Beyond the Standards:
Testing for Reliability in Photovoltaics

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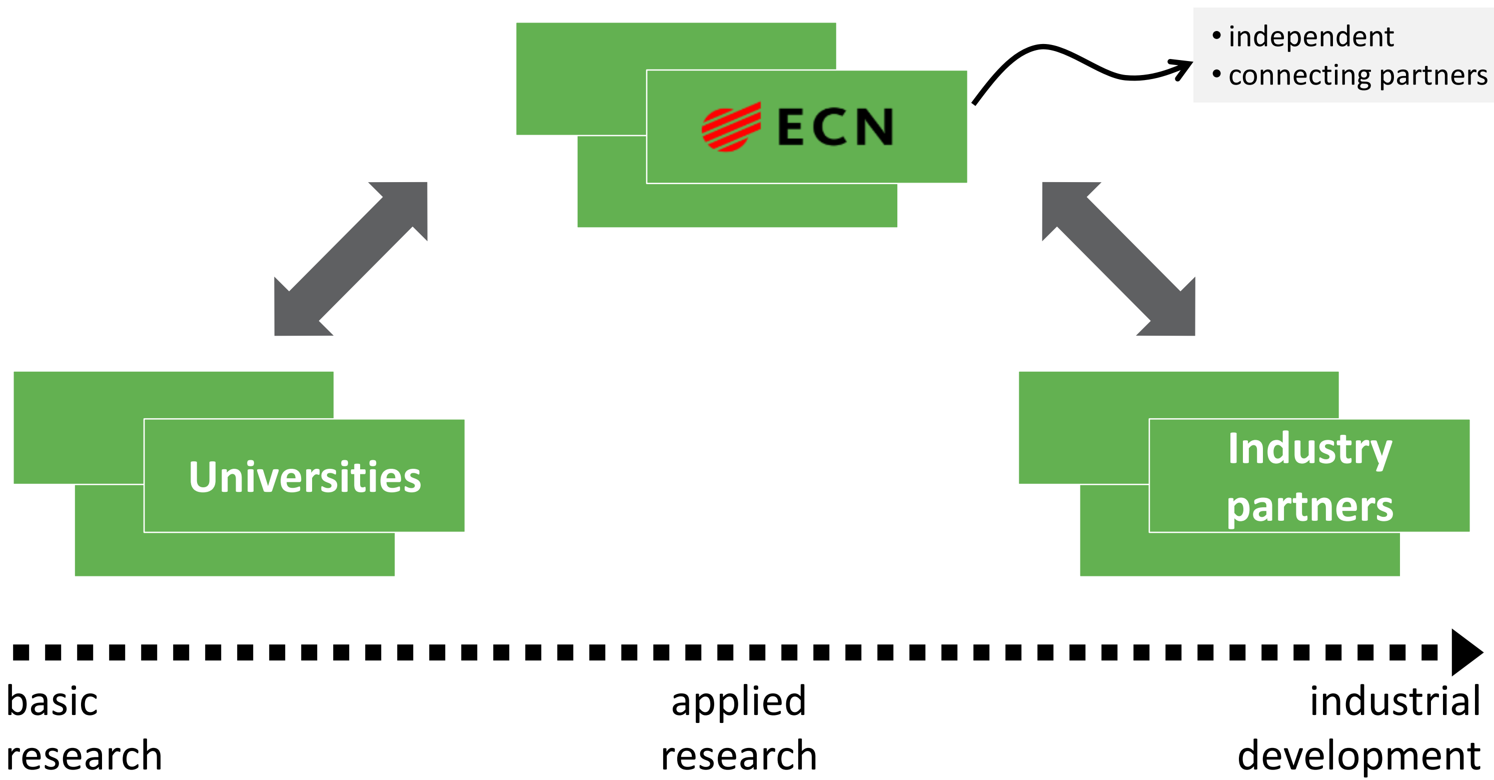
Outline

- Introduction to ECN and ECN Solar
- Photovoltaic Modules
  - Standard Rating
  - Components
  - Reliability and Failure
  - Standard Certifications tests
- Testing beyond the standards @ ECN
  - PID – Potential Induced Degradation
  - Fretting Corrosion of electrical contacts
  - Anti-Soiling coatings – Desert Applications
- Conclusion

Position


• independent
• connecting partners
ECN
Universities
Industry partners
basic research
applied research
industrial development

