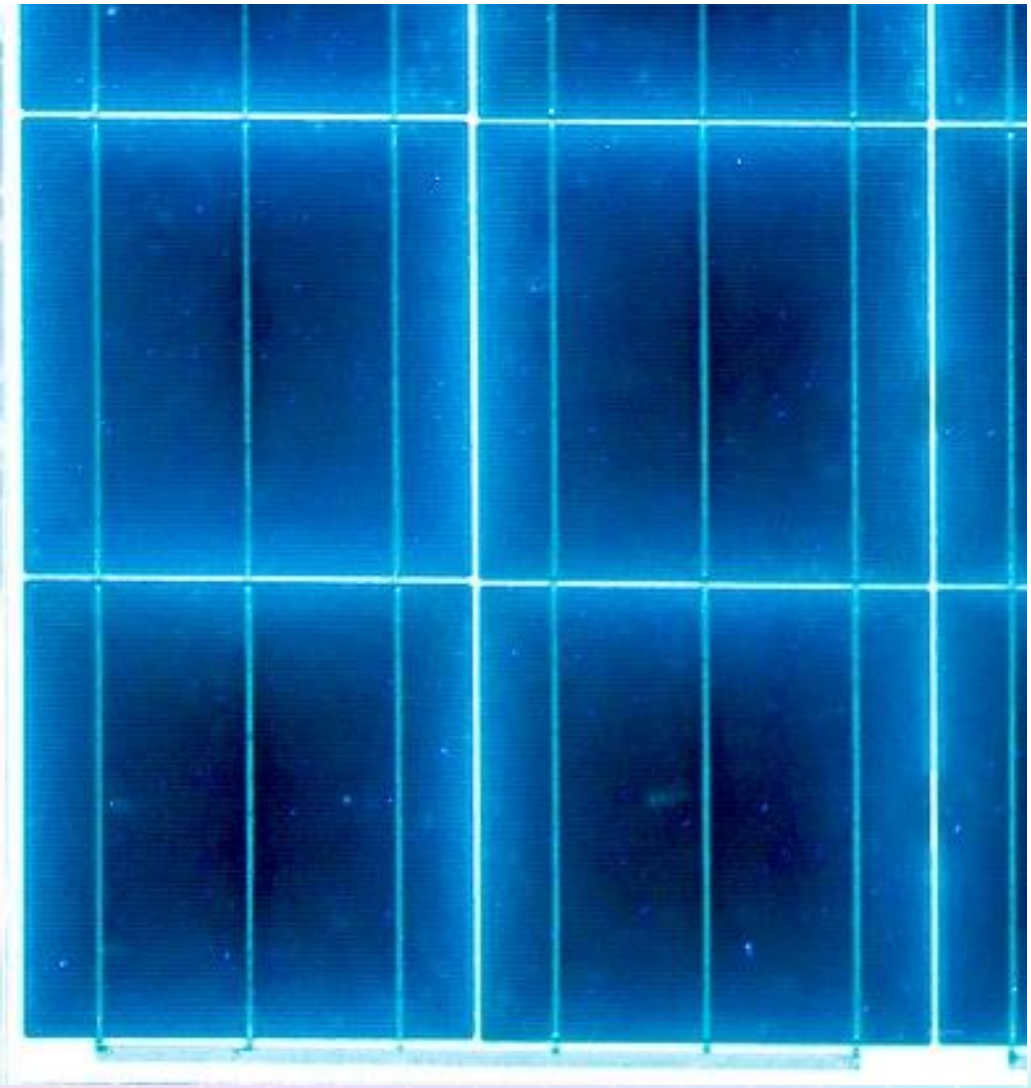

Indoor damp heat accelerated aging

- Cell gaps and sides are brighter
- Hardly visible with naked eye (only on long exposure)

- See: Schlothauer et al, DOI 10.1002/pip.2734

- See: Patent DE102015200648 Kunz/Wittmann
  ”Verfahren zur Bestimmung des Vernetzungsgrads einer Polyethylenverbindung „

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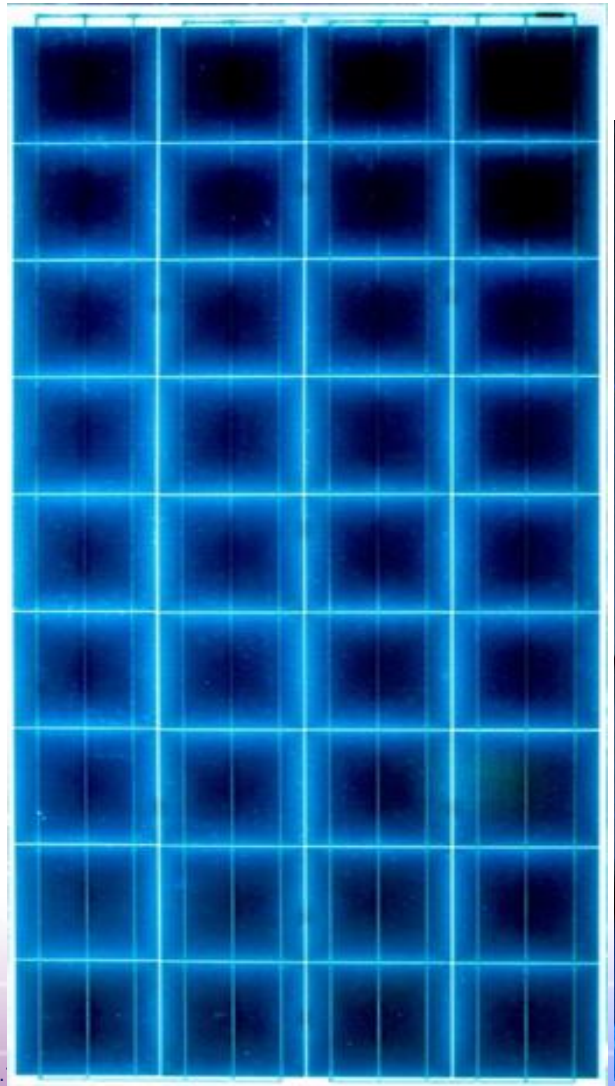
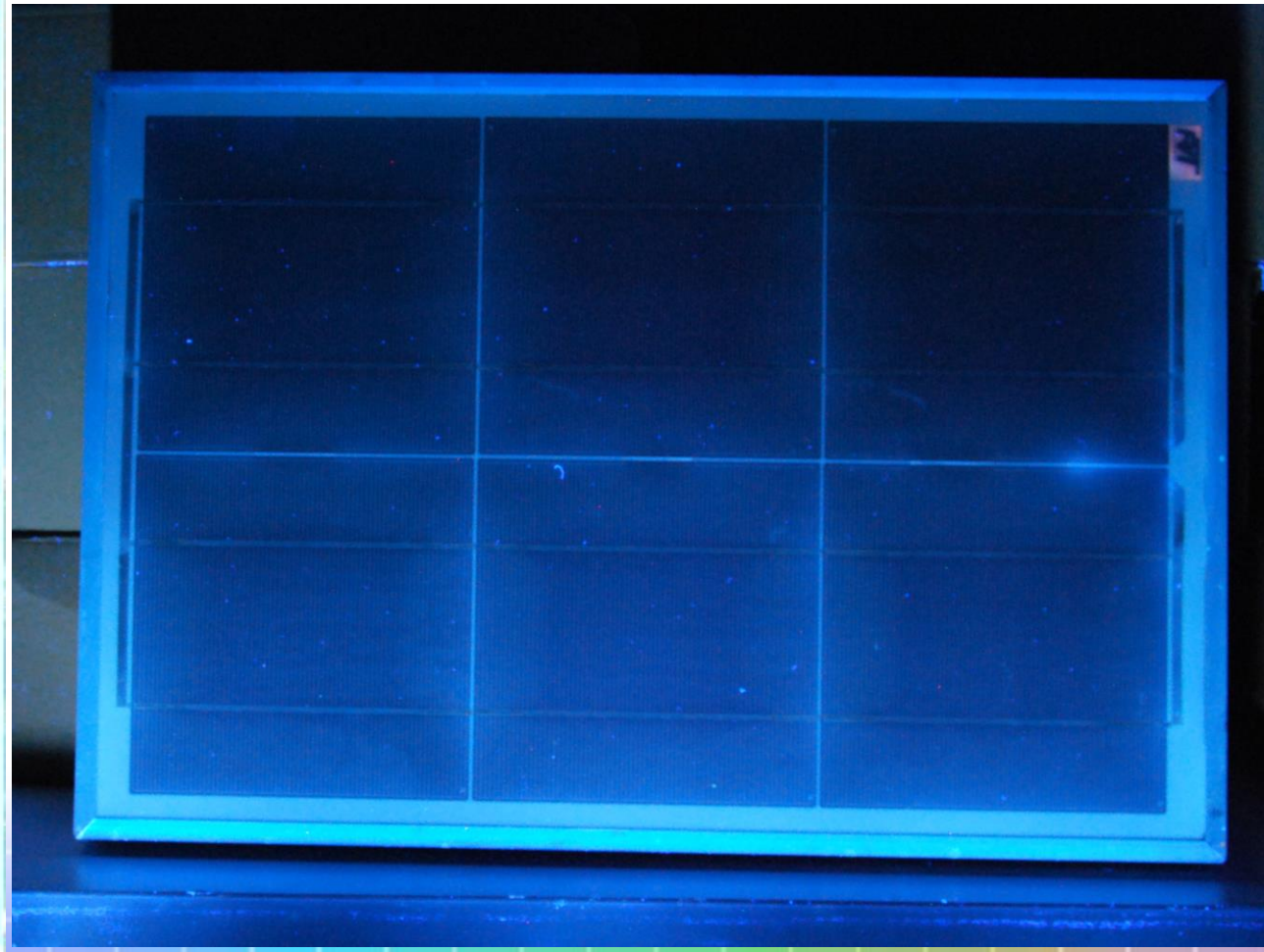
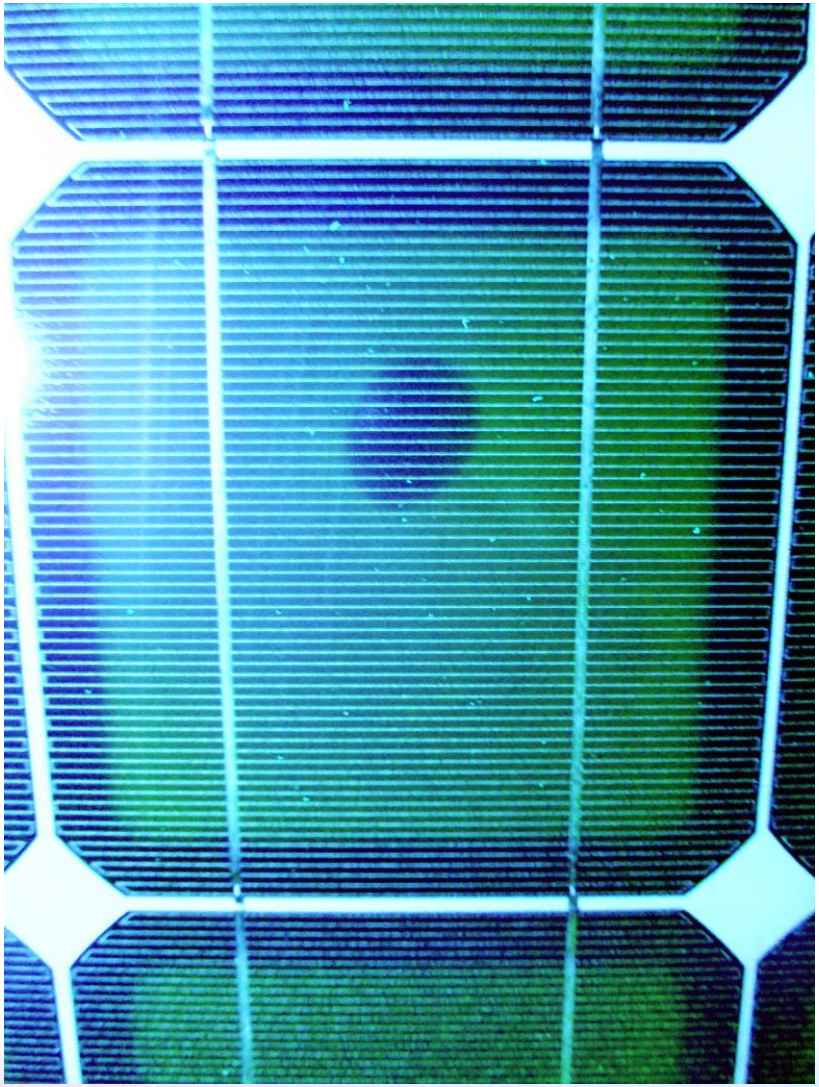
Damp heat accelerated aging





