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Ageing effects in PV cells and modules

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Outline

- Introduction to ageing factors and ageing effects
- Experiments with PV modules operating in field conditions for 13,18, 22 years
- Ageing effects identified through :
  - Visual Inspection/ digital image
  - IR thermography
- Performance degradation
  - I-V curves, electrical characteristics, Power output
- Conclusions

PV cell and module Ageing

Appears due to:

- Natural weathering
- Induced ageing by external agents

Stages:

- Initial degradation
- First signs of ageing
- Gradual/ Accelerated ageing (cause & effect)
  - Arithmetic or geometric progression

Ageing Factors

External factors:

- Vegetation / nearby objects
- Dirt or Dust
- Bird pits

Partial Shading → Short / Long Term Degradation

- Weather conditions
  - High ambient Temperatures
    High solar irradiation
    Lower UV wavelengths
  - Rain/ wind

Discoloration → Long Term Optical & Physical degradation

Humidity Ingress

Ageing Factors

Internal factors

- Crystal defects or impurities
- Manufacturing micro-cracks, micro-defects

Shunt paths → Physical & electrical Degradation

Combination of factors (cause & effect)

- UV stabilizer degradation=> EVA yellowing =>formation of acetic acid=> EVA browning

Defects lead to mismatch effects => defected cells operate in reverse bias conditions => power dissipation=> high temperatures=> hot spot formation

Ageing effects

- Discoloration of the EVA encapsulant
- Delamination of the encapsulant
- Oxidization
- High conductivity paths (shunts)
- Humidity ingress
- Hot spots/ hot areas
- Cracks, tears in the back sealing
- Bubbles
- Corrosion in bus bars and contacts

Experimental Procedure

PV modules

- BP B 1233
  - 22 years of field operation, natural weathering
- SIEMENS M55
  - 18 years of field operation, natural and induced shading effects
- SIEMENS SM55
  - 13 years of field operation, natural weathering

Examined via:

- Visual Inspection
  - visual observation/ digital camera
- IR thermography
  - TROTEC IC080LV thermocamera (res.384x288 pxls)
- I-V curve, electrical parameters
  - I-V curve analyser, pyranometers (global & diffuse radiation), IR thermometer

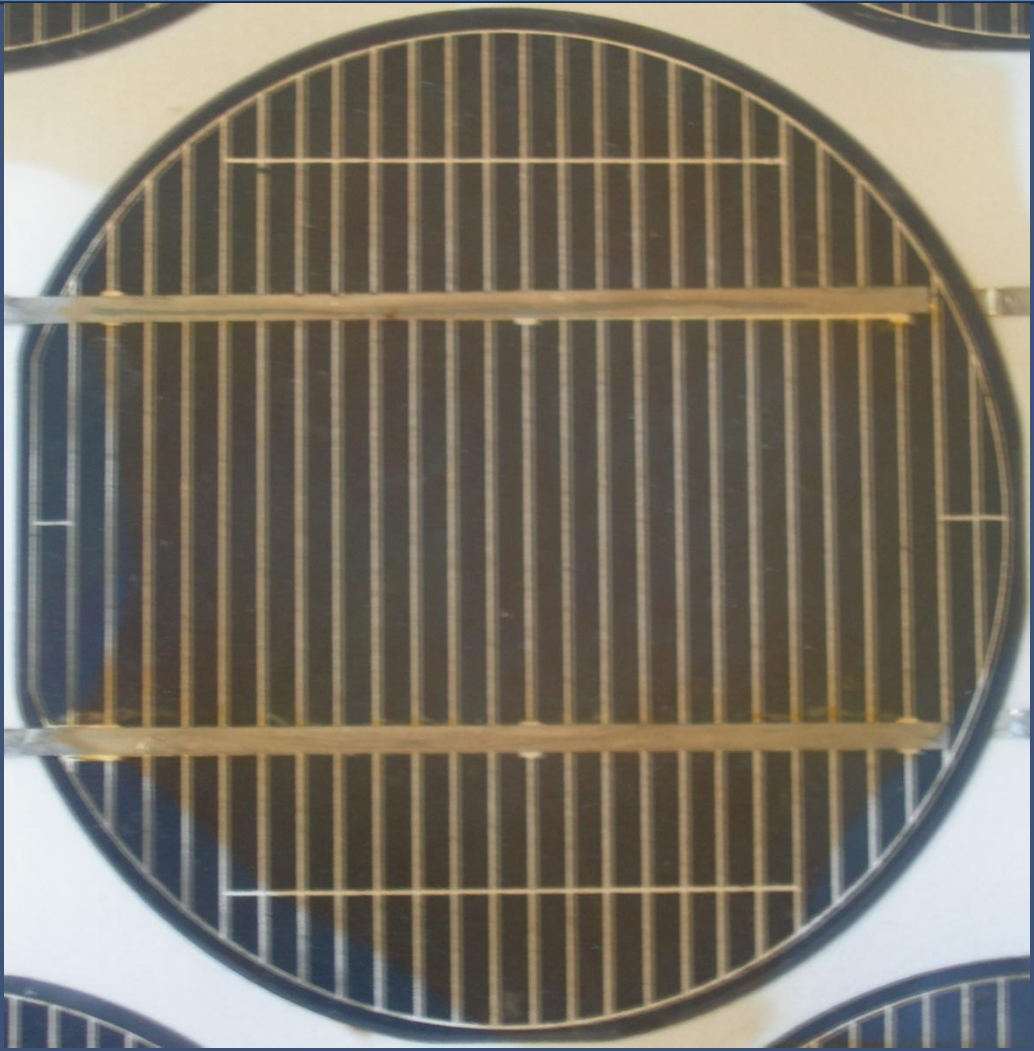
Visual Inspection

- EVA Discoloration
  - Location => central region of the cell
  - Shape => circular, square, patches, other shapes
  - Severity of Browning
    - Different degrees, from golden brown to dark brown
  - Differs between cells of the same module, and between modules
  - Acceleration of browning in surface domain and degree
- Delamination
  - Expansion
- Corrosion of contacts
- Bubbles
- Tears in the back sealing surface