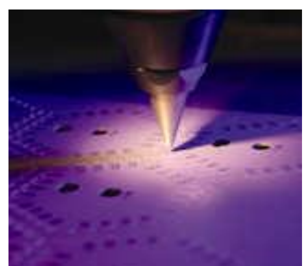
R&D fields

Policy Studies

Solar Energy

Wind Energy

Bio-energy



Energy Engineering

Environment

Energy Efficiency

Process & Energy Industry

ECN Solar Energy

Materials → Cell → Module → System → Installation & Operation

- Characterization
- Test in devices

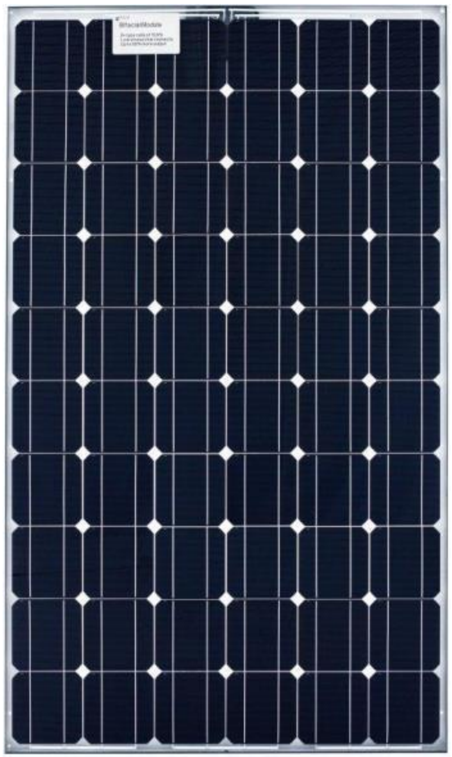
- New processes and device designs
- Production technology development

- New applications (e.g. BIPV, desert)
- Field tests and monitoring

» Lower cost
» Higher energy yield
» Better sustainability

» ECN Strength: Bringing Laboratory Technology to industrial Partners
» Failure mode analysis & bankability (durability) demonstration

