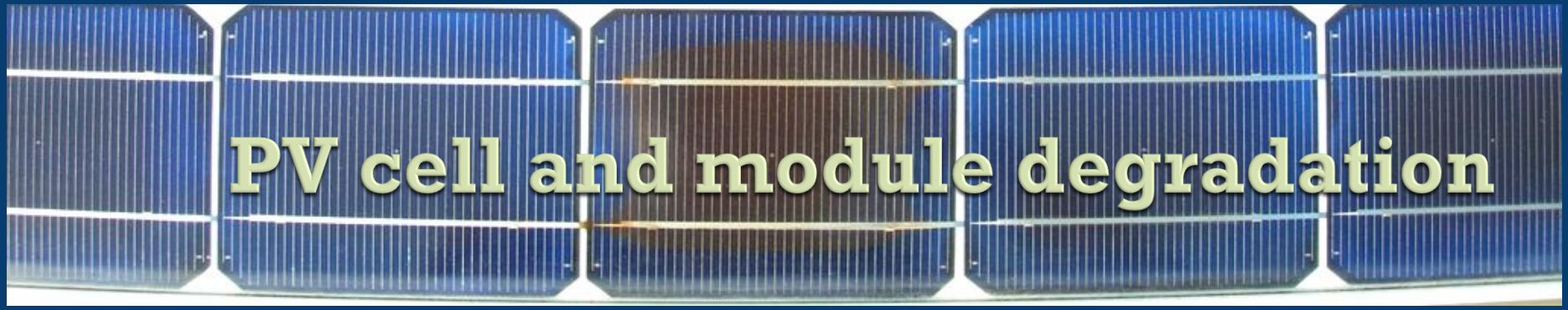
Innovation Week on "PV Systems Engineering and the other Renewable Energy Systems".

1- 10 July 2013, Patras, Greece



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Outline

- Introduction to ageing factors and ageing effects
- Ageing effects in sc-Si PV modules operating in field conditions for 13,18, 22 years
- Identification of degradation effects:
  - 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 droppings

Partial Shading → Short / Long Term Degradation

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

Discoloration

Humidity Ingress

→ Long Term Optical & Physical degradation

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
- Degradation of the AR coating
- Degradation of the cell-encapsulant interface
- High conductivity paths (shunts)
- Humidity ingress
- Hot spots/ hot areas
- Cracks, tears in the back sealing
- Bubbles
- Corrosion in bus bars and contacts

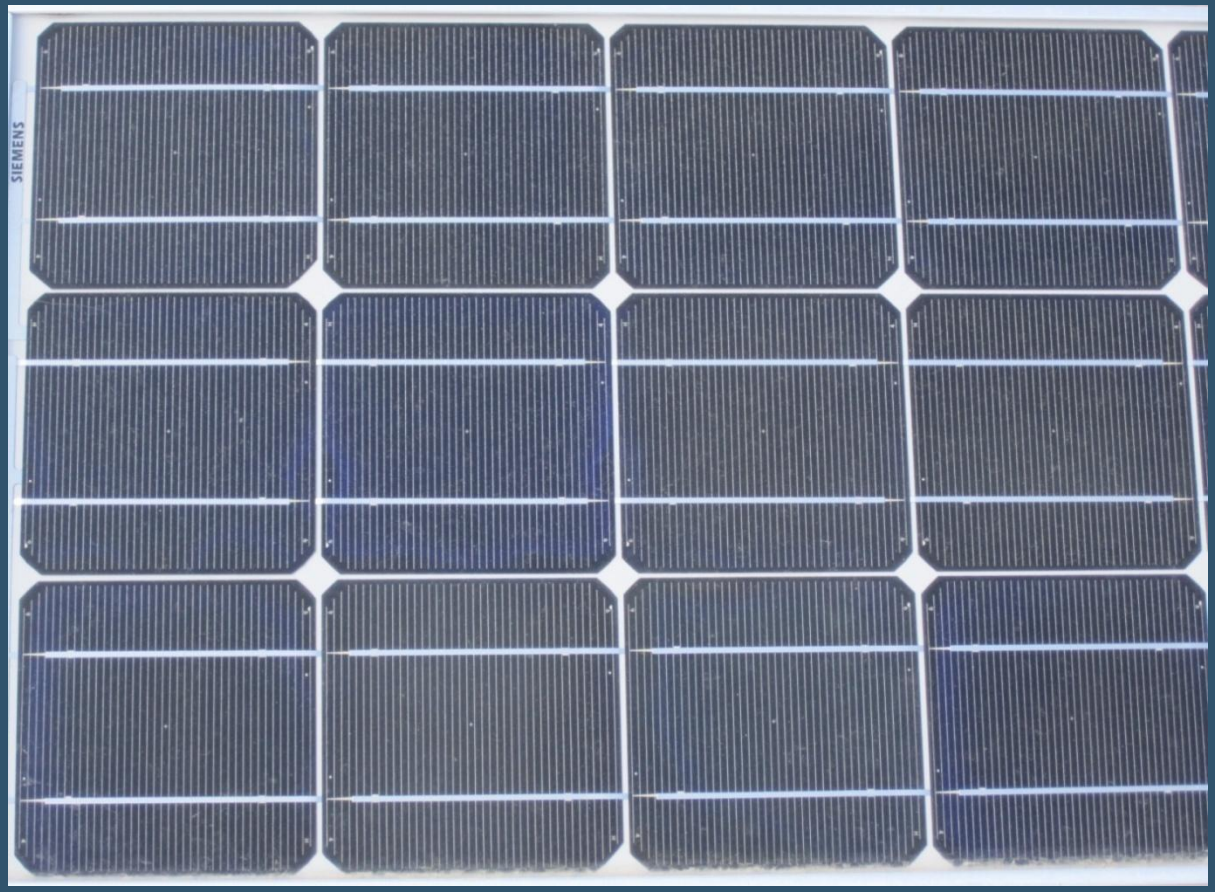
Identification of cell and module degradation

- Visual Inspection
  - visual observation/ digital image
- IR thermography
  - Identification of hot spots and hot cells
- I-V curve analysis & electrical characteristics, Isc, Voc, Pm