PVPS T13: Exceptional UV



Punctual extinction, “Freckle”

- Either a local microcrack
  - Not visible in our EL in some cases
  - See IEA-PVPS T13-01-2014 “Review of Failures of Photovoltaic Modules”
- Or a droplet of e.g. solder flux, oil or similar during the production.

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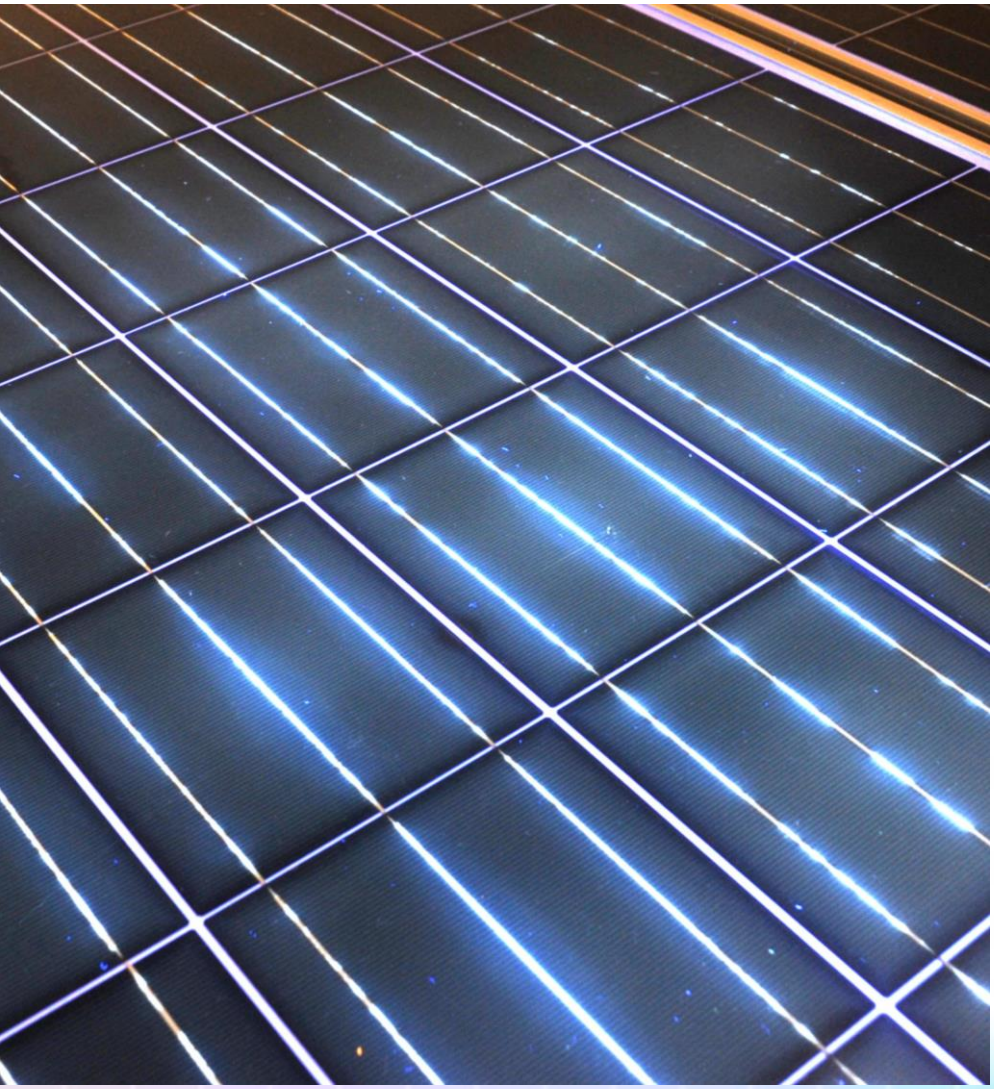