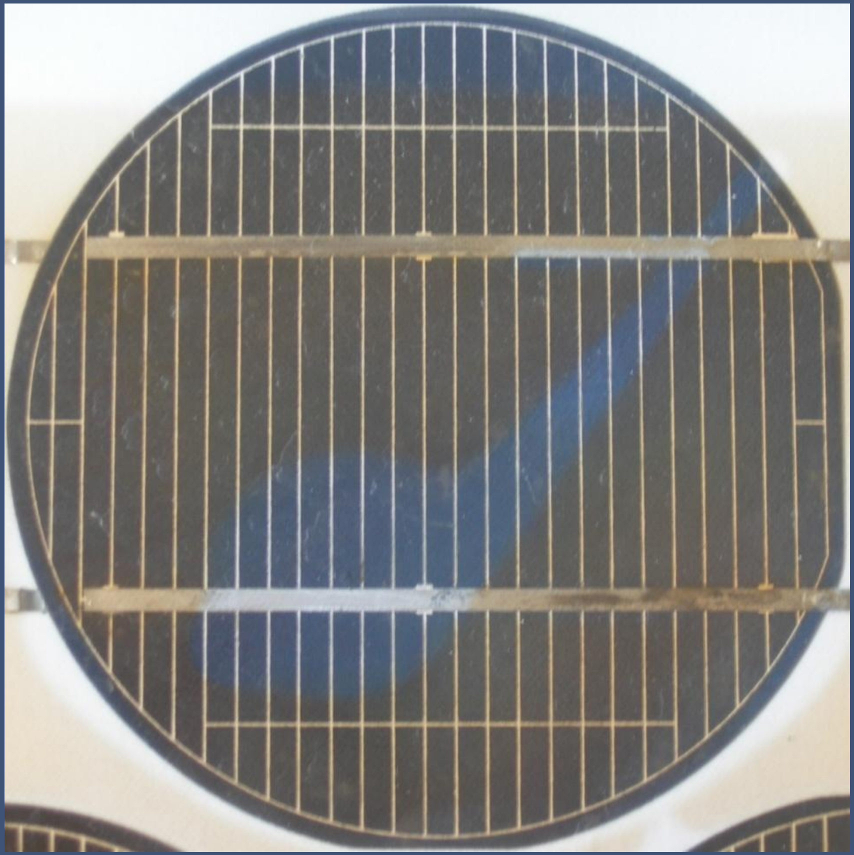
EVA Discoloration

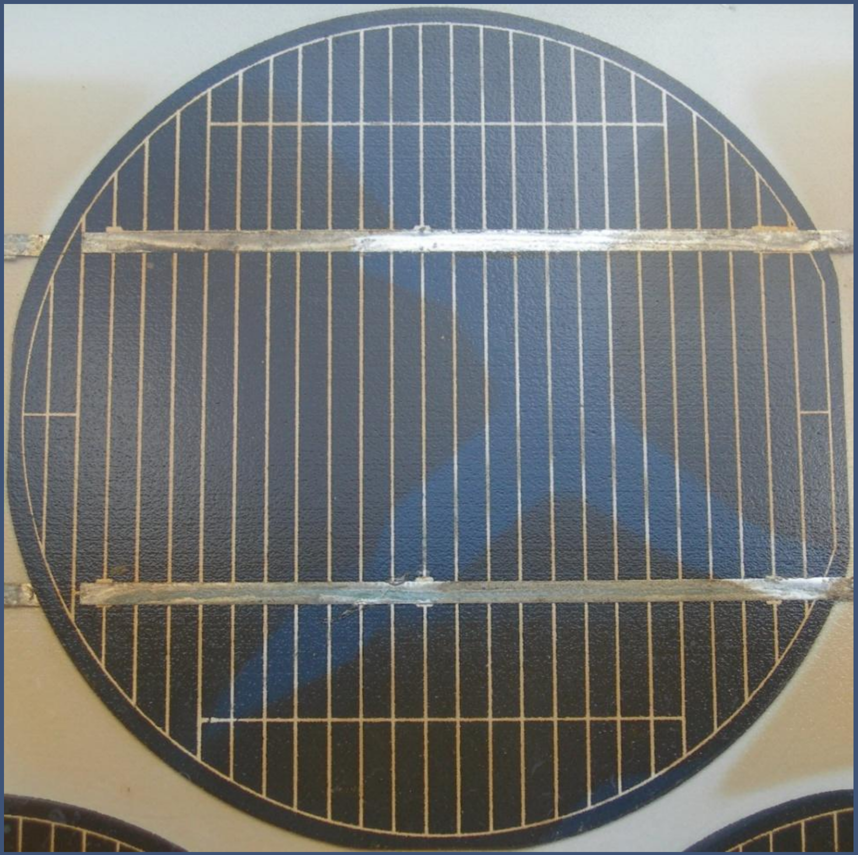
BP B 1233

EVA Discoloration – BP B 1233



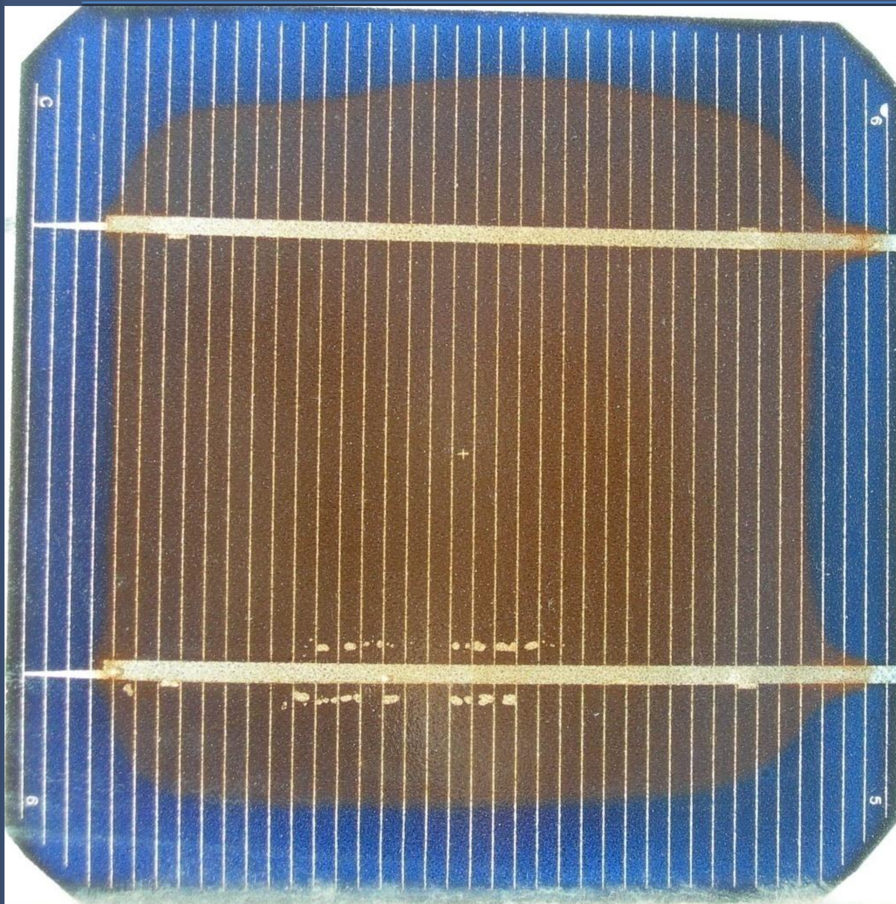
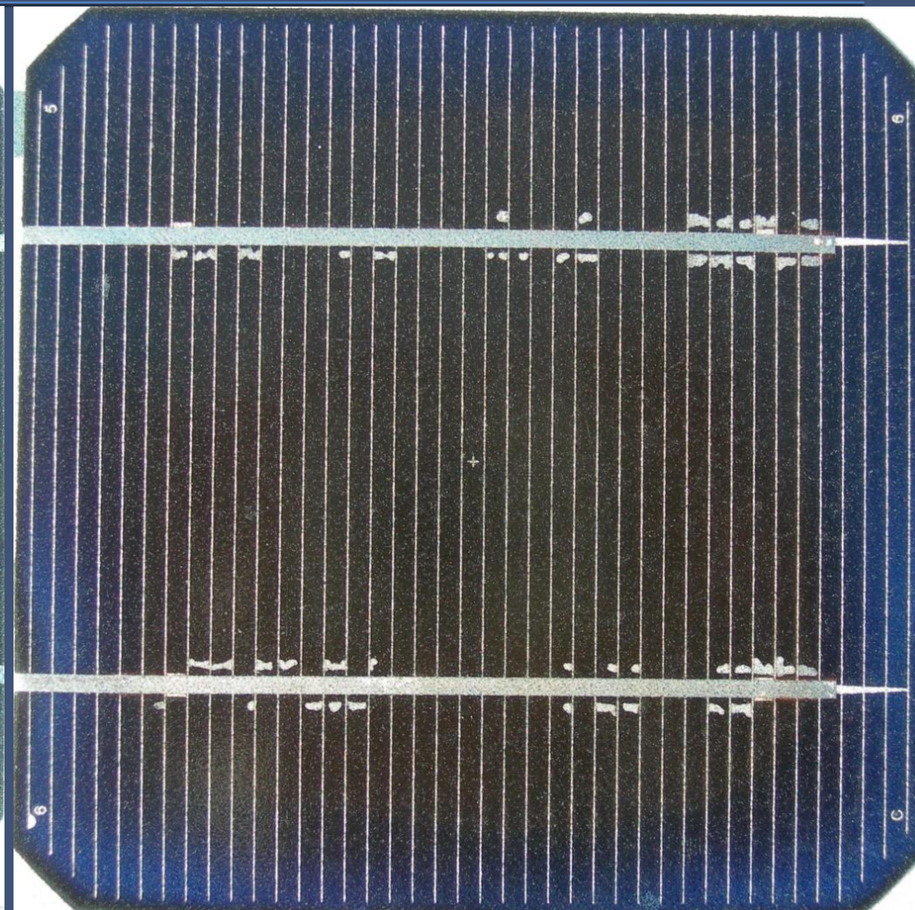
EVA Discoloration – BP 1233