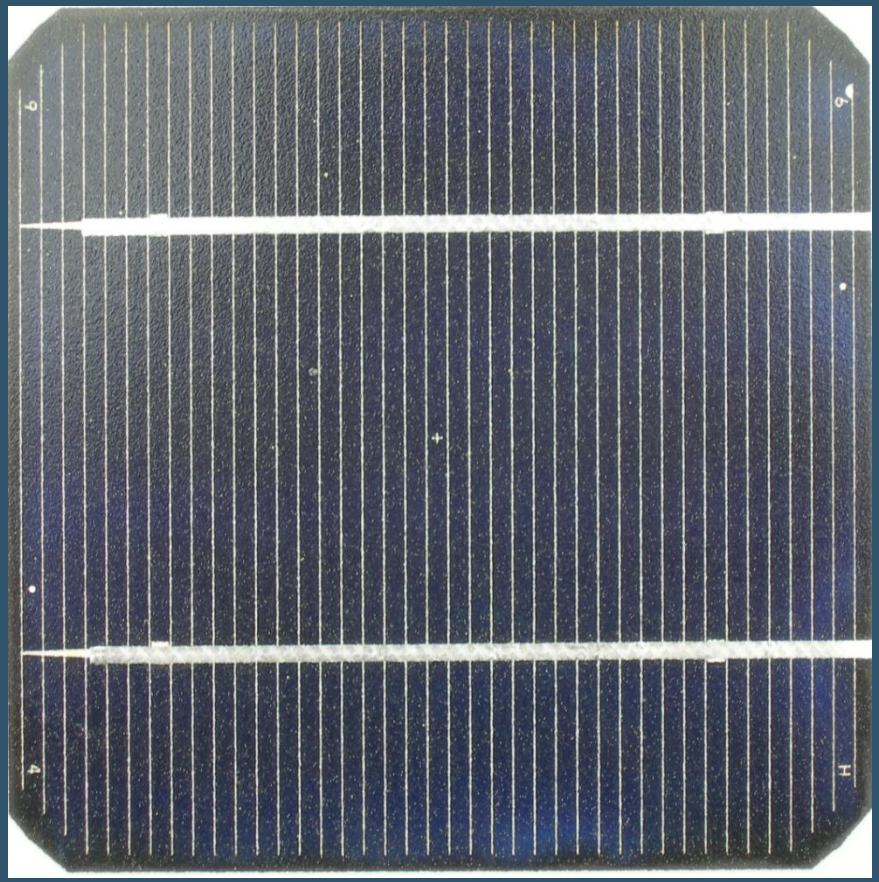
Visual Inspection

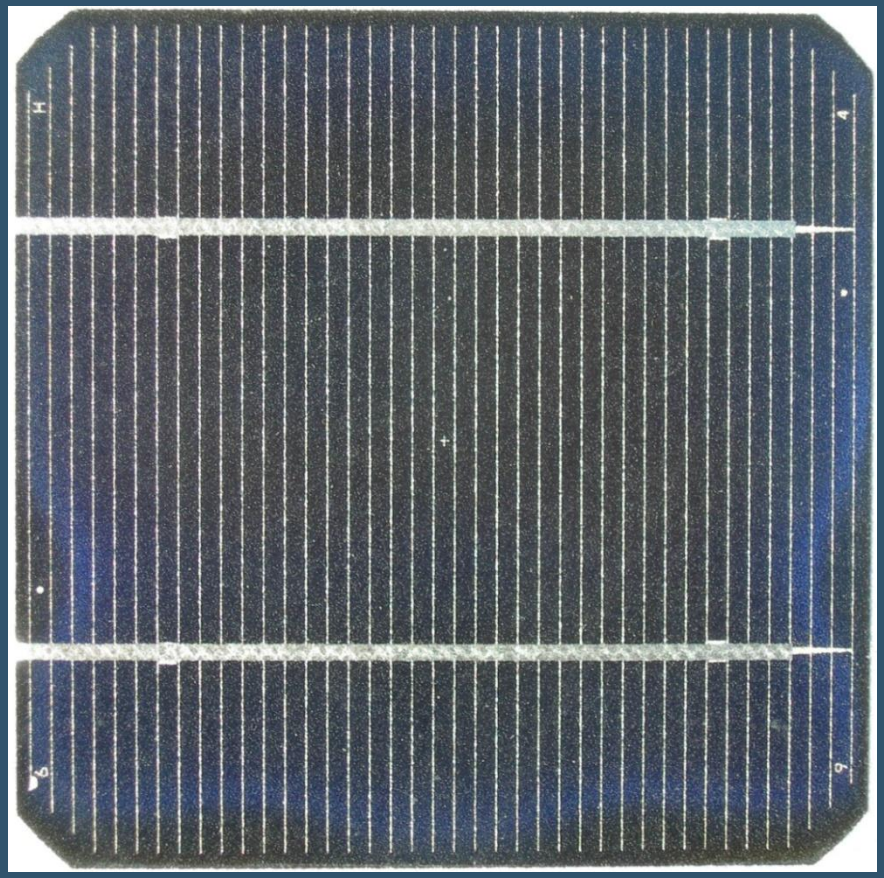
- EVA Discoloration
  - Location => central region of the cell
  - Shape => circular, square, patches, other shapes
  - Severity of Browning
    - Different degrees, from golden brown to dark brown
  - Differs between cells of the same module, and between modules
  - Acceleration of browning in surface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