Bright Busbars

- Very likely residue of the solder flux

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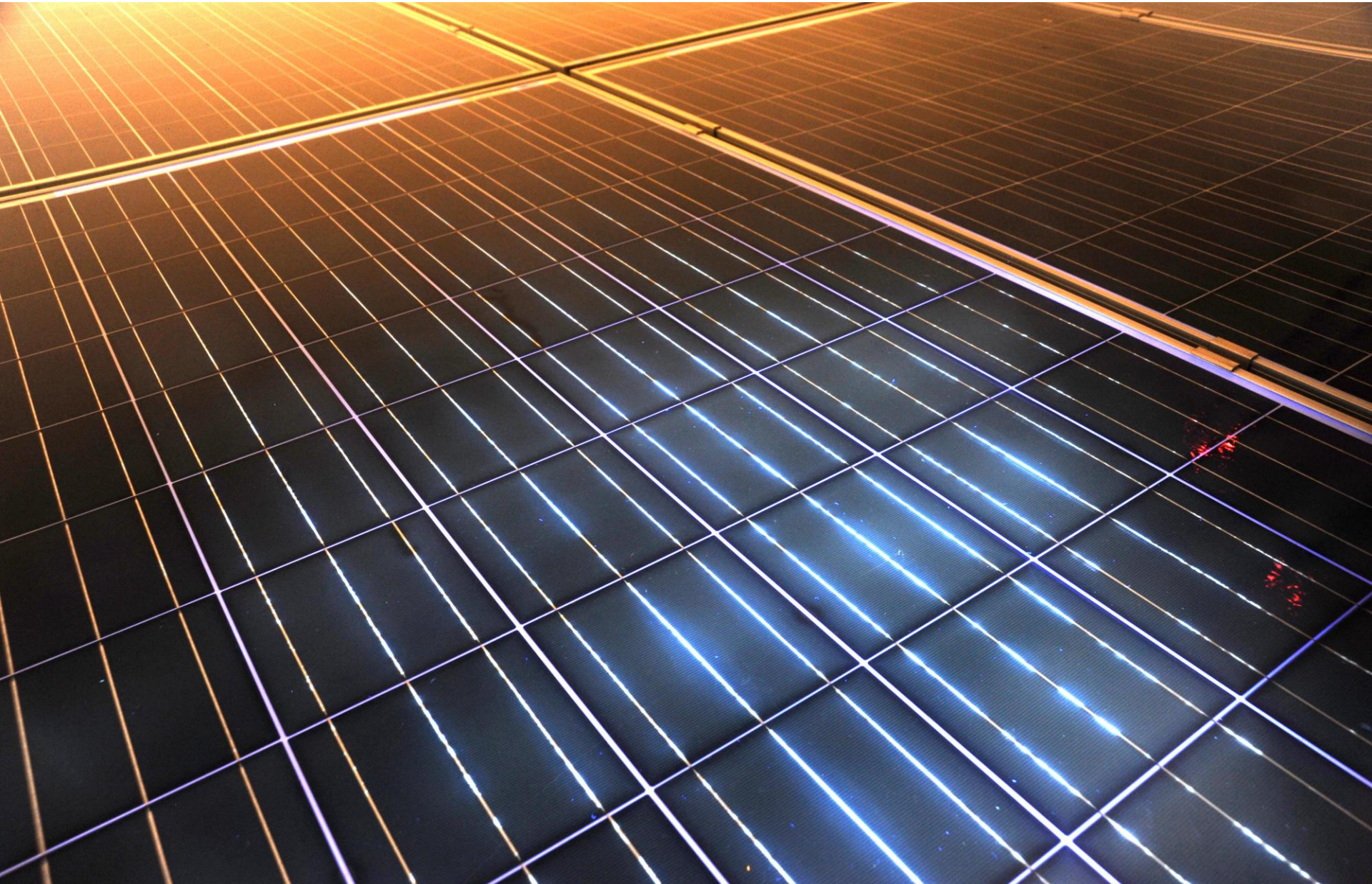

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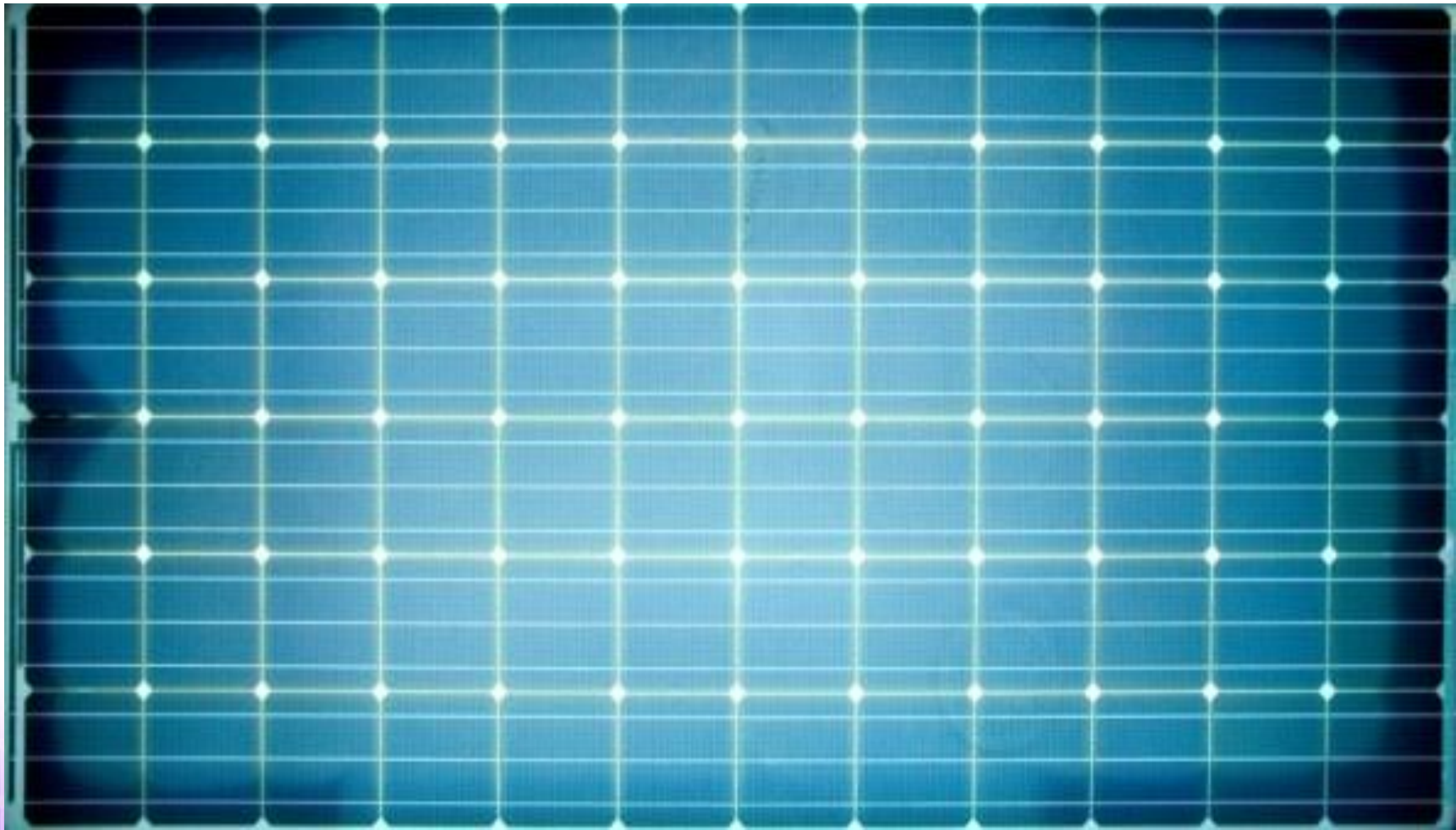
Impermeable aluminium backsheet



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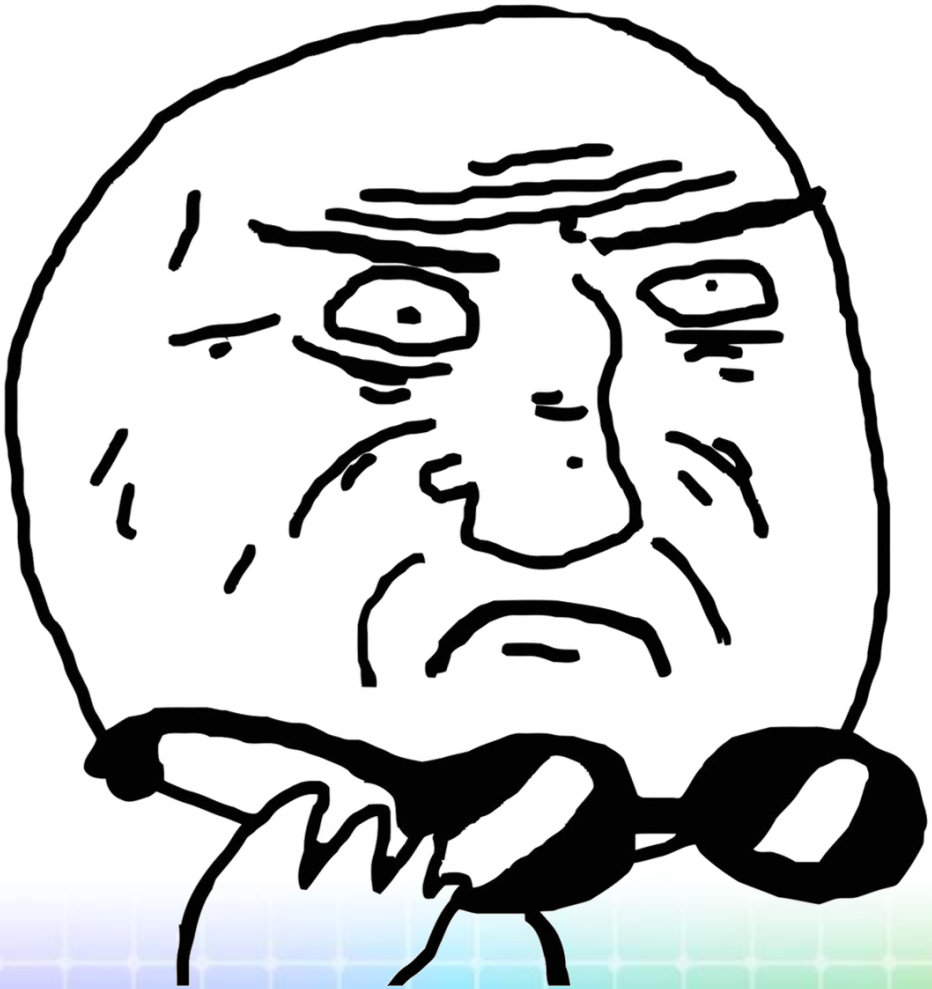
Exotic Findings