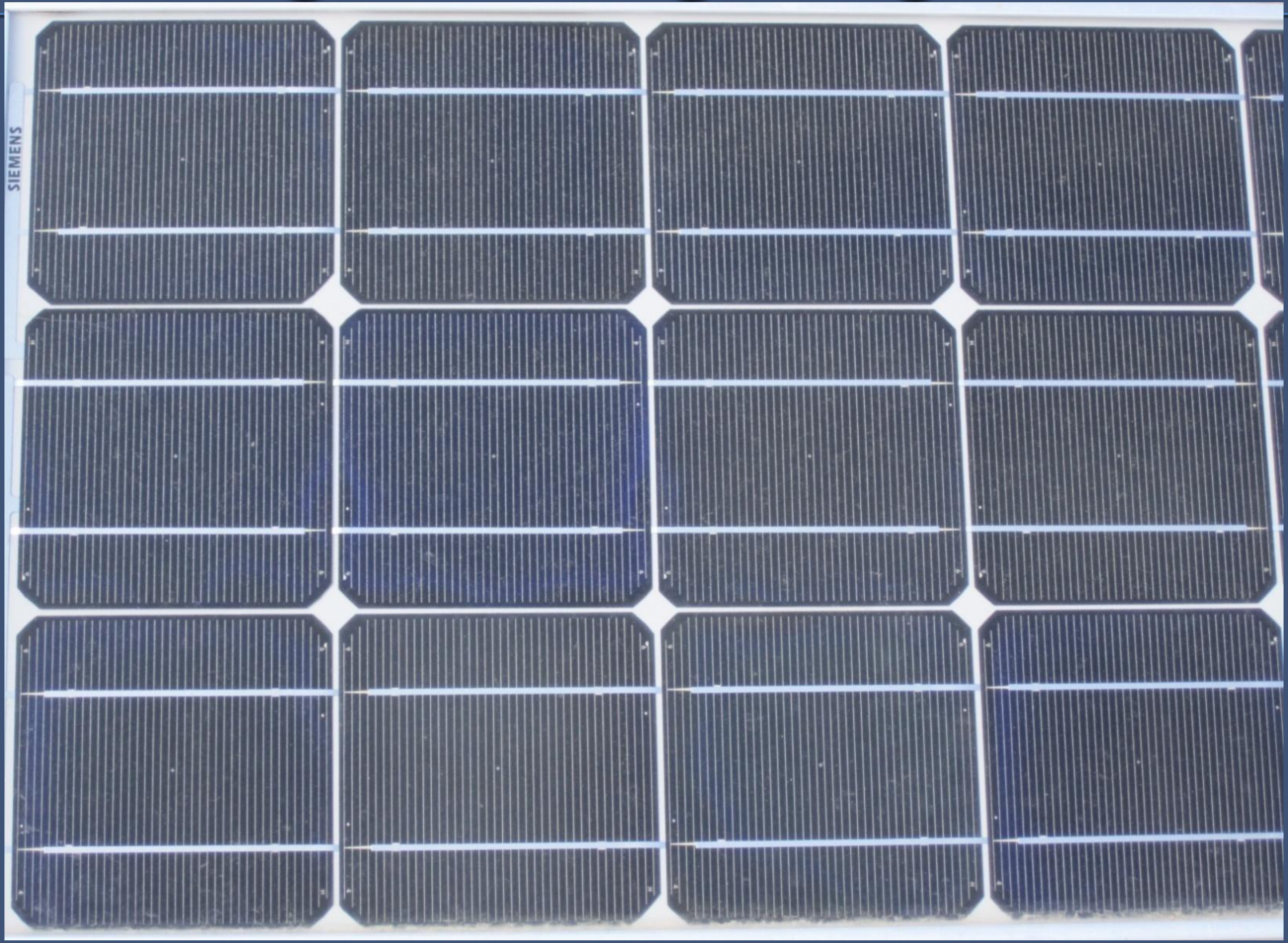


EVA Discoloration – M55

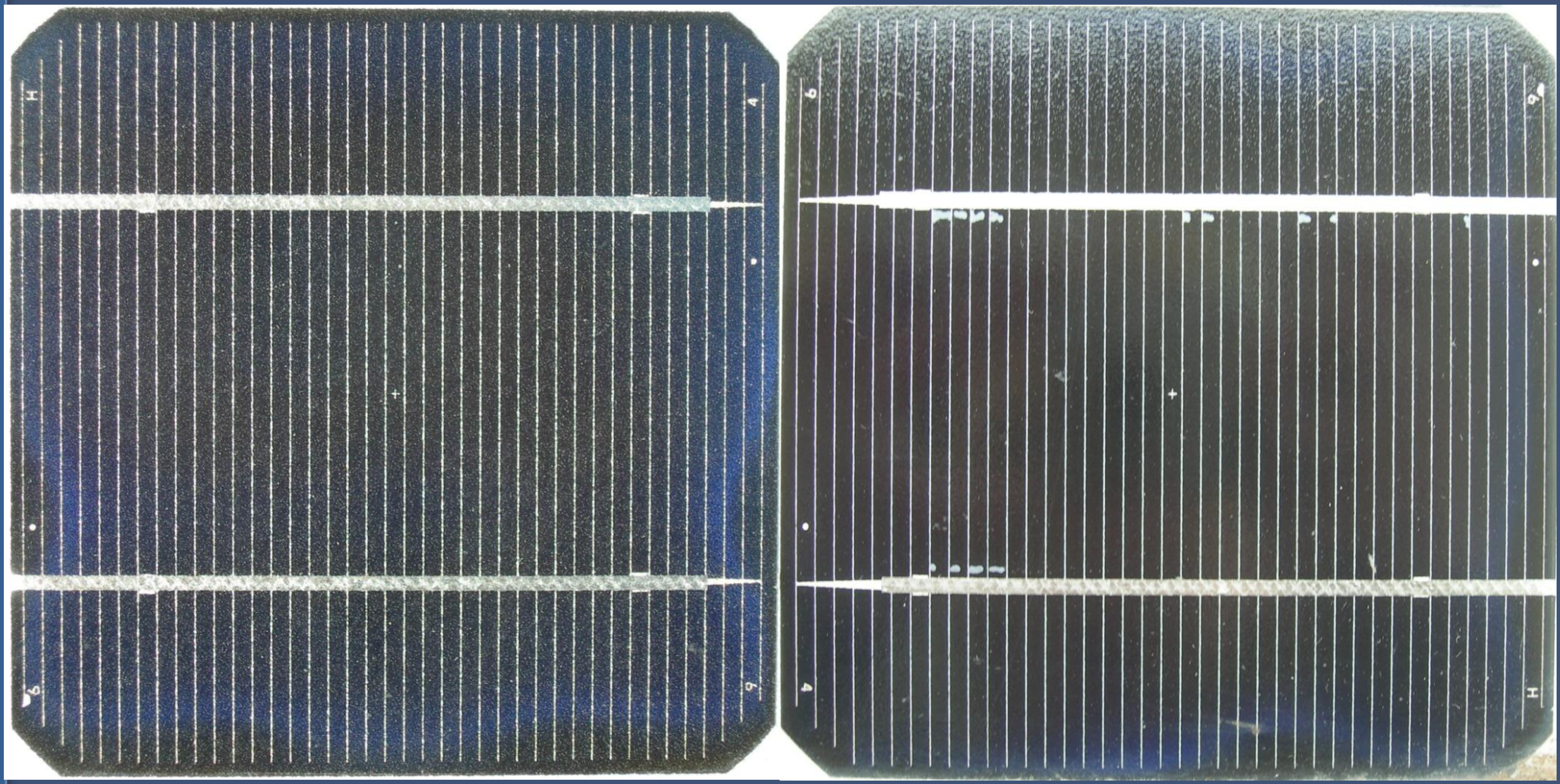
EVA Discoloration – M55

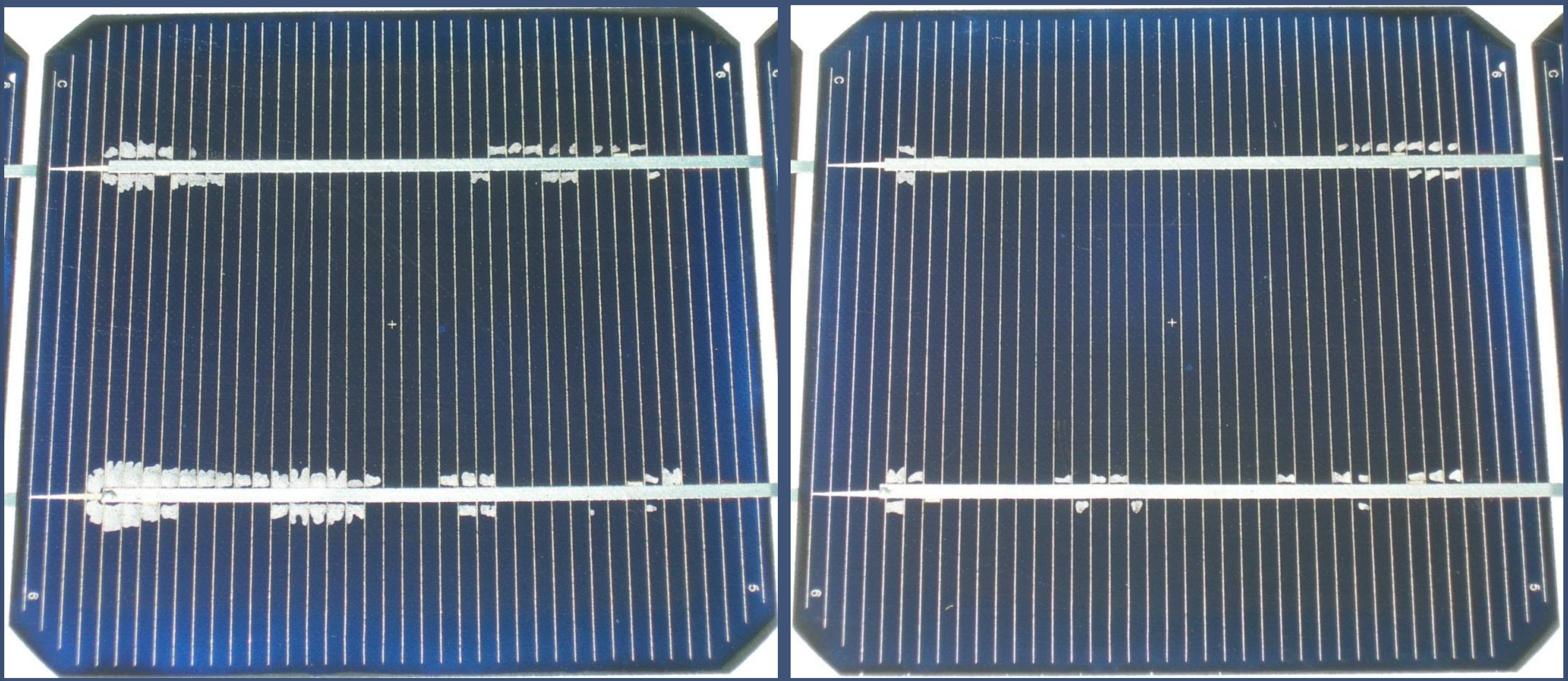
First signs of ageing – SM55