First signs of natural ageing in 13 year old PV module

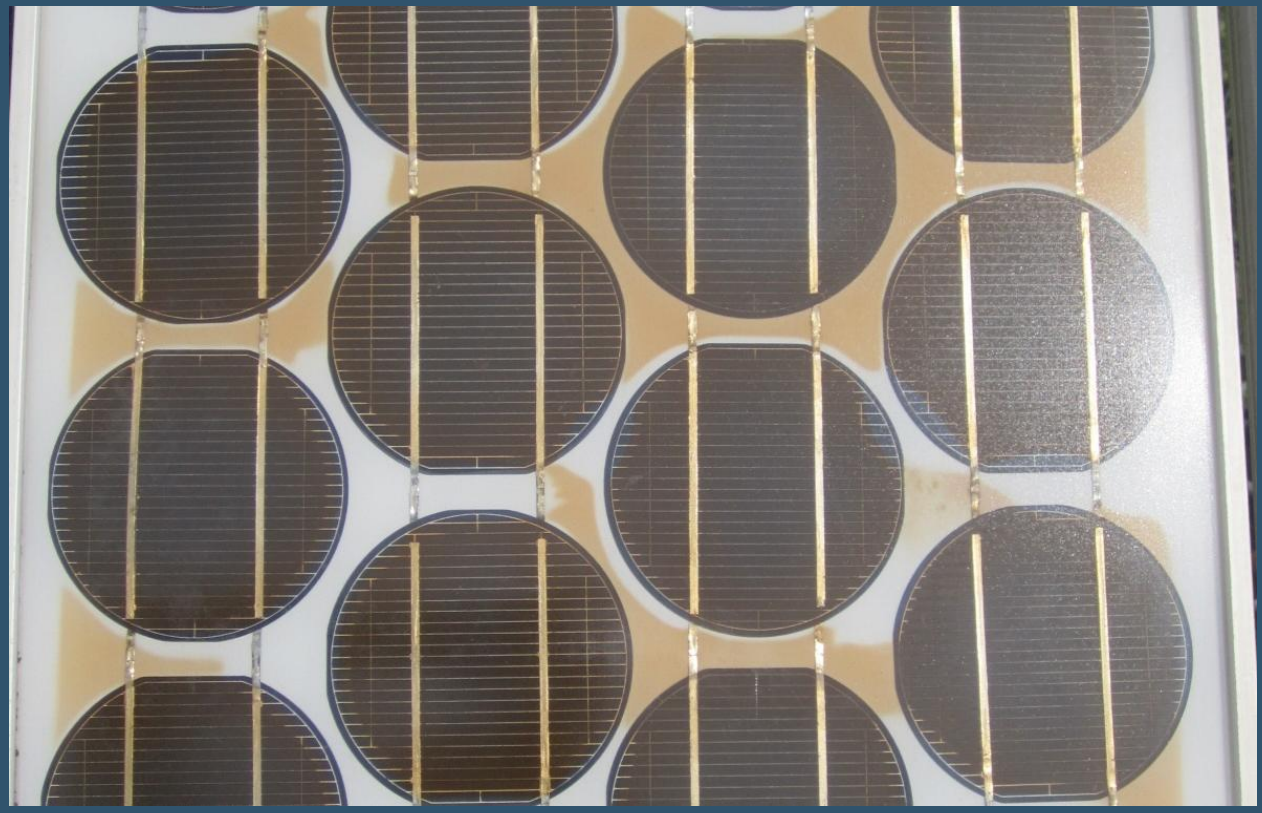


Degradation of the AR coating

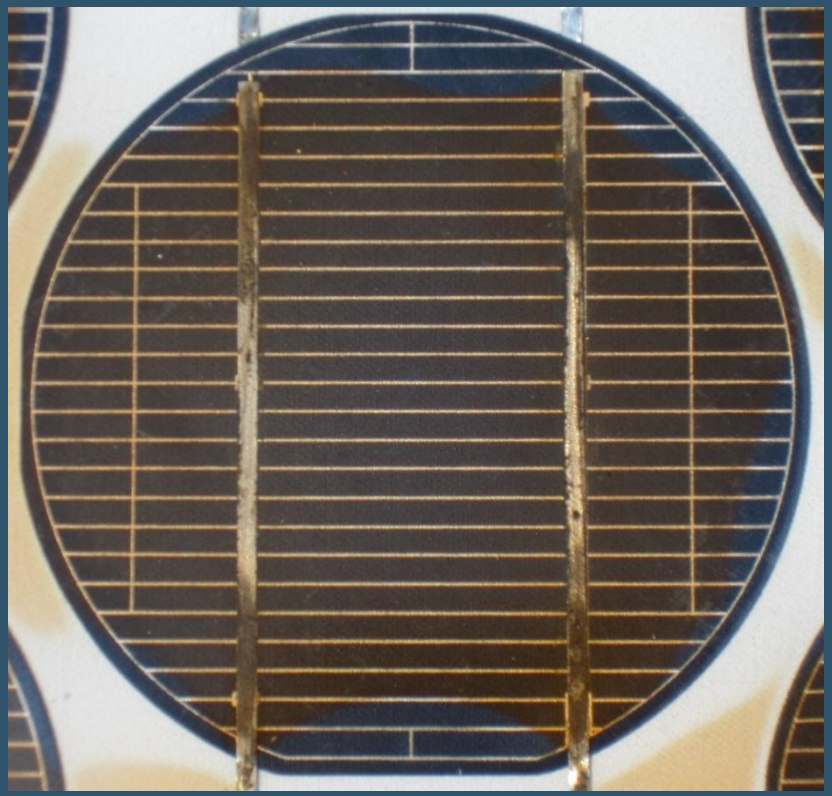


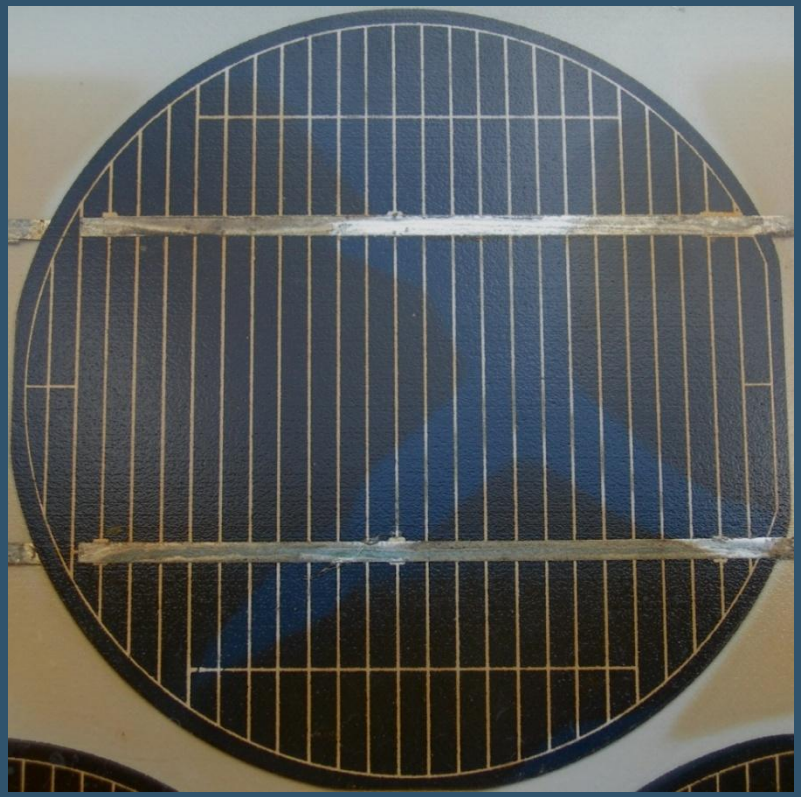


