## Characterization

**Solar cell/modules characterization**

- Spectral response
- IV curve

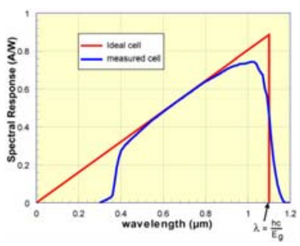
**Other relevant tests**

- Degradation/ageing
- Reflectance
- Lifetime
- Infrared mapping

## Characterization

Solar cell/modules characterization

- **Spectral response**




## Characterization

Solar cell/modules characterization

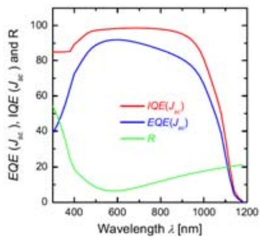
- Spectral response (SR) is the short circuit current produced by the cell when illuminated by a given power
- External quantum efficiency (EQE) is the probability of a incident photon contributing to one electron to the short circuit current
- Internal quantum efficiency (IQE) is the probability of a absorbed photon contributing to one electron to the short circuit current

$$SR(\lambda)=\frac{I_{sc}}{P_{opt}} \qquad SR(\lambda)=\frac{q\lambda}{hc}EQE \qquad IQE=\frac{EQE}{1-R(\lambda)}$$

# Characterization

Solar cell/modules characterization

- Spectral response

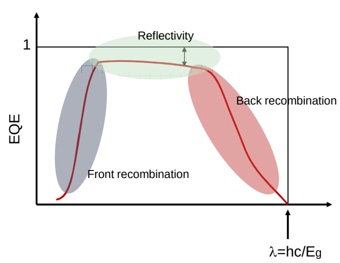



H. Mackel, *Capturing the spectra of solar cells*, PhD Thesis, Australian National University, 2004

# Characterization

Solar cell/modules characterization

- Spectral response




# Characterization

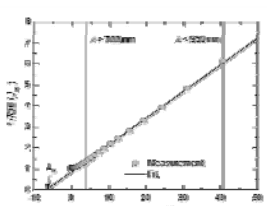
Solar cell/modules characterization

- Spectral response

**Determination of diffusion length:**
if $\alpha^{-1} << t$ and $L << t$ then, it can be shown that, for 800-1100nm:

$$\frac{1}{IQE} = 1 + \frac{1}{\alpha L}$$

and thus $L$ can be extracted from plot IQE vs $\alpha^{-1}$

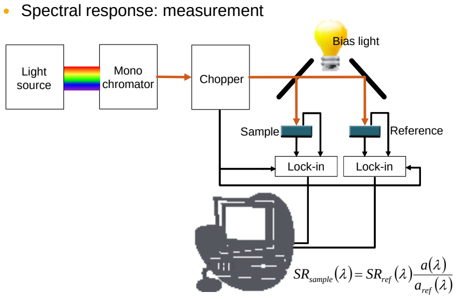


H. Mackel, *Capturing the spectra of solar cells*, PhD Thesis, Australian National University, 2004

## Characterization

Solar cell/modules characterization

- Spectral response: measurement

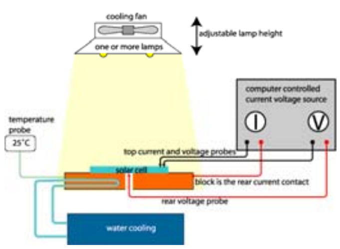



$$SR_{sample}(\lambda) = SR_{ref}(\lambda)\frac{a(\lambda)}{a_{ref}(\lambda)}$$

## Characterization

Solar cell/modules characterization

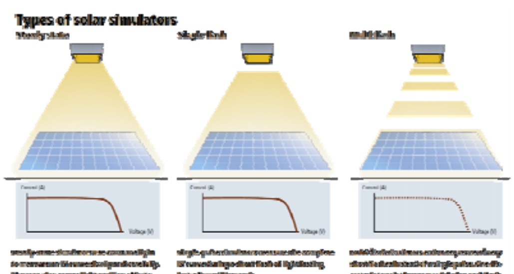
- **IV curve**




## Characterization

Solar cell/modules characterization

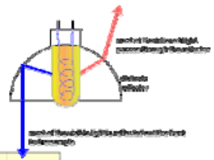
- IV curve

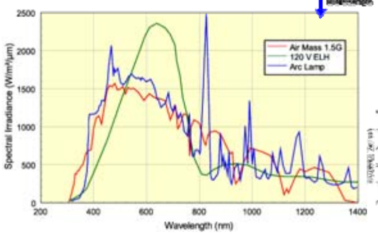


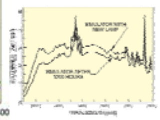
## Characterization

Solar cell/modules characterization

- IV curve





## Characterization

Solar cell/modules characterization

- IV curve: use callibration cell with same spectral response

or, if one knows spectral response of sample and reference cell and spectral irradiance of solar simulator, one may calculate the mismatch error:

- C.H. Seaman, *Calibration of Solar Cells by the Reference Cell Method - The Spectral Mismatch Problem*, Solar Energy, vol. 29, No. 4, 1982, pp. 291-298

## Characterization

Solar cell/modules characterization

- IV curve

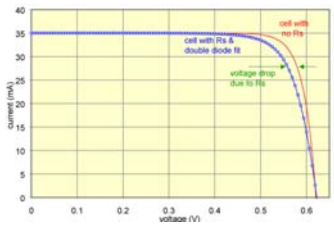
**IEC 904-9**: Requirements for solar simulators for crystalline Si single-junction devices

| | Class A | Class B | Class C |
|---|---|---|---|
| Spectral match | 0.75 – 1.25% | 0.6 – 1.4% | 0.4 – 2.0% |
| Non-uniformity | <±2% | <±5% | <±10% |
| Temporal instability | <±2% | <±5% | <±10% |

## Characterization

Solar cell/modules characterization

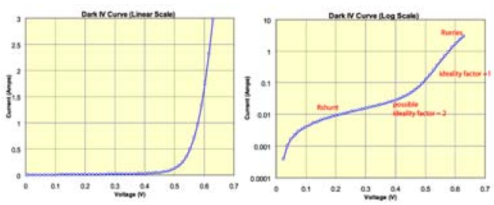
- IV curve




## Characterization

Solar cell/modules characterization

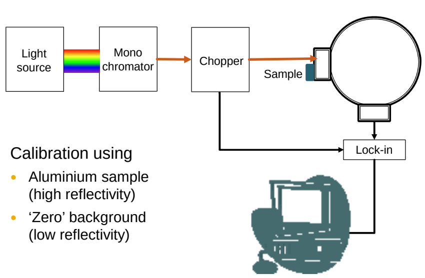
- IV dark curve




## Characterization

Solar cell/modules characterization

- **Reflectance**



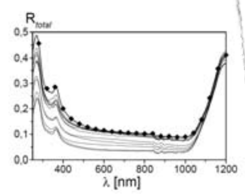

Calibration using

- Aluminium sample (high reflectivity)
- 'Zero' background (low reflectivity)

# Characterization

Solar cell/modules characterization

- Reflectance



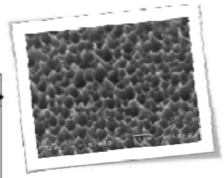


**Figure 4:** Reflectivity spectra of a macroporous texturised POLIX wafer (straight lines). For comparison the reflectivity curve of NaOH texturised, (100) oriented c-Si is also shown (◆).

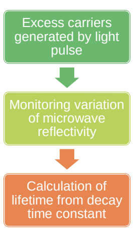
S. Lust, *et al, Mono and multicrystalline silicon solar cells based on macroporous silicon*, Proc.of the 17th EPVSEC, Munich 2001

# Characterization

Solar cell/modules characterization

- **Lifetime**

Most common technique: **M**icro**W**ave **P**hoto**C**onductance **D**ecay



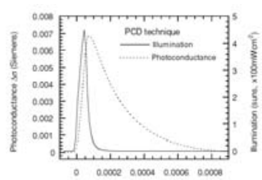



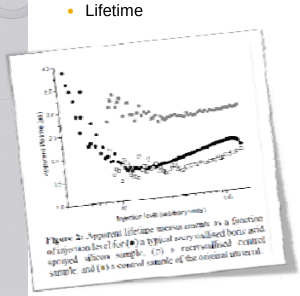

*Figure 1.5. A typical inductively-coupled photoconductance decay (PCD) trace for a 0.3Ωcm FZ wafer showing the sharp illumination peak and the ensuing carrier decay. The calculated effective lifetimes for this trace are shown in Figure 1.6.*

D.M. Macdonald, *Recombination and trapping in multicrystalline silicon solar cells*, PhD Thesis, Australian National University, 2001