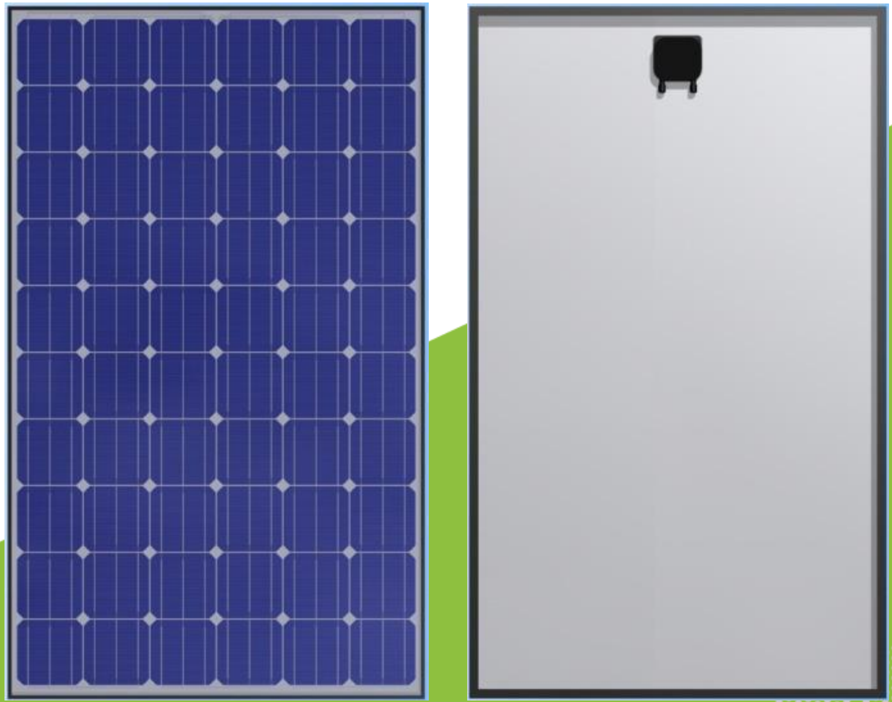
ECN Module Technologies



ECN Bifacial
Glass – EVA – Glass

ECN Black Beauty
Glass – EVA – Conductive Back Sheet

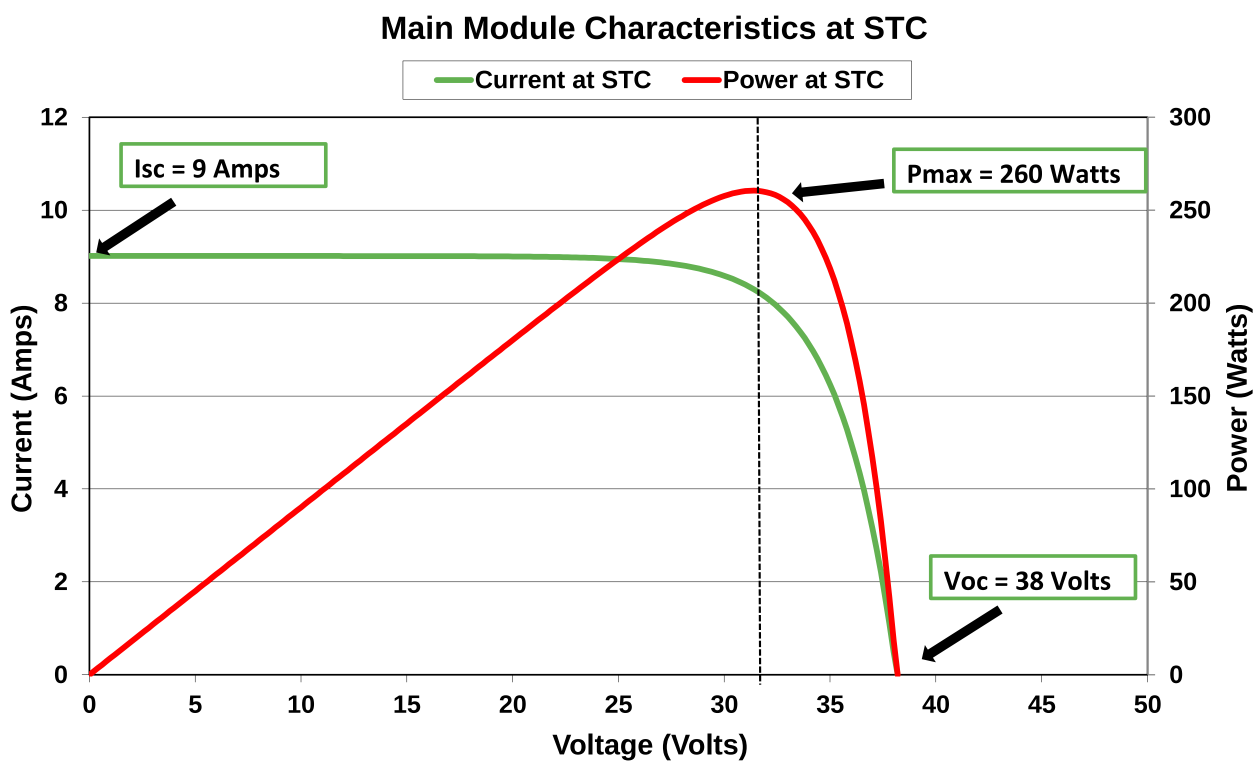
PV Modules



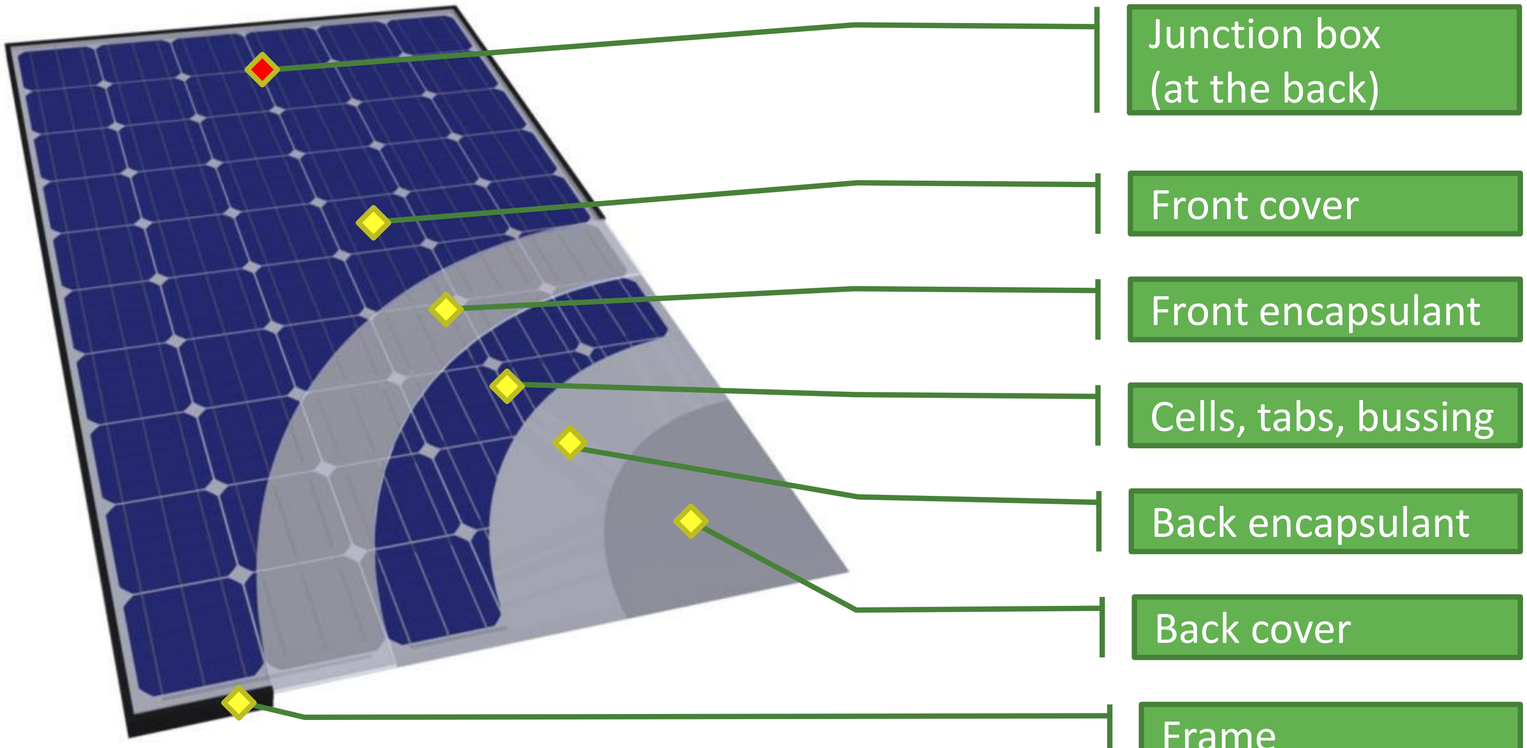
Standard Module Rating

- PV modules and systems sold by Watt peak (Wp)
- Wp is a standard accepted measure
  - The maximum power produced by a module at standard test conditions (STC)
- STC
  - Illumination (irradiance) = $1000 W/m^2$
  - Temperature = 25°C
  - Spectrum = Air Mass 1.5 (AM1.5)
- Key parameters
  - Maximum Power (P_{max})
  - Open circuit Voltage (V_{oc}) & Maximum Power Voltage (V_{mp})
  - Short circuit Current (I_{sc}) & Maximum Power Current (I_{mp})
  - Efficiency (η)

Standard Module Rating



Module Components



Module Components

Requirements

- Protection for fragile and moisture sensitive solar cells
- Good optical coupling on front side of cells – both sides for bifacial
- Safe (electrically, low flammability, no falling shards)
- Durable (temperature, moisture, UV)
- Robust (handling, transport, snow loading)
- Mountable