Natural degradation in 22 year old PV module



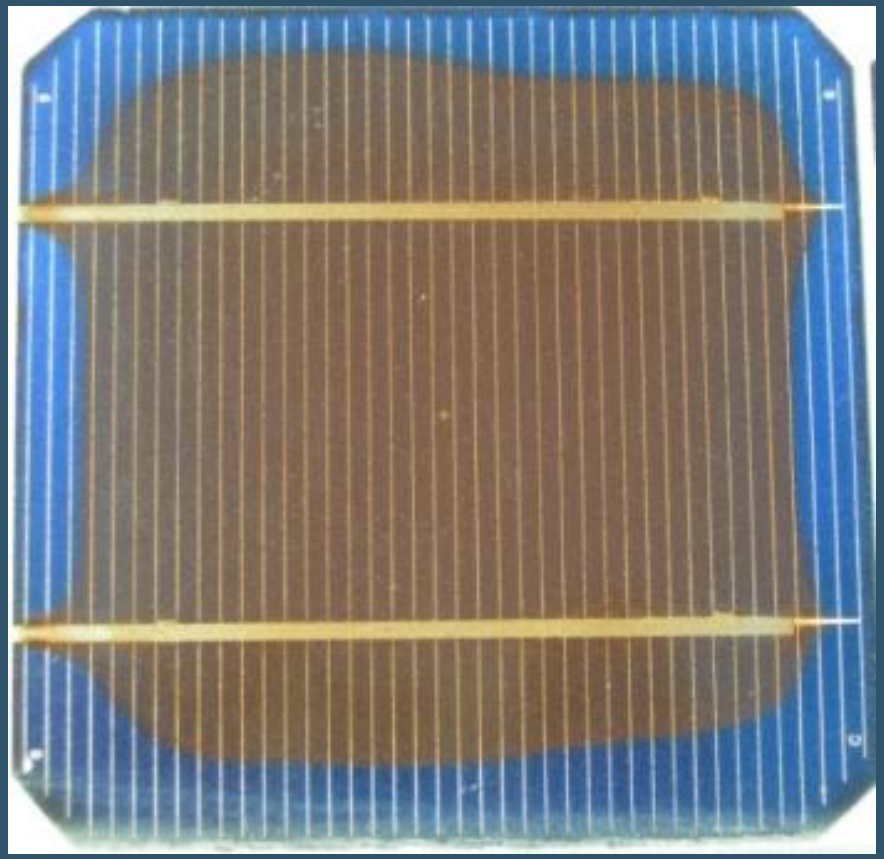
EVA Discoloration

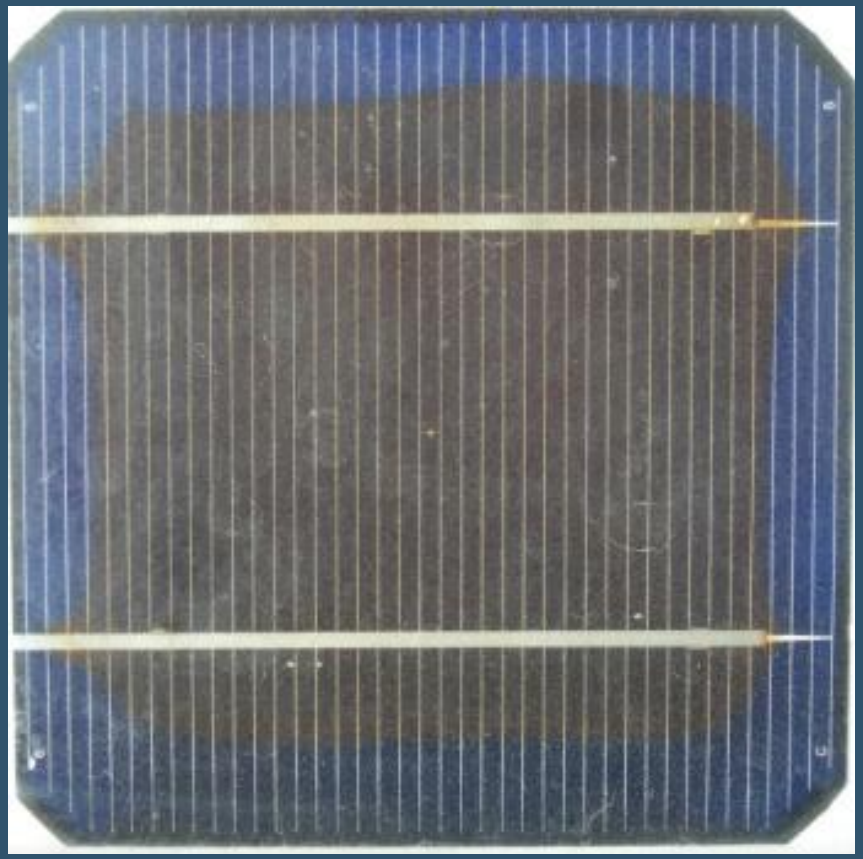




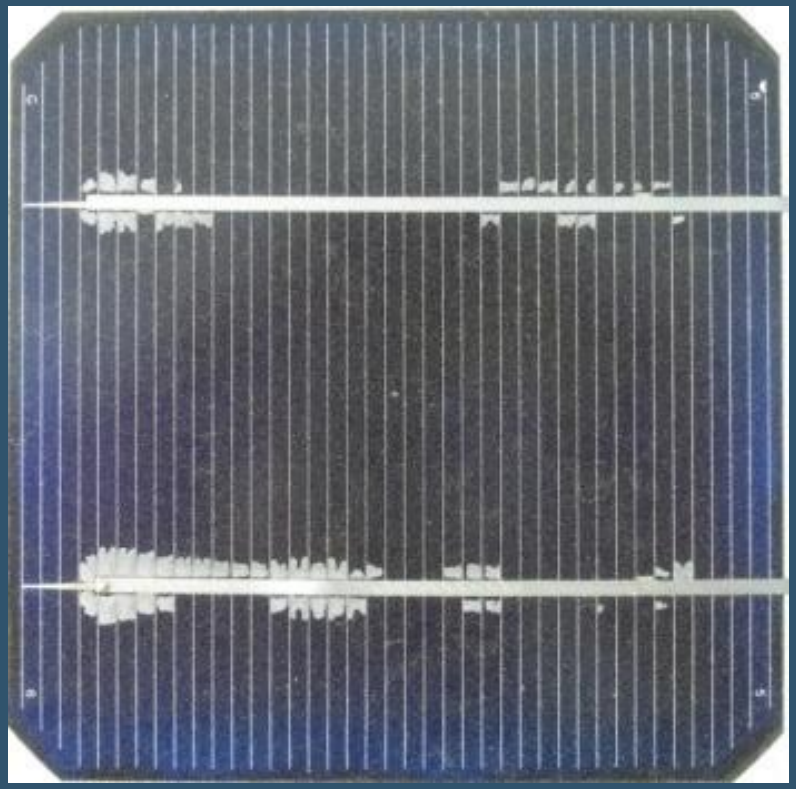