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Brighter Cells

- Opposed to hot cells, the UV-F has the same color, but is just brighter
- No cracks visible
- Weak hypothesis:
  - ~~Maybe a double layer of EVA?~~
  - ?????????!!!!11

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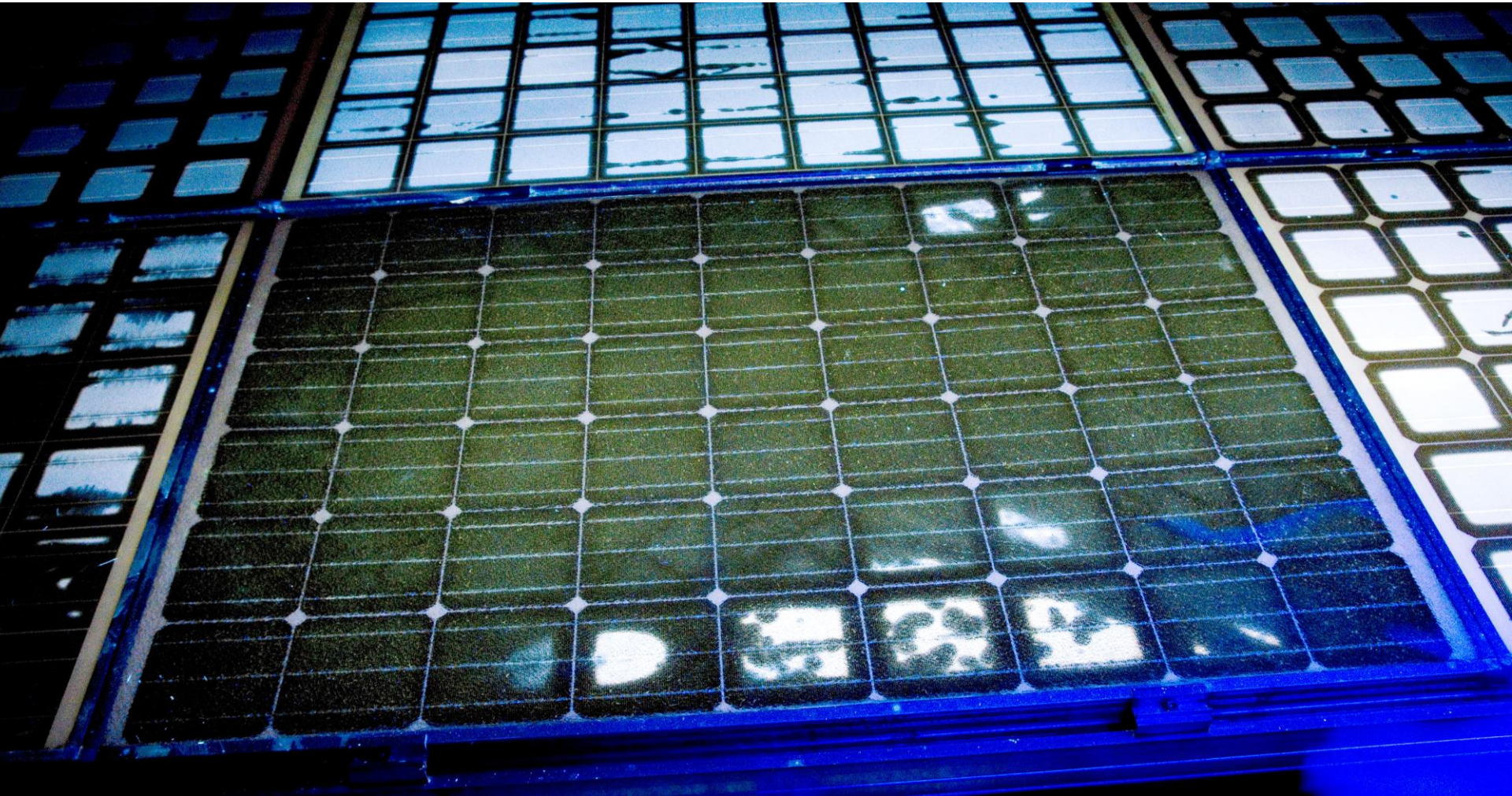
Broken glass



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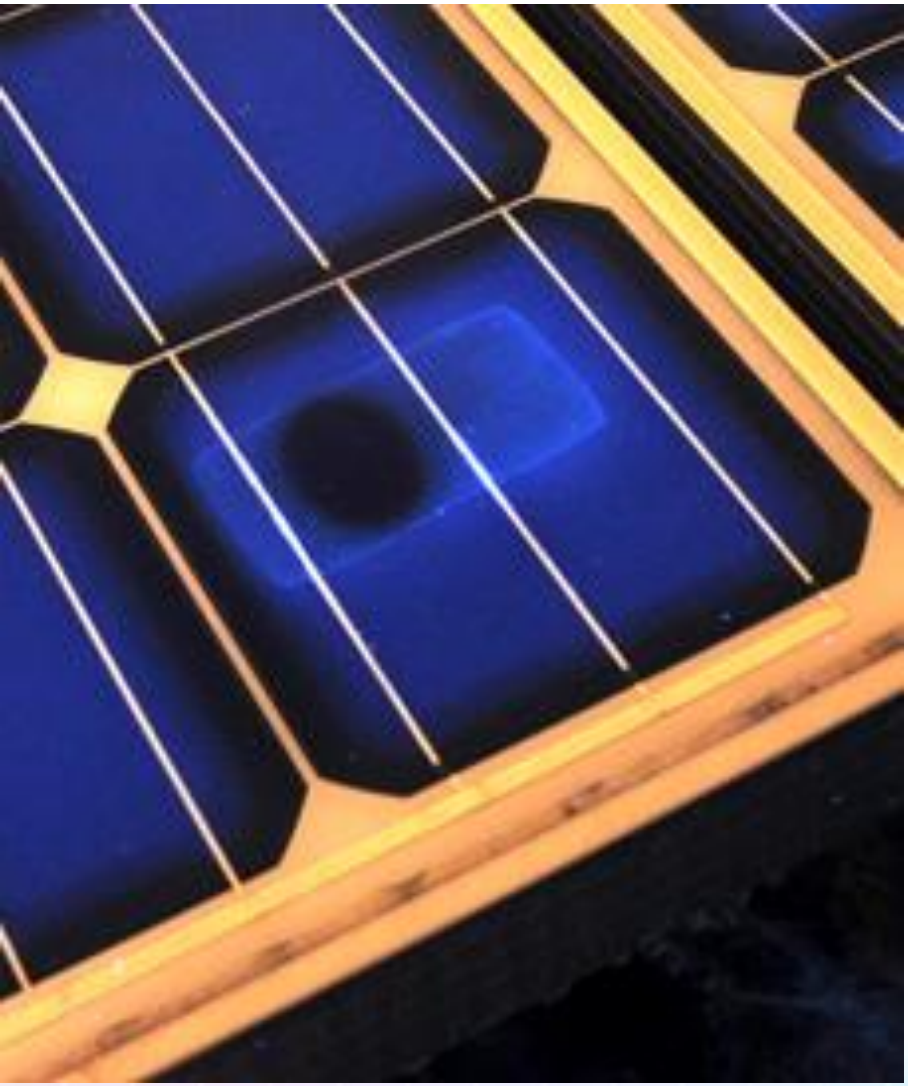

Residue of Glue

- Very likely the residue of a sticker/label either on the glass or on the EVA before lamination