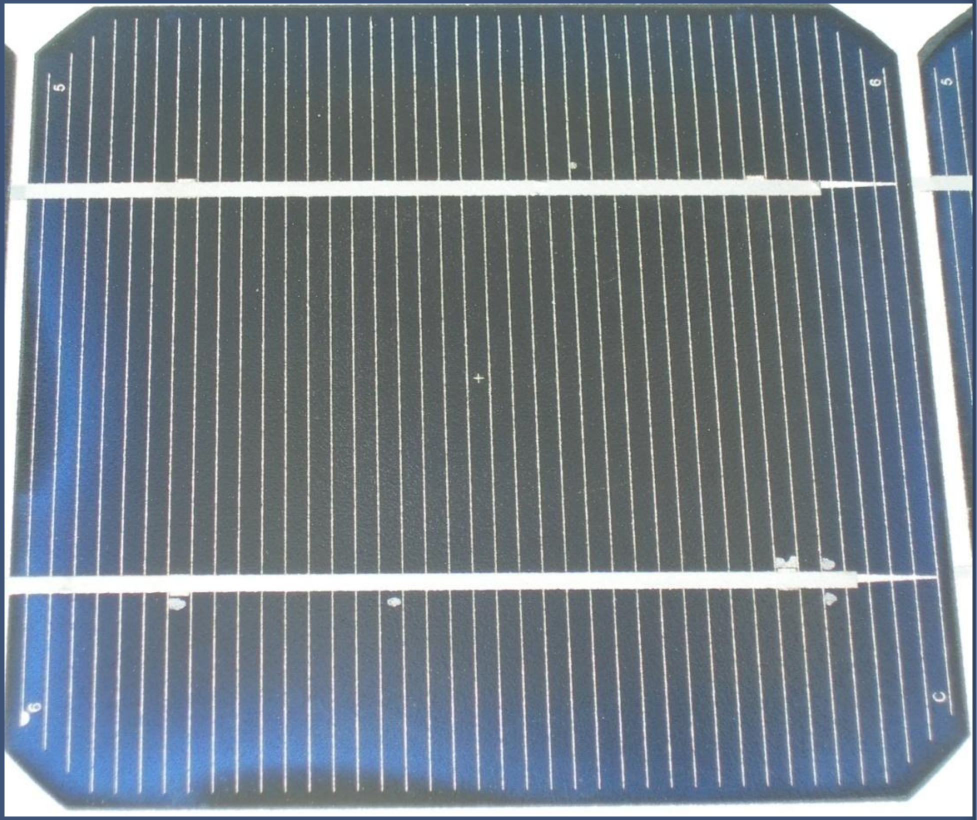
AR deterioration – SM55



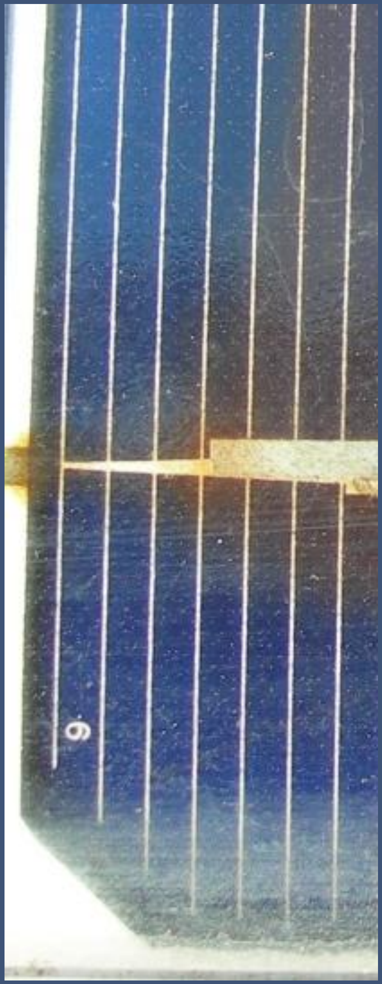
Delamination – M55

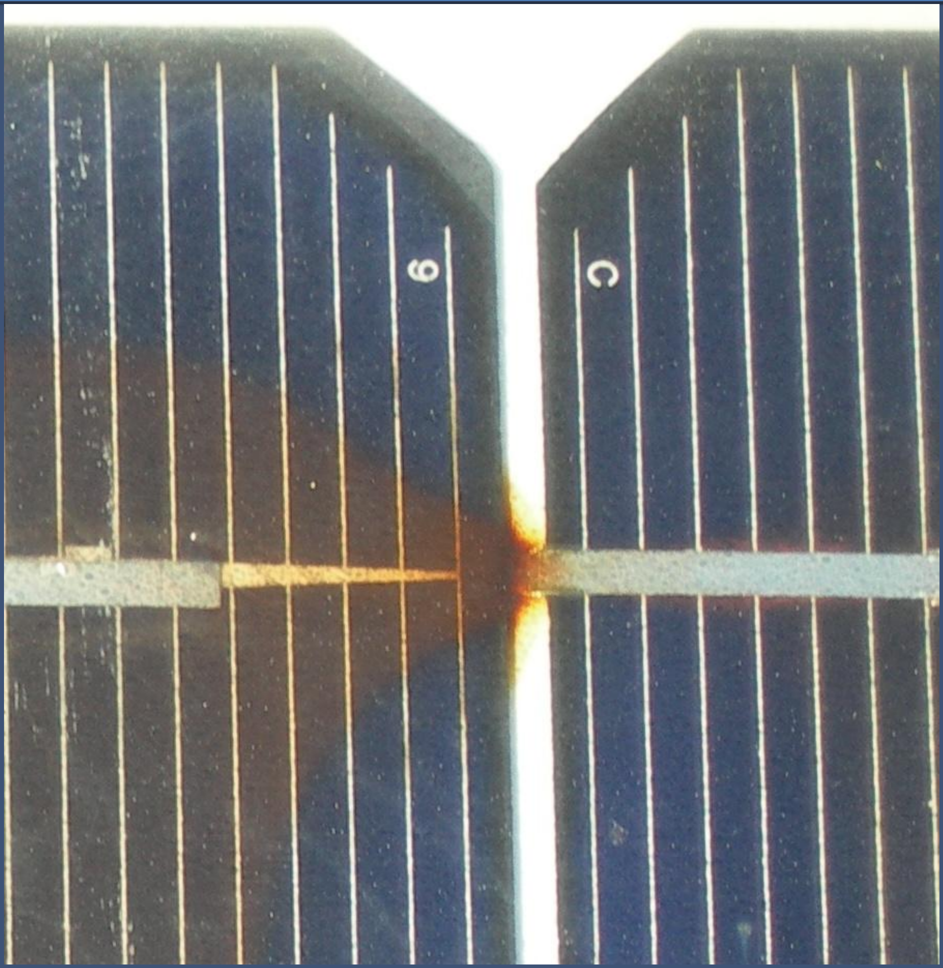