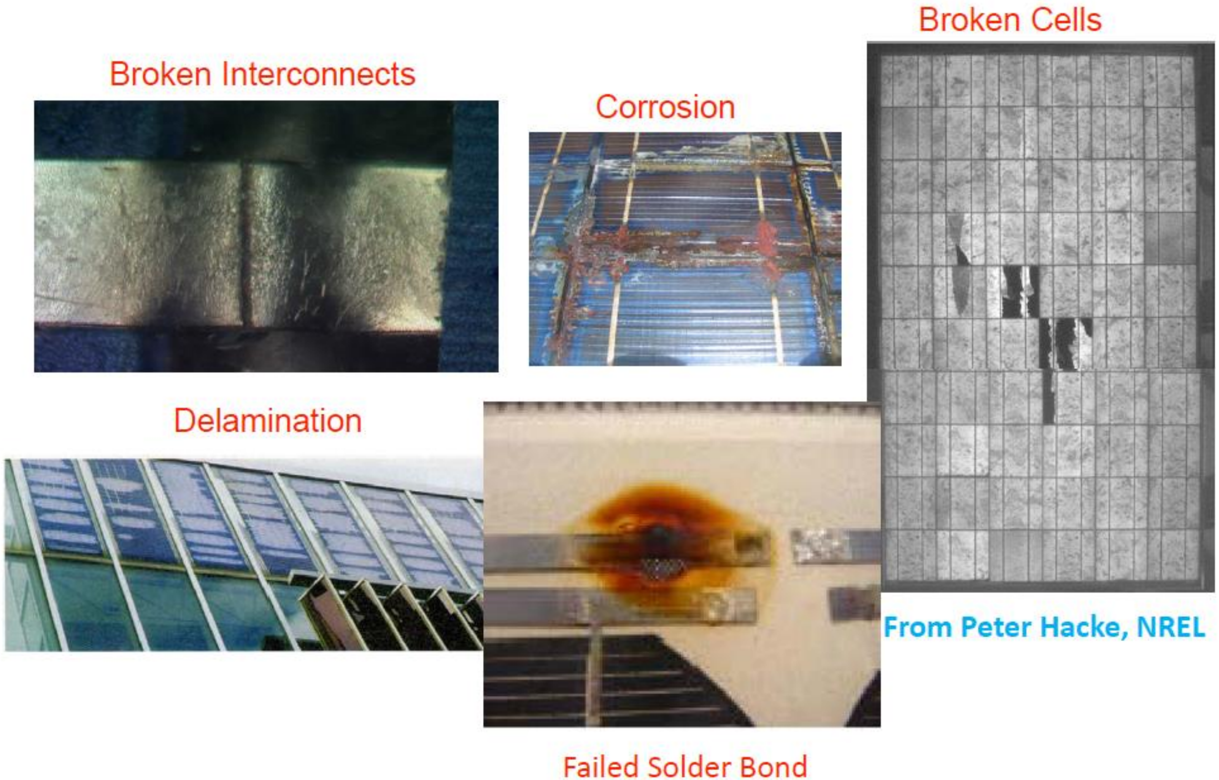
Warranties are typically 25 – 30 years

Example:

Power > 80% after 25 years

Materials and workmanship – 10 years

Failure Examples



Source: NREL – Atlas NIST workshop – 2013
http://www.slideshare.net/m4rcel02005/determining-the-acceleration-rates-for-pv-module-stress-tests