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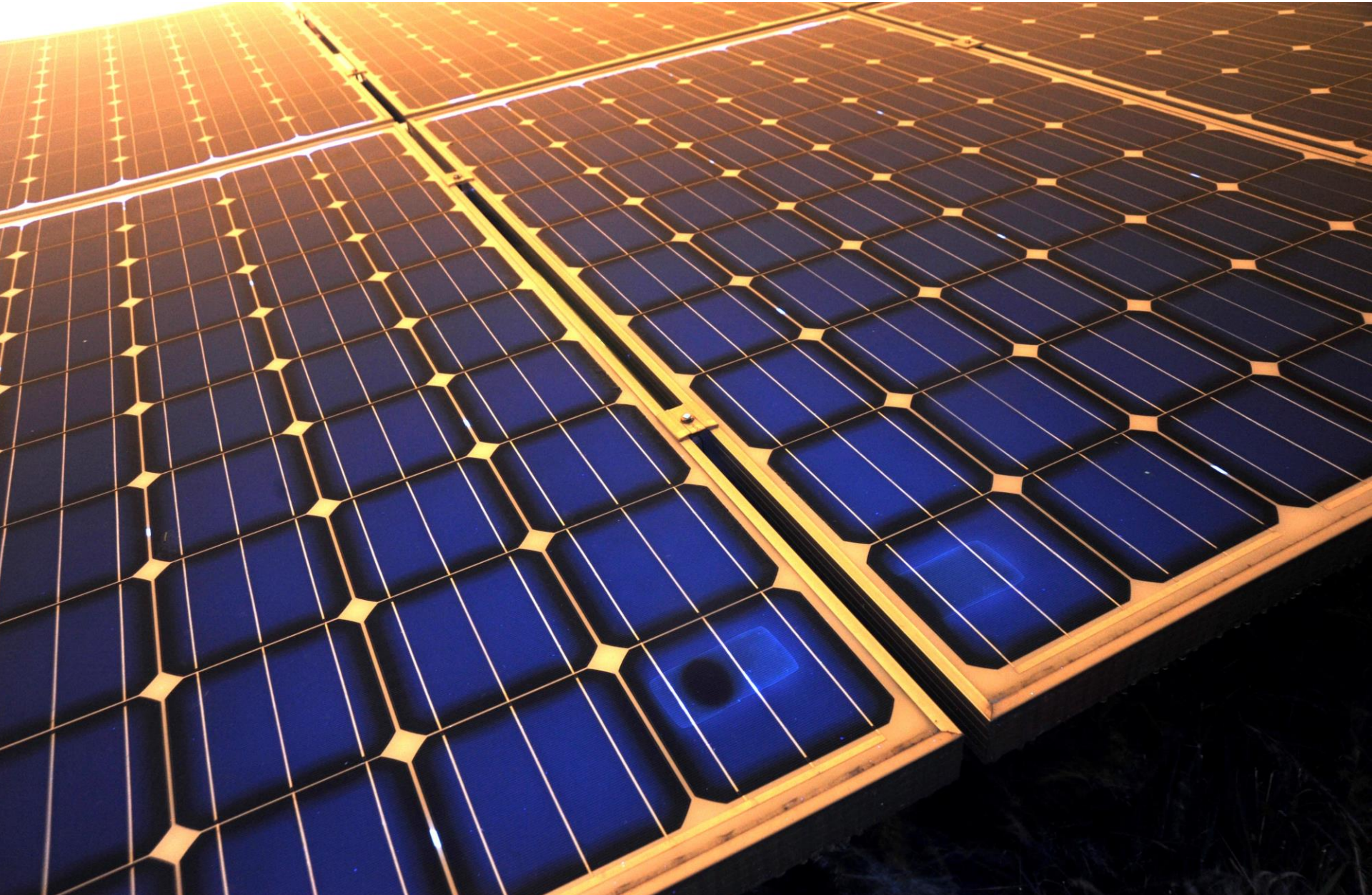

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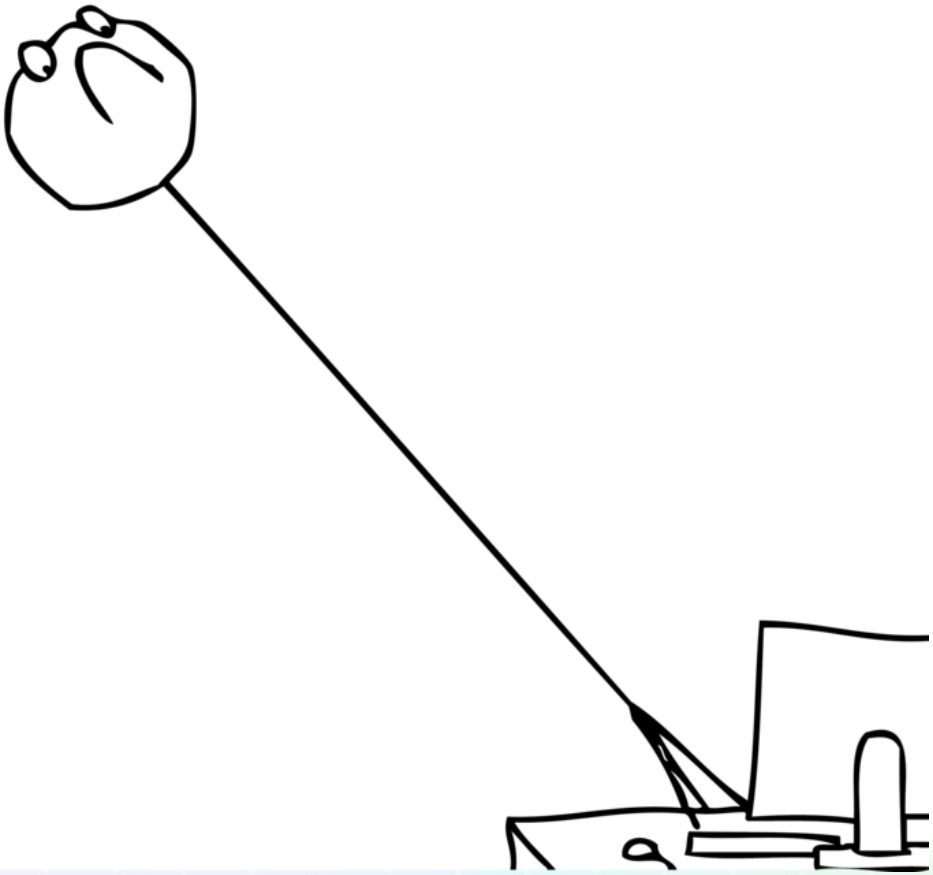
Even more exotic findings



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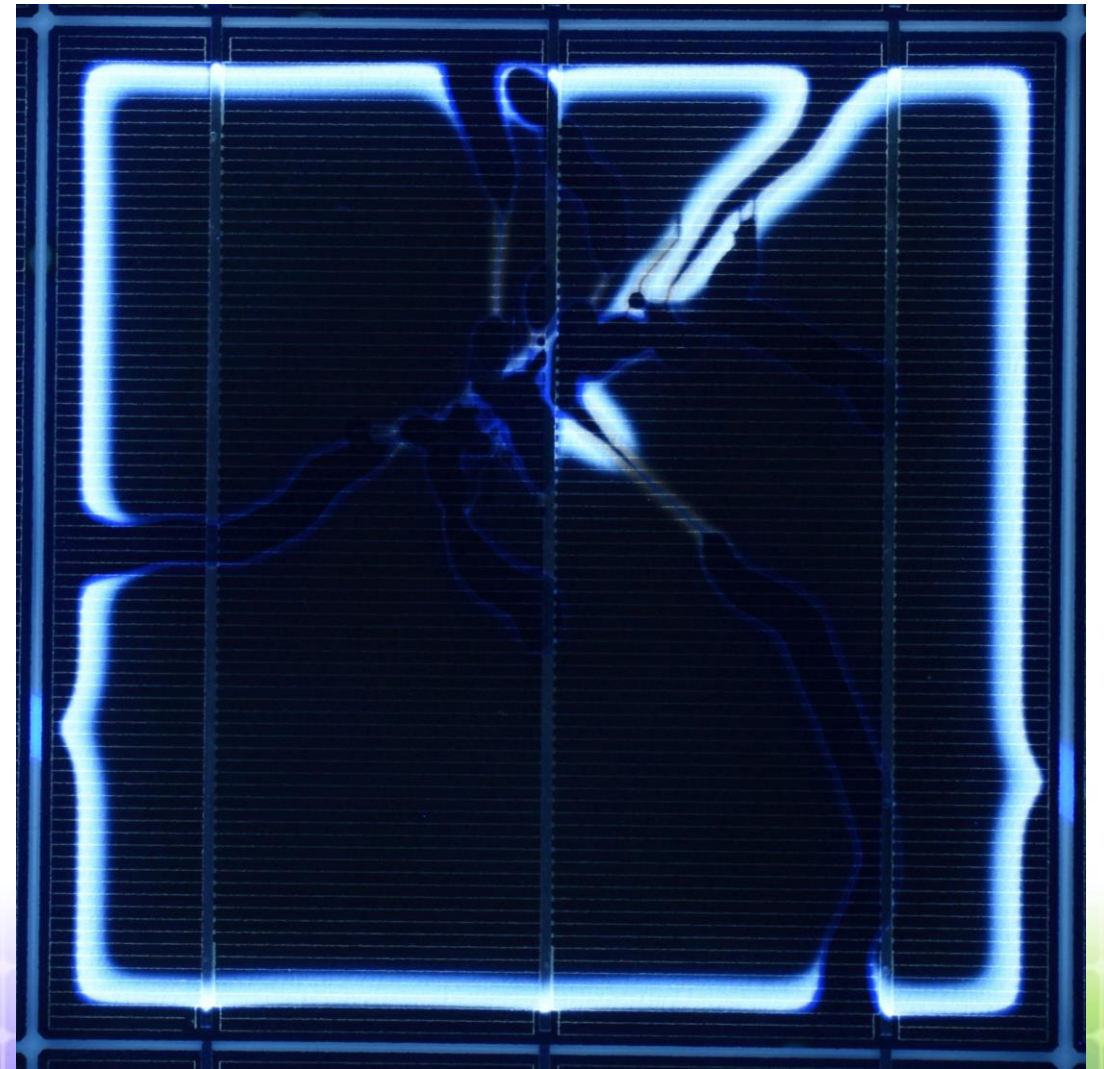
Cell of Module after UV-chamber ageing