# Characterization

Solar cell/modules characterization

- Lifetime



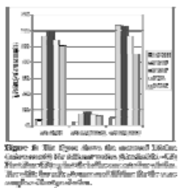
J. A. Silva, *et al, Solar cells on silicon ribbons doped with sprayed boric acid as a doping source*, Proc. 23rd EPVSEC, Valencia 2008

## Characterization

Solar cell/modules characterization
- Lifetime

Critical issue for lifetime measurements: **surface passivation**

May be achieved by many different approaches:
- Growth deposition of a dielectric film or pn junction (e.g. a-Si)
- Corona discharge on $SiO_2$ film
- Immersion in hydrofluoric acid (HF)
- or alcoholic iodine solution



D. Pera, *et al*, *Reliability of microwave photoconductivity lifetime measurements*, Proceedings of the 23rd EPVSEC, Valencia 2008

## Characterization

Solar cell/modules characterization
- **INFRARED IMAGING**

Includes
- Electroluminescence (EL)
- photoluminescence (PL) and
- lock-in thermography (LIT).

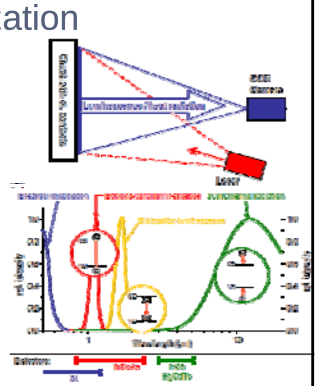
Allows measurement of
- Series or shunt resistance
- Junction breakdown
- Hot spots
- Lifetime

*Kasemann et al*, *Progress in silicon solar cell characterization with infrared imaging methods*, Proc. of the 23rd EPVSEC, Valencia 2008

## Characterization

**INFRARED IMAGING SETUP**.

- Homogeneous irradiation of the entire solar cell is typically performed with lasers in the wavelength range from 790nm to 940nm. Different cameras can be used to detect radiation in different wavelength ranges.
- Spectral range of photon emission from silicon solar cells, the underlying mechanisms, and the detectors used.

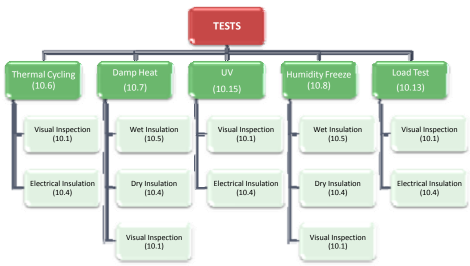


*Kasemann et al*, *Progress in silicon solar cell characterization with infrared imaging methods*, Proc. of the 23rd EPVSEC, Valencia 2008

# Characterization

Solar cell/modules characterization

- **DEGRADATION**

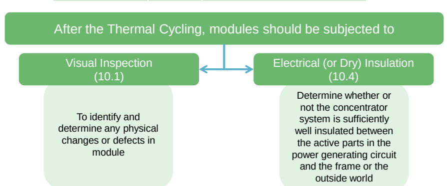



# Characterization

Solar cell/modules characterization

- Degradation: **THERMAL CYCLING**

| Maximum cell temperature (°C) | Total Cycles | Applied Current |
|---|---|---|
| 85 | 1000 | Apply 1,25xISC when T>25°C. Cycle speed is 10 electrical/thermal |
| 110 | 500 | |
| 65 | 2000 | |



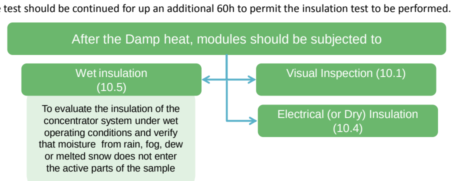

# Characterization

Solar cell/modules characterization

- Degradation: **DAMP HEAT**

To determine the ability of the modules or assemblies to withstand the effects of long-term penetration of humidity.

Relative humidity should be controlled to 85 % ± 5% and the temperature to 85°C ± 2°C for 1000h.
The test should be continued for up an additional 60h to permit the insulation test to be performed.



## LAB ASSIGNMENT

**Characterization** of one solar cell using:

- Spectral response measurement
- IV curve measurement

**Deliverable:**

- Report results in a paper format (chck template)
- Solar cell parameters: Isc, Voc, Pmax, eff, Rs, Rsh, … and lifetime
- Discuss cell results
- Compare SR and IV measurement