Module Reliability

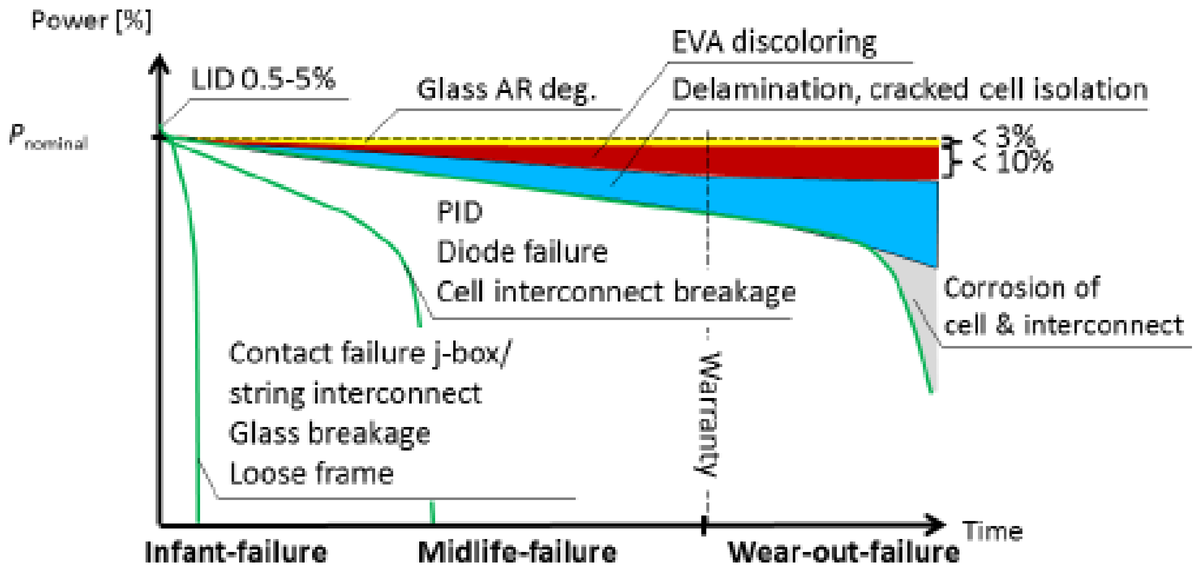
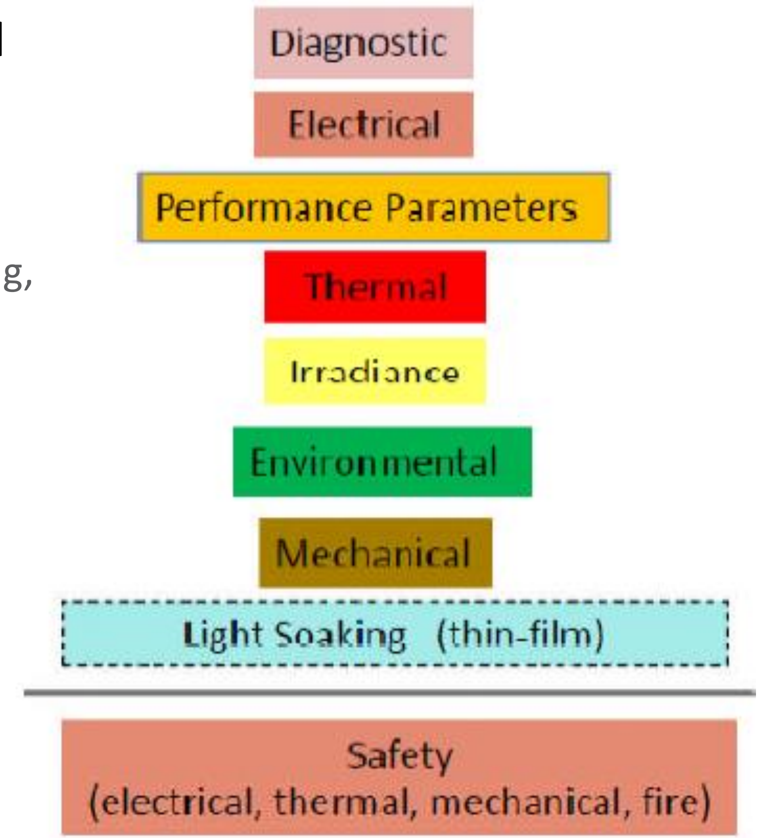


Fig. 3.1: Three typical failure scenarios for wafer-based crystalline photovoltaic modules are shown. Definition of the used abbreviations: LID – light-induced degradation, PID – potential induced degradation, EVA – ethylene vinyl acetate, j-box – junction box.

Source: IEA-PVPS 2014

Standard Certification Tests

- IEC 61215 /61646 – Performance standard
  - Diagnostic – visual inspection, hot spot
  - Electrical – insulation resistance, wet leakage
  - Performance – Pmax @ STC etc.
  - Accelerated aging – Damp Heat, Thermal Cycling, Humidity Freeze, UV exposure ….
  - Mechanical – Hail impact, mechanical load…
- IEC 61730 – safety standard - various hazards
  - Electrical, Thermal, Mechanical & Fire



Source: TÜV America

Beyond the Standards

Potential Induced Degradation

What is PID?

- Potential Induced Degradation (due to elevated system voltage 600 – 1000V)– responsible for rapid and severe degradation of power output of some modules.

- Ionic transport occurs through the glass and encapsulant, and those ions are involved in the degradation.

- Driving forces:
  - Potential difference between frame and cell
  - High Humidity
  - Elevated temperature

What is PID?