Induced degradation of PV module

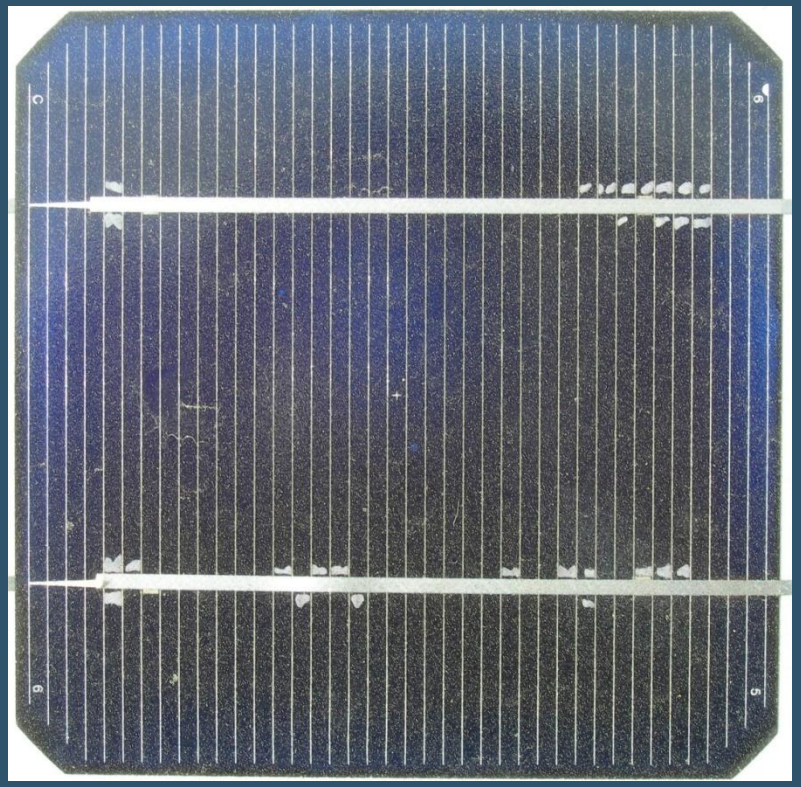
EVA Discoloration



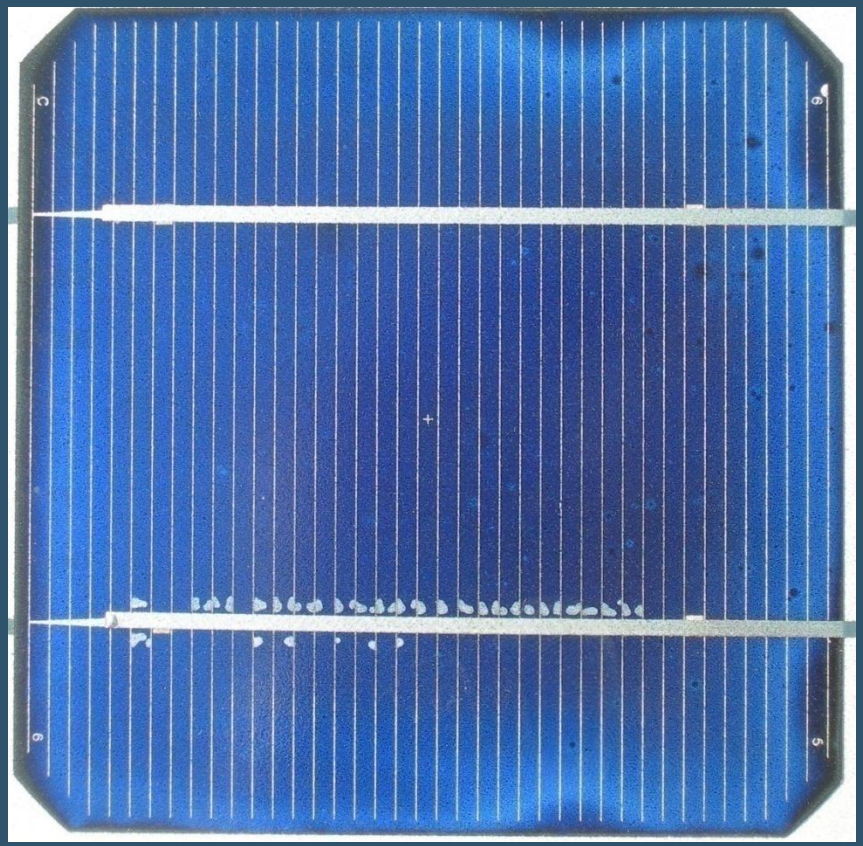


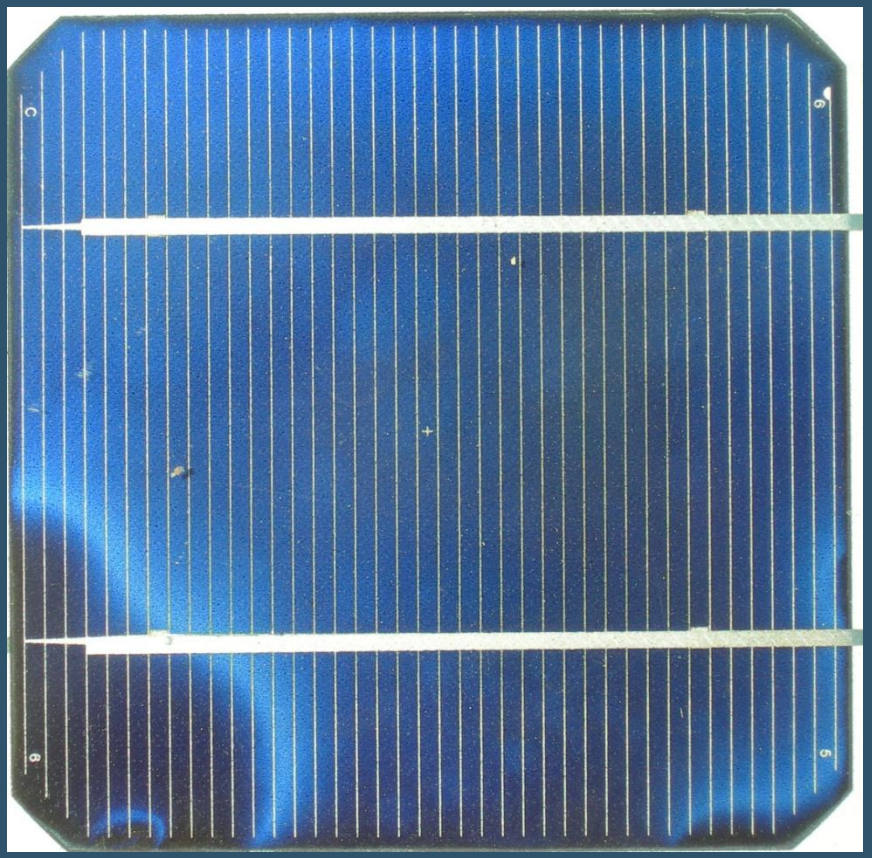
Degradation of the cell-encapsulant interface