AR deterioration/oxidization – M55



Corrosion of contacts – M55





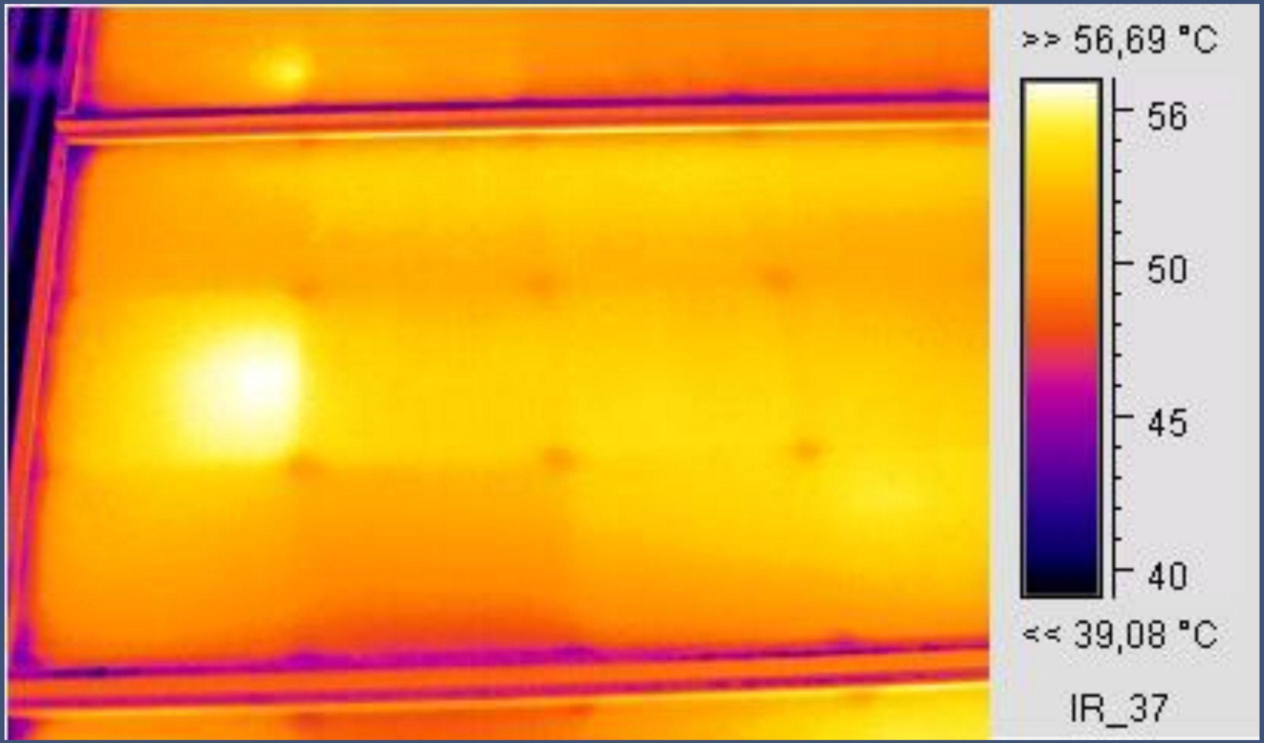
Damage in the back sealing – BP B 1233

Bubble formation – M55

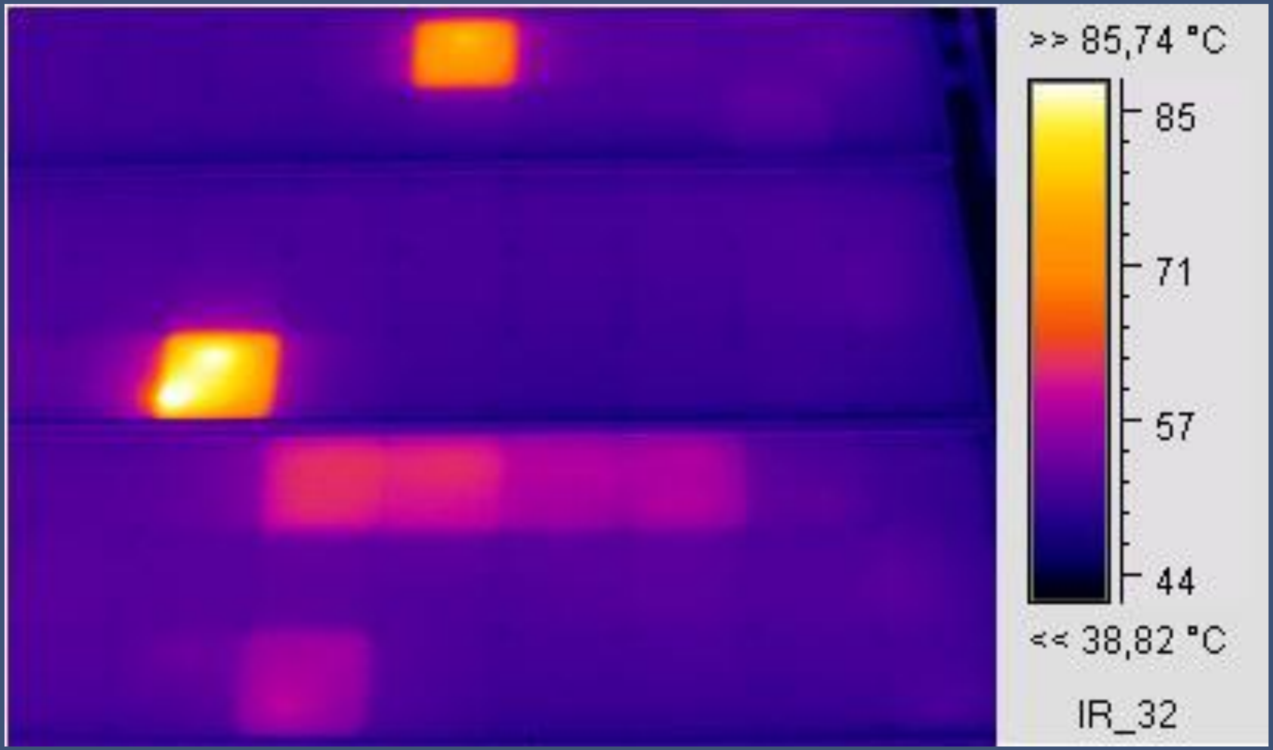
IR Thermography

- Temperature distribution on cells and modules
- Front and back of the module
- Hot spots/ hot areas
  - Junction box
  - Discolored cell areas
  - Bus bars