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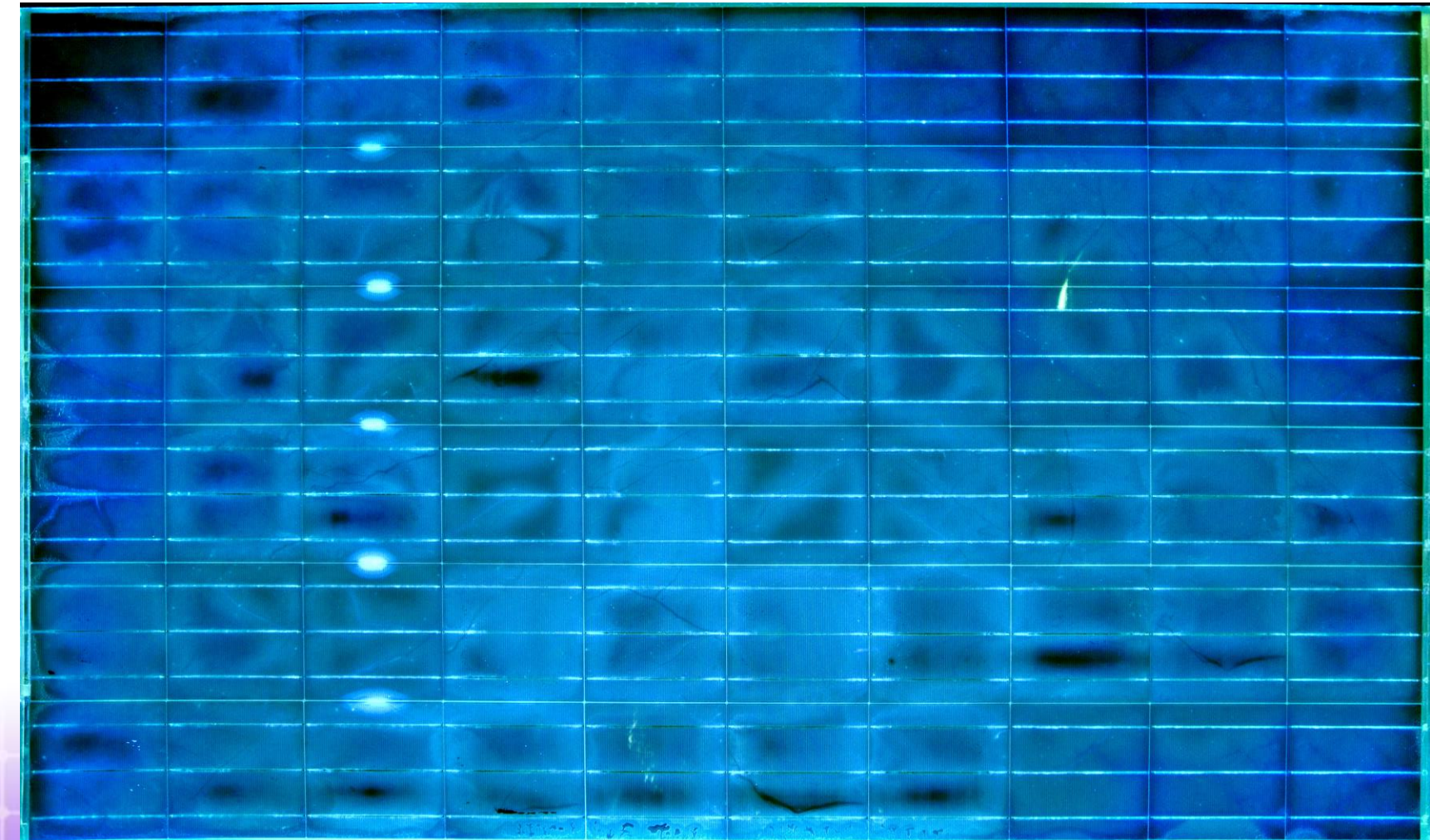
Silicone-encapsulated



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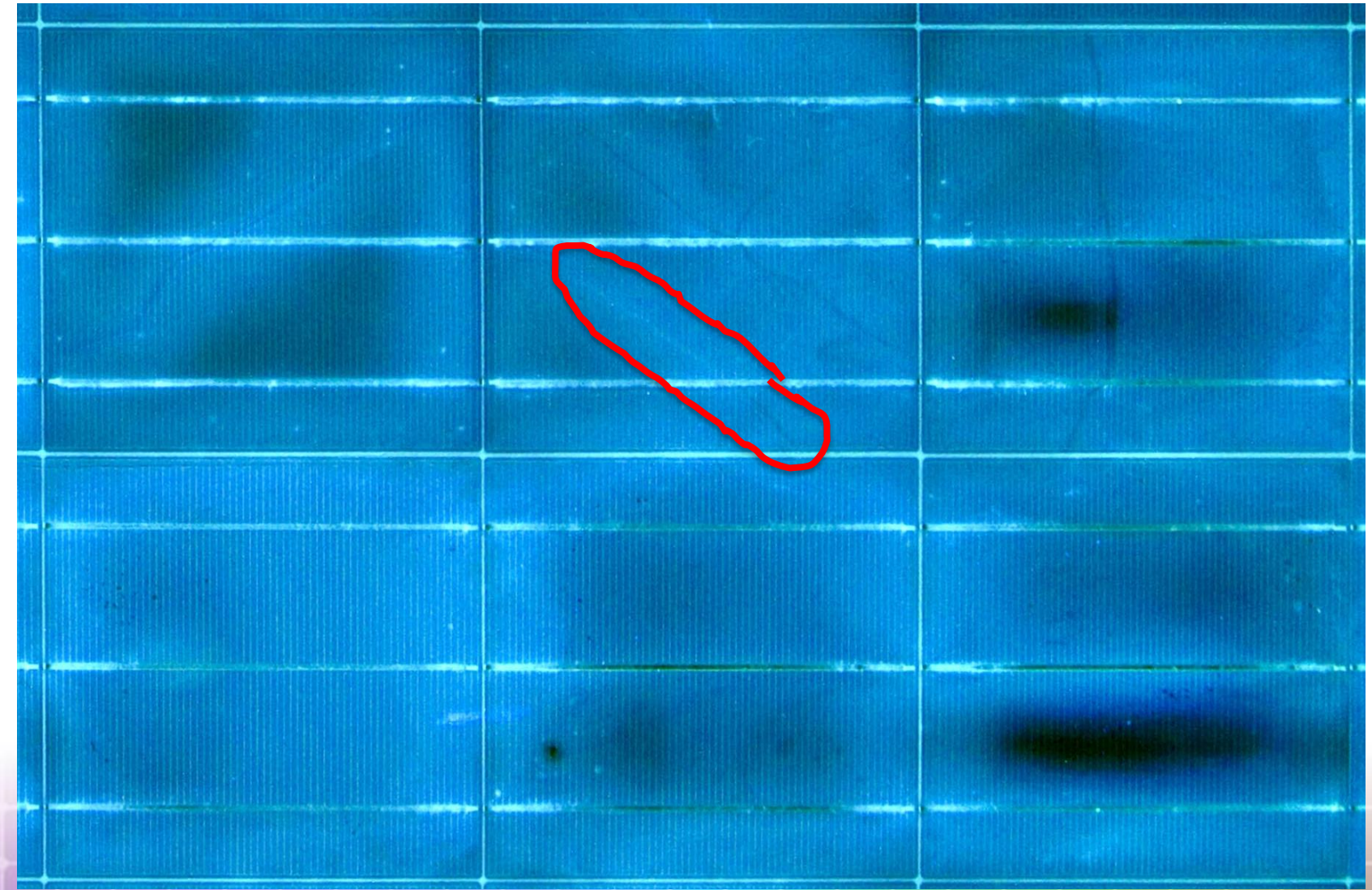
Zoom:



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Conclusion:

- UV-F shows much more features than thermography
- Many features are really very strange.
  - Let's research!
- However, major module defects are quite obvious
  - even to slightly trained personal.