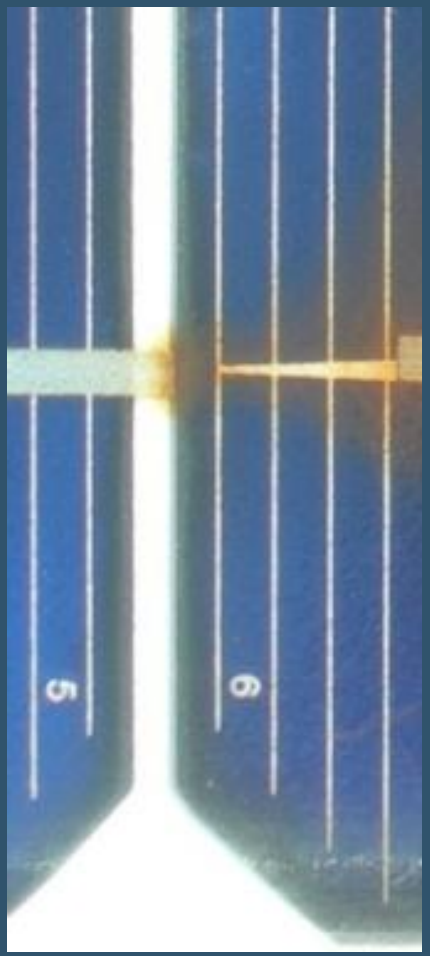


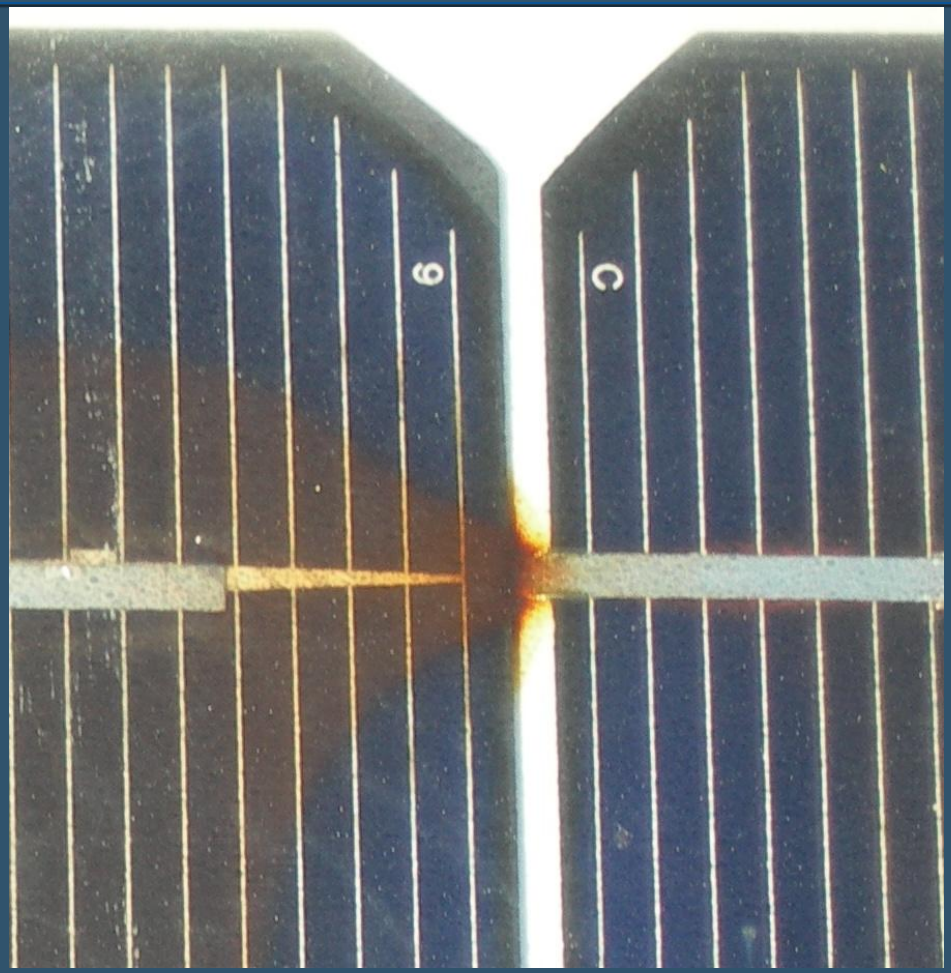
Degradation of the AR coating





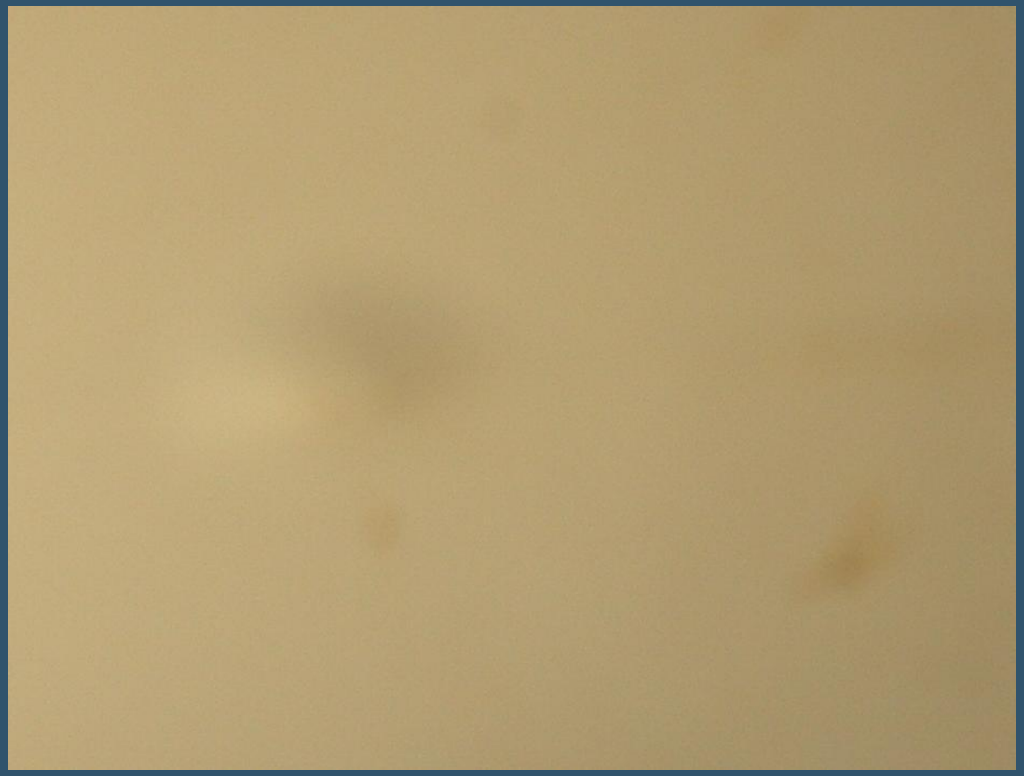
Corrosion of busbars and contacts





Damage in the back sealing

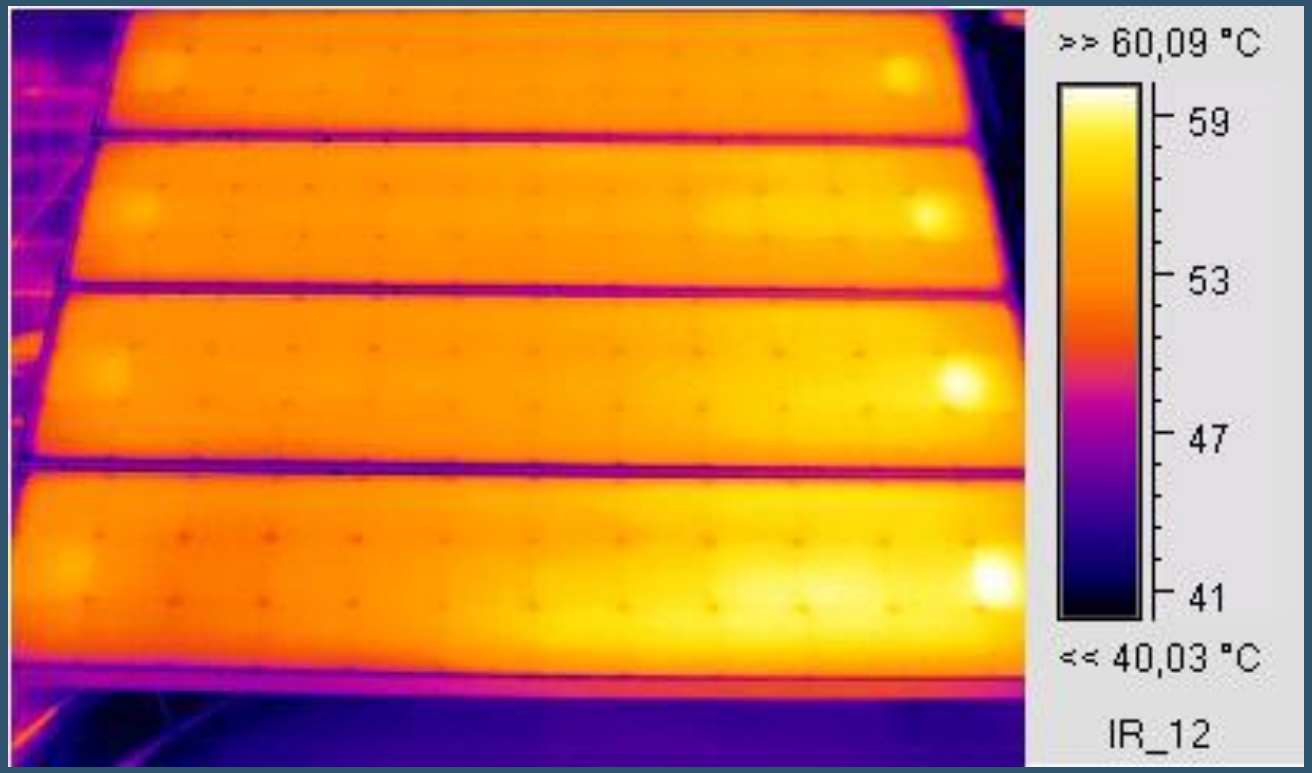
Bubble formation



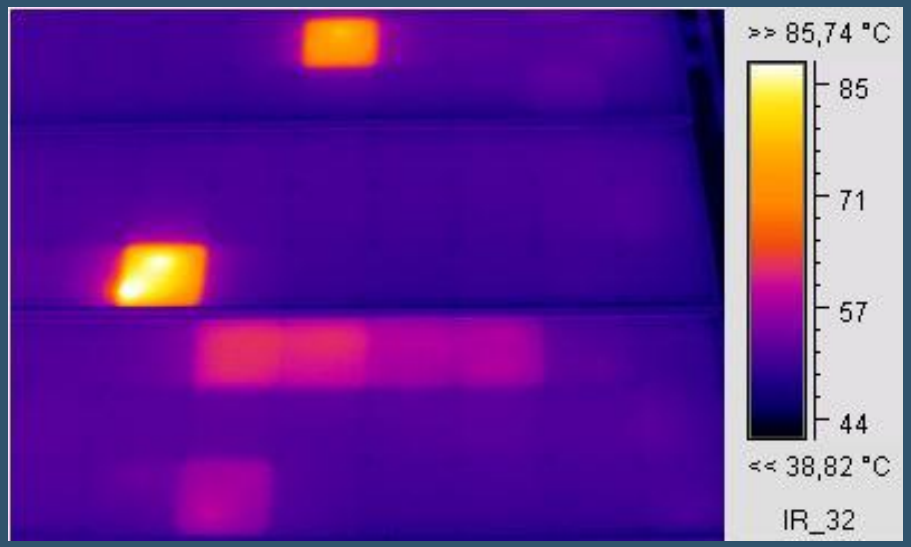
IR Thermography

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

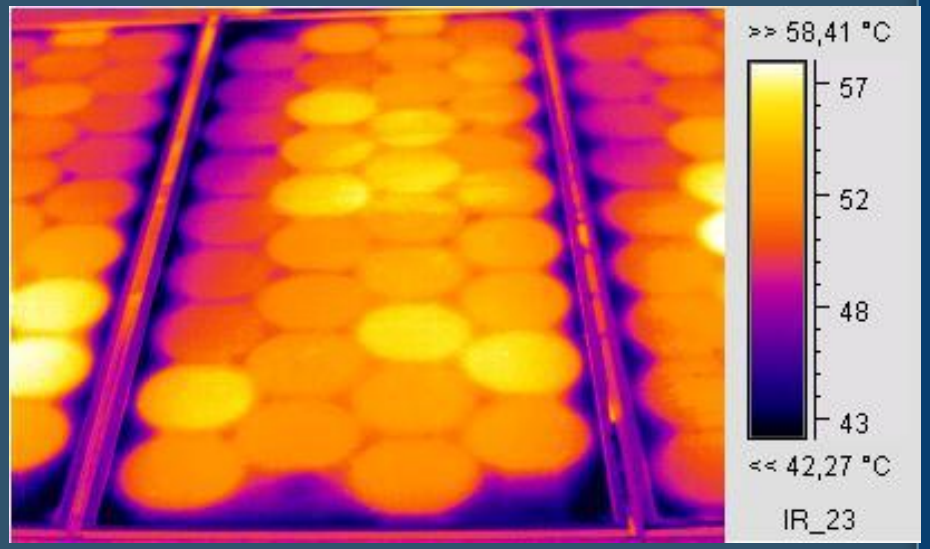
Increased temperature at junction box



Hot spots/ areas in PV modules

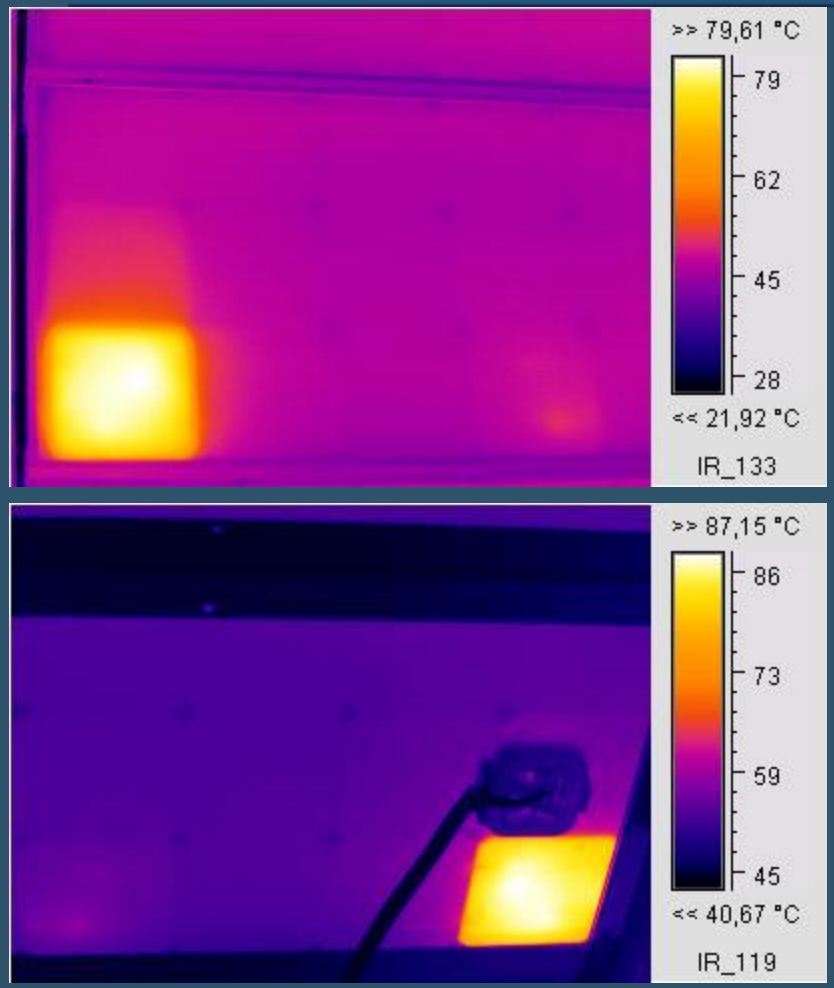


Induced ageing



Natural ageing

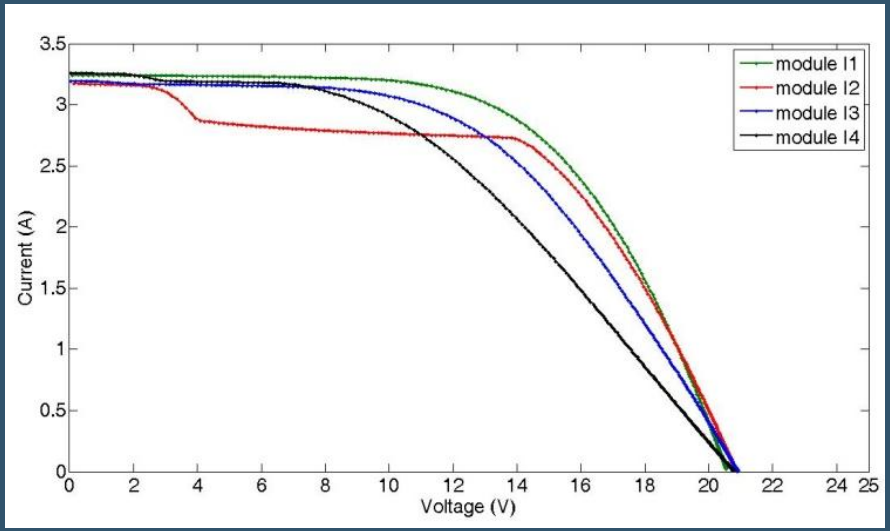
Hot spots/ hot areas/ hot zones at busbars

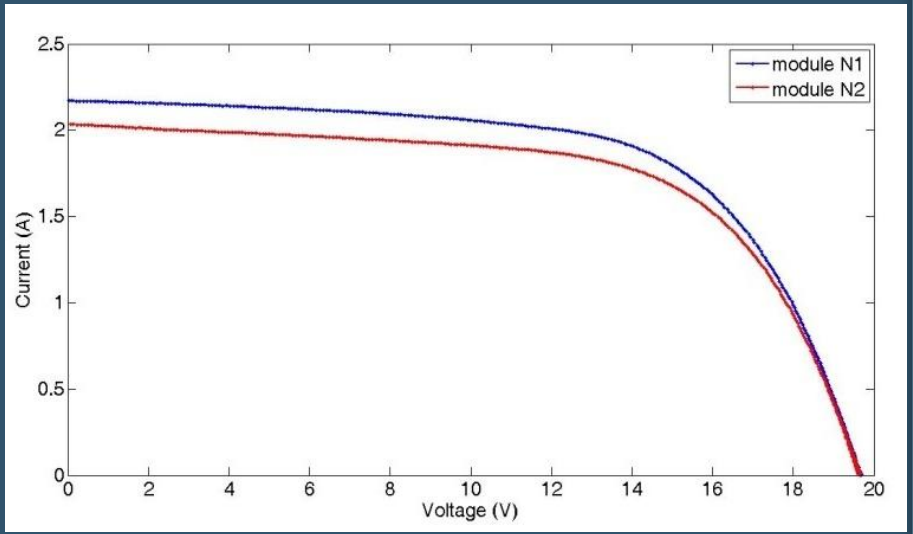


Performance Degradation