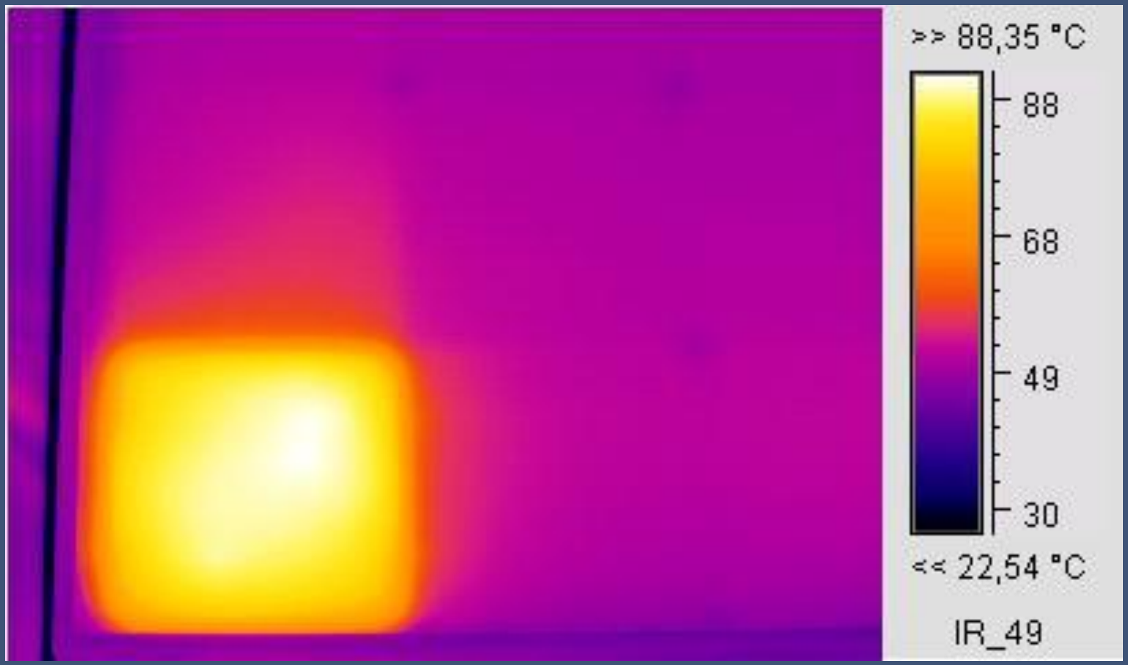
Junction box – M55



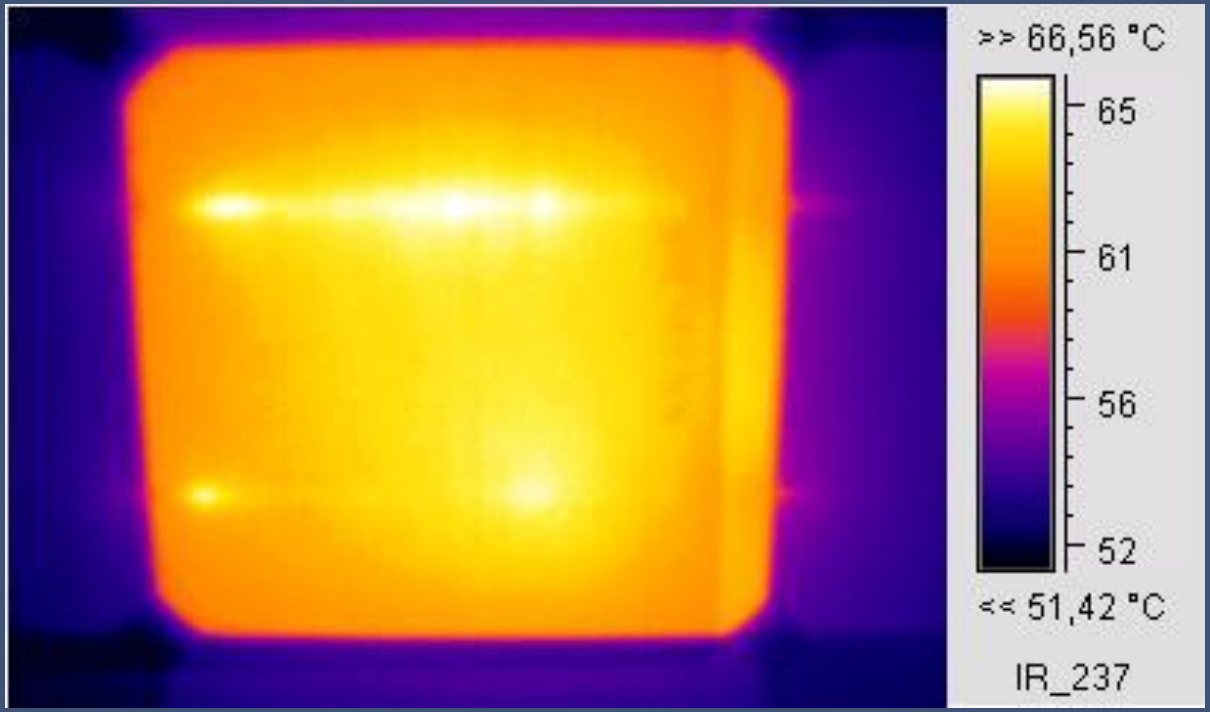
Hot spots/ hot areas – M55



Hot spots/ hot areas – M55



Hot zones at bus bars – M55

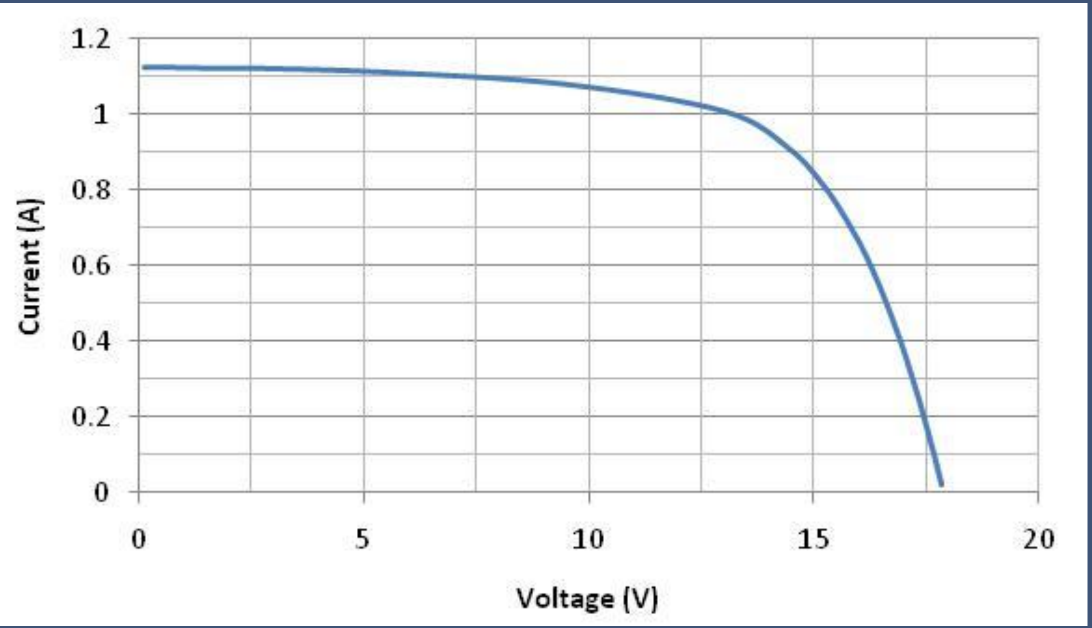


Performance Degradation

- Experimental results
  - Example: BP B 1233 and M55.
  - I-V curves obtained in field conditions
  - Recording the global and diffuse solar radiation, the cell temperature, and the ambient temperature.
  - Converting the electrical characteristics of the modules Isc, Voc, Pm, and FF to STC for comparison with the nominal values.

I-V curve analysis

- BP B 1233

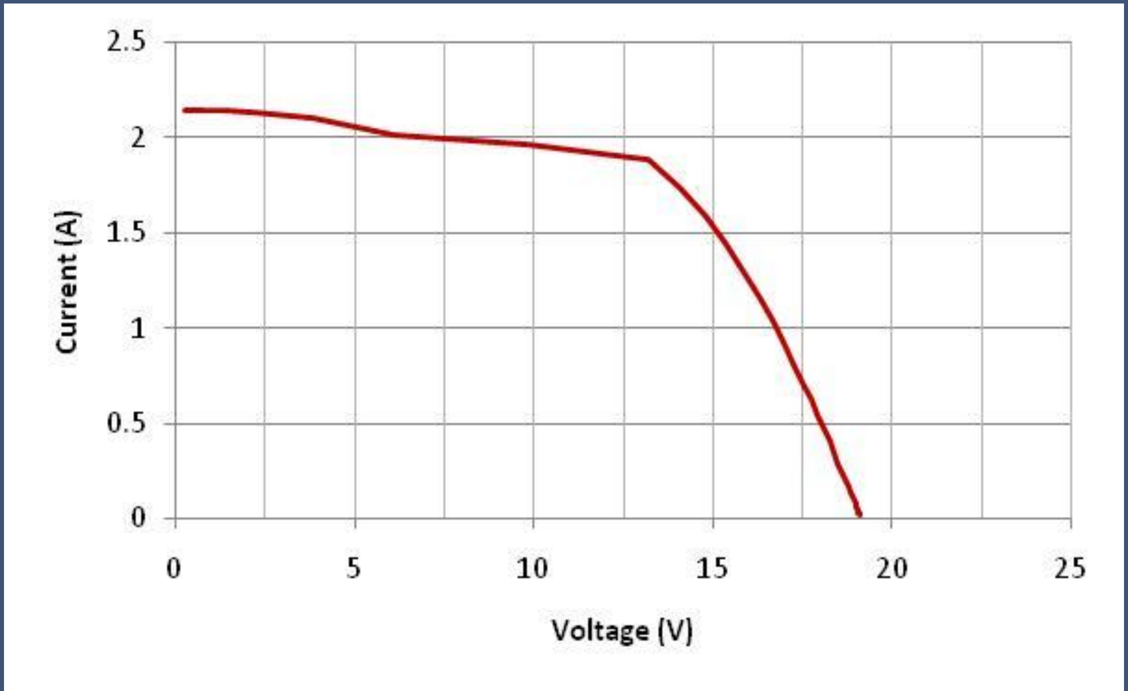


Nominal	BP B 1233
Isc	2.3
Voc	20
Pm	33
Im	2
Vm	16.5
FF	0.717

I_T=482.7 W/m^2, T_c=39.8°C

I-V curve analysis

- M55



Nominal	**M55**
Isc	3.35
Voc	21.7
Pm	53
Im	3.05
Vm	17.4
FF	0.729

I_T=617 W/m^2, T_c=47.8°C

PV module degradation

A measure of the mean PV module degradation:

$$\frac{P_m(STC) - P'_m(STC)}{P_m(STC)} \qquad \frac{FF(STC) - FF'(STC)}{FF(STC)}$$

module	$P_m(STC)$ Wp	$P'_m(STC)$ Wp	FF(STC)	$FF'(STC)$	$\frac{P_m(STC) - P'_m(STC)}{P_m(STC)}$	$\frac{FF(STC) - FF'(STC)}{FF(STC)}$
M55	53	44.56	0.729	0.619	15.9%	15.1%
BP B1233	33	29.67	0.717	0.666	10.1%	7.1%

Conclusions (1)

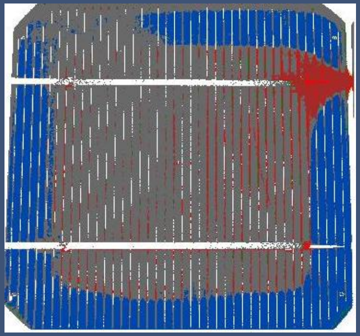
- PV ageing is a complex process being the result of independent and interrelated factors.
- Different ageing effects are observed between cells and modules, of different severity, and different stage of development.
- The ageing process seems to follow a geometric progression after the first stage of ageing.