- IR shows the production/energy harvest relevant defects
- UV-F more the general state of the modules
- Seasonal:
  - UV-F, EL, Dark-IV are best done in winter
  - IR, Bright-UI,

- Please respect the ICNIRP UV radiation guidelines (basis for standards)

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BONUS: Comparison of Methods

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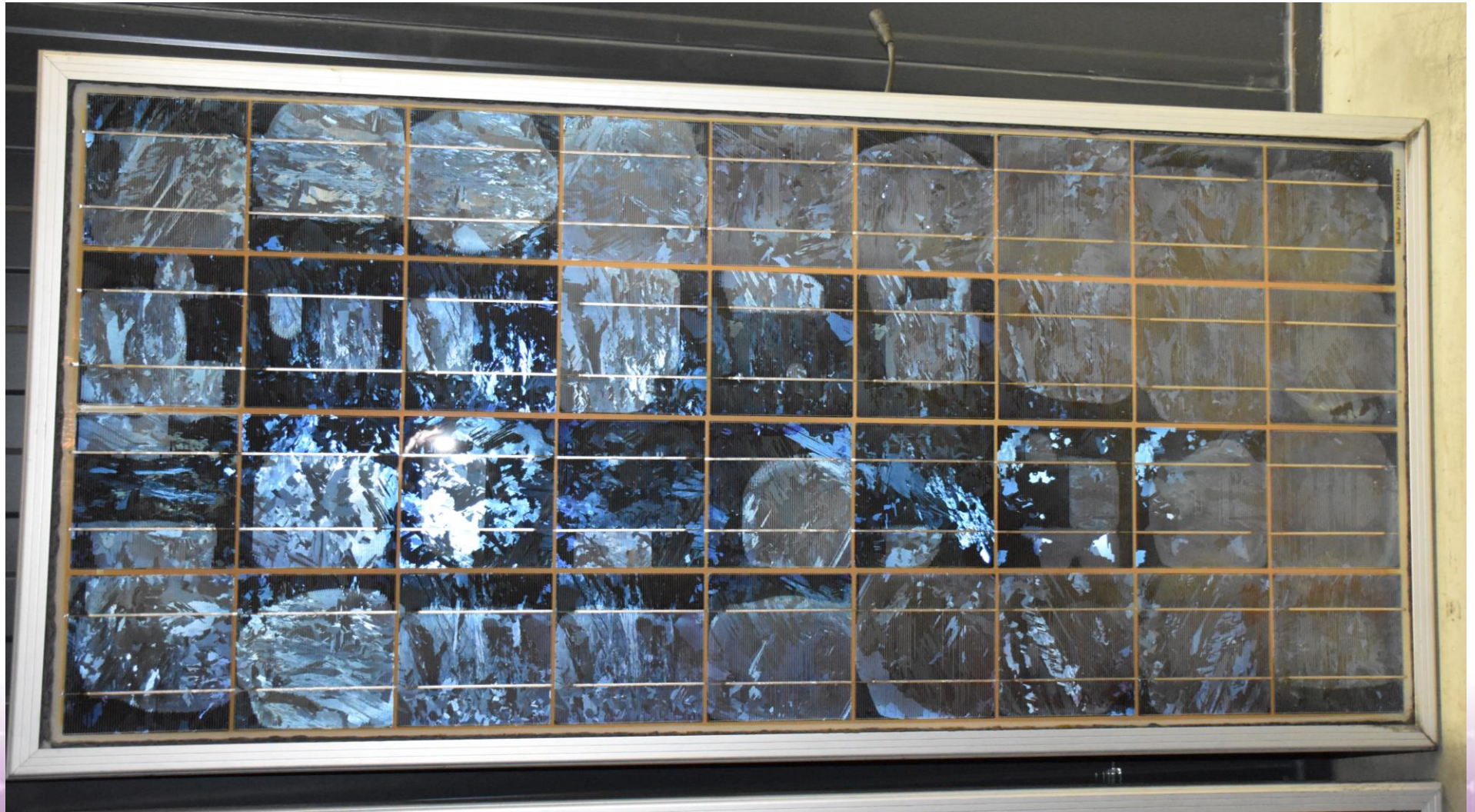
Extremely aged; delaminated



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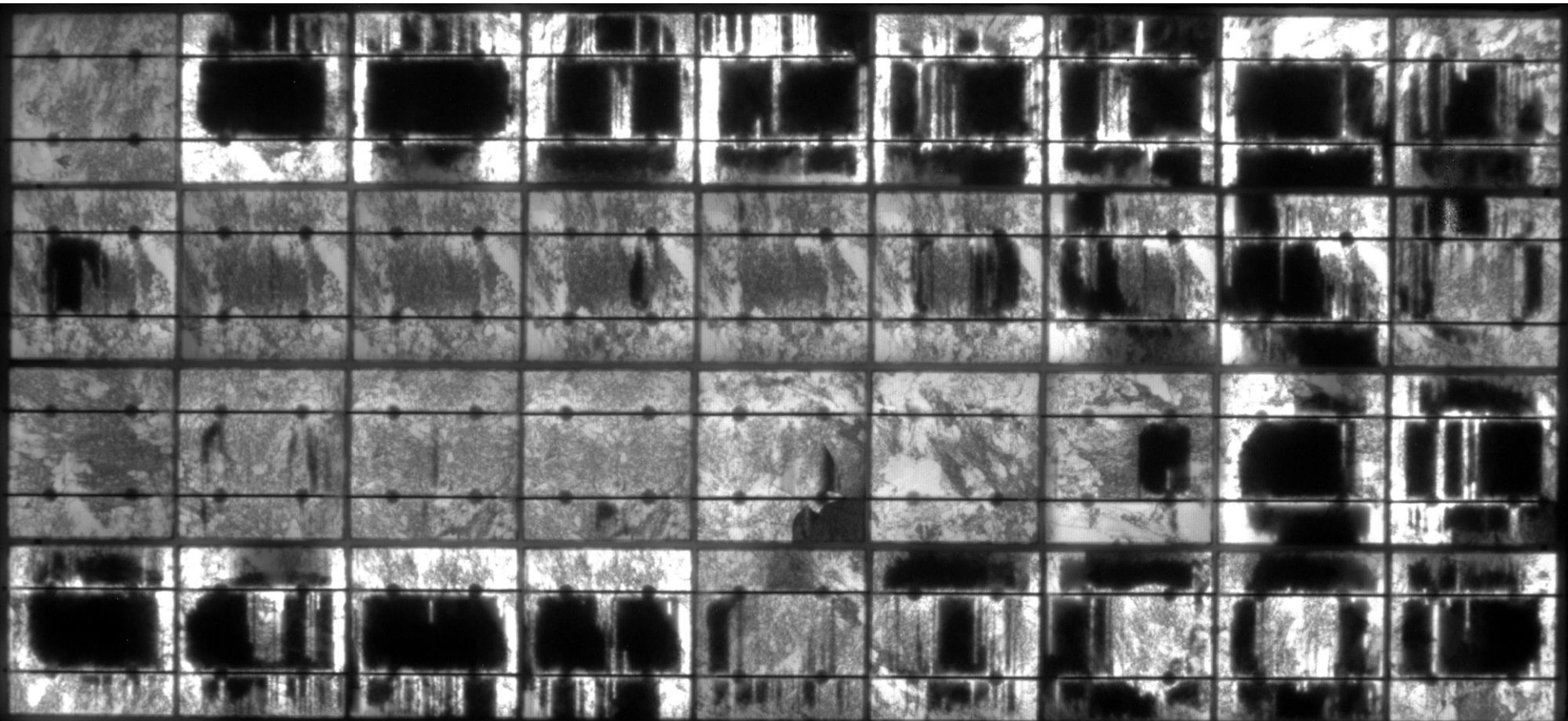