- Electrical characteristics.
  Isc, Voc, Pm, and FF converted to STC for comparison with the nominal values.
- I-V curve analysis.
  I-V obtained in field conditions
- Performance comparison for PV modules with different type and degree of ageing.

I-V curve analysis





Normalized I-V curves of modules with different ageing effects (induced and natural)

E. Kaplani (2012). Degradation Effects in sc-Si PV modules subjected to natural and induced ageing after several years of field operation. Journal of Engineering Science and Technology Review, Vol. 5(4), pp. 18-23.

A measure of PV module degradation

Indicative Results:

Relative change in Pm and FF: $\frac{P_m(STC) - P'_m(STC)}{P_m(STC)}$ $\frac{FF(STC) - FF'(STC)}{FF(STC)}$

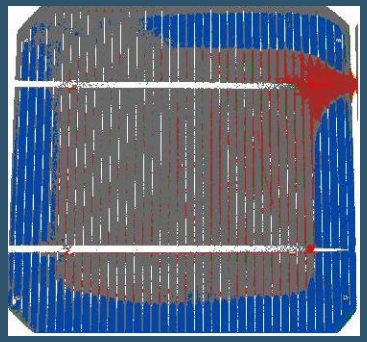
ageing	Relative change in Pm %	Relative change in FF %
natural 22 years	18-24	12
induced 18 years	24-42	17-38

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.
- Milder degradation effects in naturally aged PV modules than that of younger modules subjected to induced ageing.

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 R.E.S. Laboratory

- E. Kaplani (2012). Degradation Effects in sc-Si PV modules subjected to natural and induced ageing after several years of field operation. Journal of Engineering Science and Technology Review, Vol. 5(4),pp.18-23.
- 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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