- The overall power degradation for the naturally aged PV module of 22 years operation was estimated about 0.5% per year. For the naturally and induced aged PV module of 18 years operation was estimated about 0.9 per year.

Conclusions (2)

- The I-V curve analysis assists in the identification of the existence of critical defects in cell(s) in a module. It also provides an estimate of the performance degradation of the PV module $\delta Pm/Pm$, $\delta FF/FF$, Rs, Rsh.

- The IR thermography assists in the identification of the exact location and type of defect.

- Current work is involved in the identification of defects through digital image processing.



Related Work in the RES Lab, TEI of Patras

- E. Kaplani (2012). Detection of degradation effects in field-aged c-Si solar cells through IR thermography and digital image processing. *International Journal of Photoenergy*, Vol. 2012, Article ID 396792, pp.1-11.
- S. Kaplanis, E. Kaplani (2011). Energy performance and degradation over 20 years performance of BP c-Si PV modules. *Simulation Modelling Practice and Theory*, Vol. 19, pp. 1201-11.
- E. Kaplani, S. Kaplanis (2012). PV ageing effects and performance degradation of c-Si PV cells. Proc. 6th Int. Workshop on Teaching in Photovoltaics (IWTPV'12), 22-23 March, Prague, Czech Republic.
- E. Kaplani, S. Kaplanis (2012). Temperature distribution effects in PV modules operating in field conditions. Proc. 5th Int. Conf. on Sustainable Energy & Environmental Protection (SEEP 2012), 5-8 June, Dublin, pp.256-261.

Acknowledgements

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