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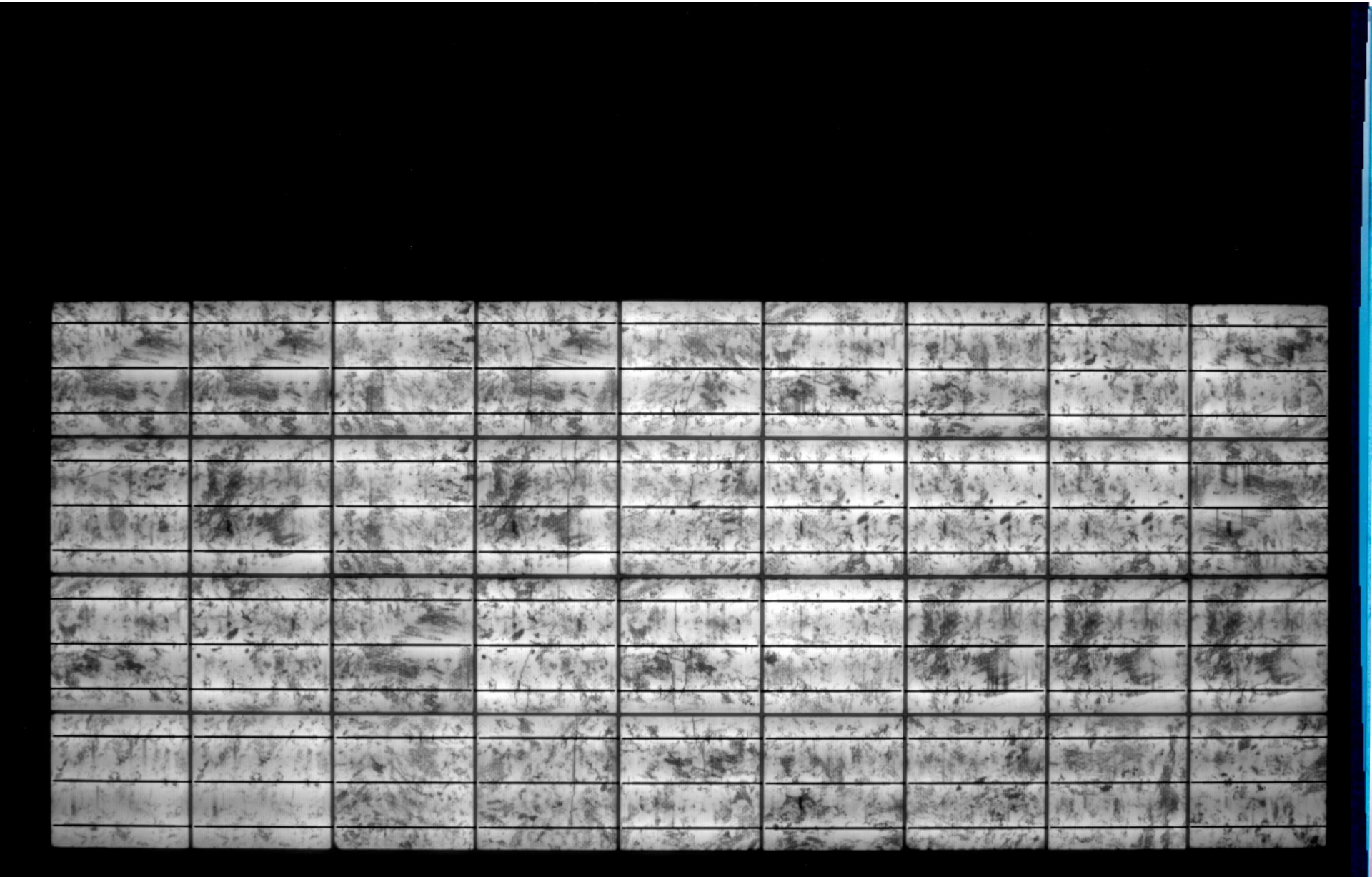

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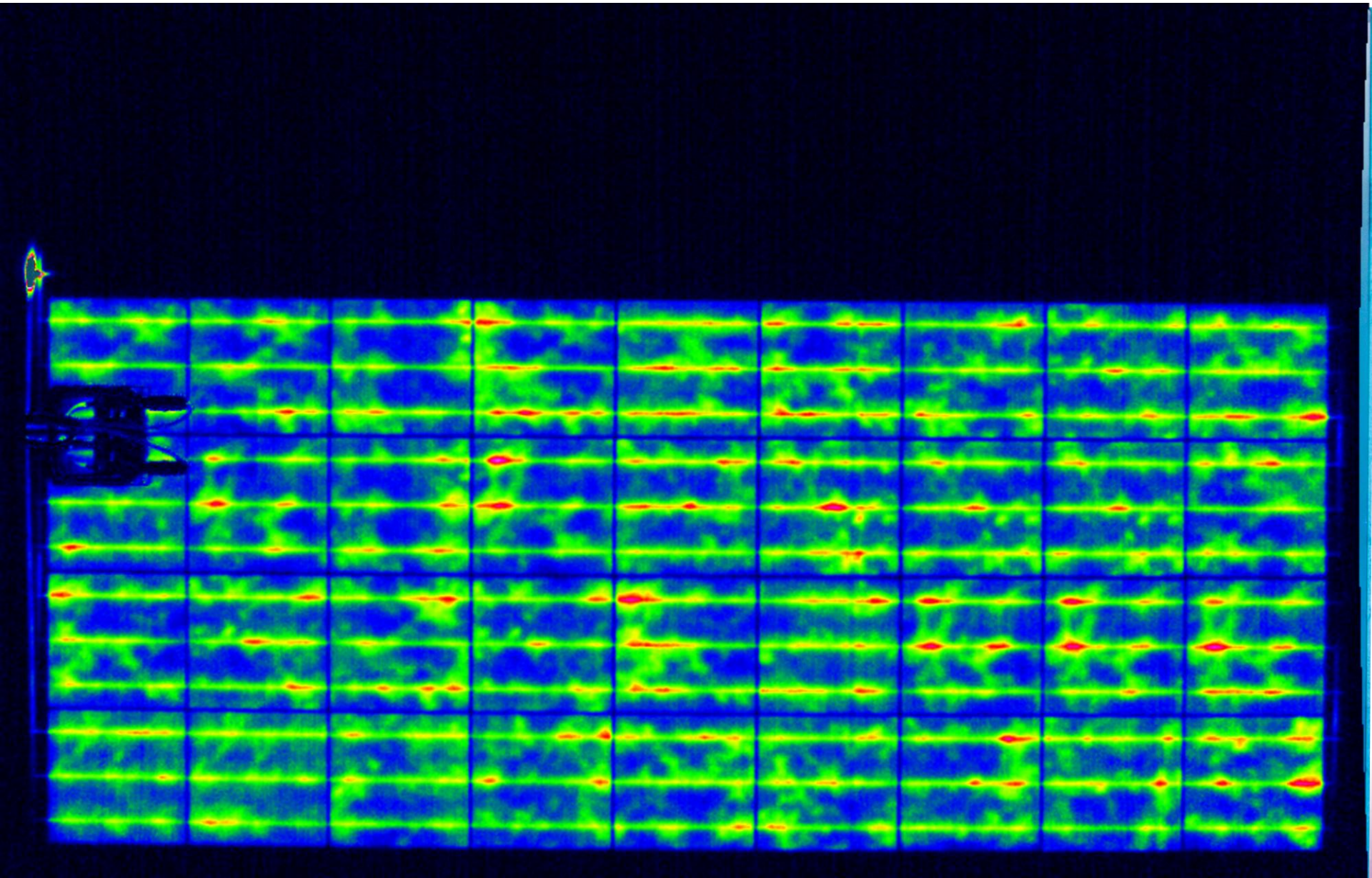

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Literature: last update 2016

J. C. Schlothauer, K. Grabmayer, I. Hintersteiner, G. M. Wallner, B. Röder, Non-destructive 2D-luminescence detection of EVA in aged PV modules: Correlation to calorimetric properties, additive distribution and a clue to aging parameters, Solar Energy Materials and Solar Cells 159, 317 (2017) DOI: 10.1016/j.solmat.2016.09.011

J. C. Schlothauer, K. Grabmayer, G. M. Wallner, B. Röder," Correlation of spatially resolved photoluminescence and viscoelastic mechanical properties of encapsulating EVA in differently aged PV modules", Prog. Photovolt: Res. Appl. (2016) DOI: 10.1002/pip.2734

B. Kubicek, D. Mayrhofer, G. C. Eder, Y. Voronko, UV-luminescence imaging of fielded PV-modules, PV-Module Reliability Workshop, Vienna, 2016.

GABRIELE C.EDER1, YULIYA VORONKO1, BERNHARD KUBICEK2 UND KARL KNÖBL3," FLUORESCENCE SPECTROSCOPY AND IMAGING ON AGED POLYMERIC PV-ENCAPSULANTES", 20th European Symposium on Polymer Spectroscopy, 2016

Schlothauer, J.; Jungwirth, S.; Köhl, M.; **Röder**, B., "Degradation of the encapsulant polymer in outdoor weathered photovoltaic modules: Spatially resolved inspection of EVA ageing by fluorescence and correlation to electroluminescence", Solar energy materials and solar cells 102, pp.75-85, (2012)

Roeder, B.; Schlothauer, J.; **Koehl**, M., "Fluorescence imaging for analysis of the degradation of PV-modules", 37th IEEE Photovoltaic Specialists Conference, PVSC 2011, Seattle, WA, USA, (2011).

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