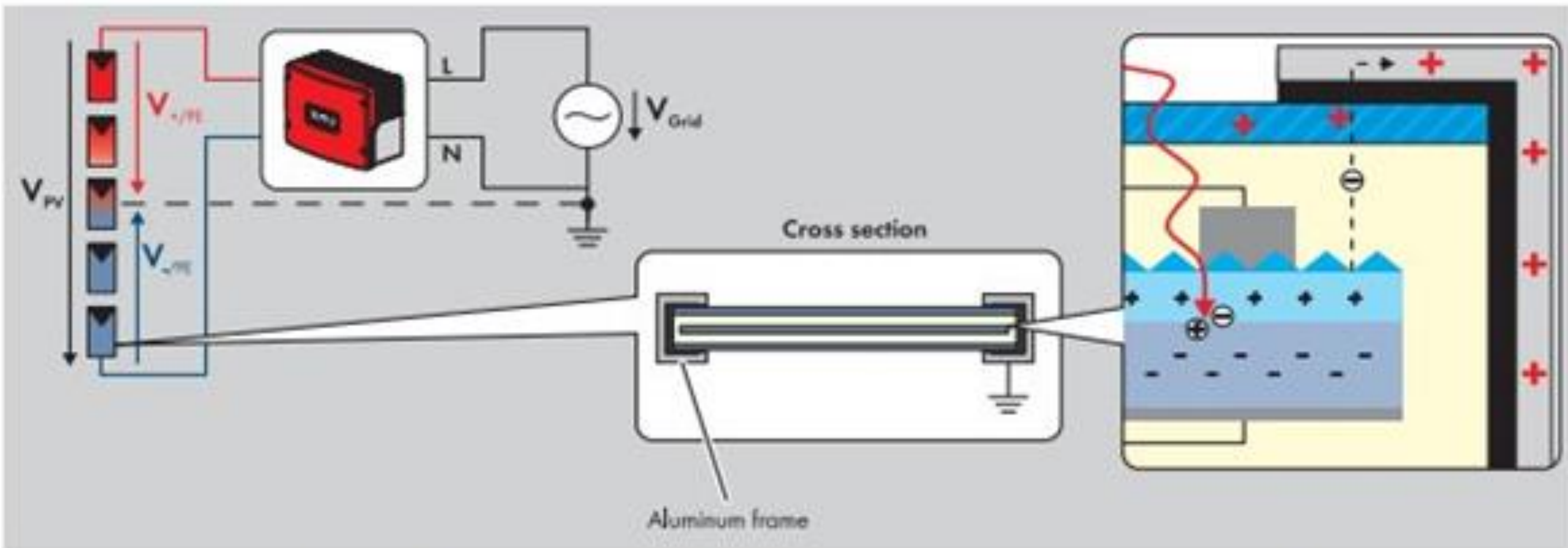


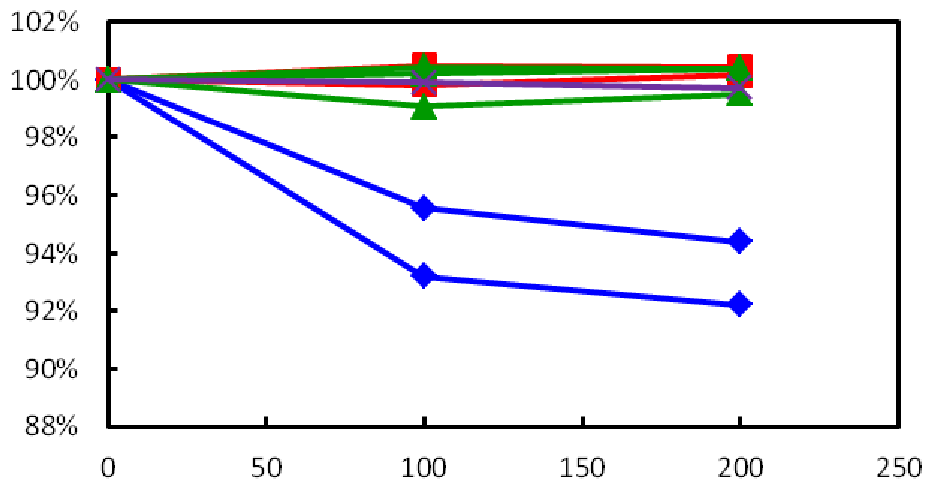
Figure 1: Build-up of electrical charges due to a leakage current between the PV cell and module frame

Image Source
http://www.cenergymaxpower.com/introduction-solar-pv-modules

PID Test and set up

- No test for PID in IEC 61215
- Proposed standard IEC 62804 is being developed
  - 96 hours @ 85% RH, 60°C, Cells at system voltage relative to frame
  - Pass / fail limit 5% relative power degradation @STC

PID Tests at ECN

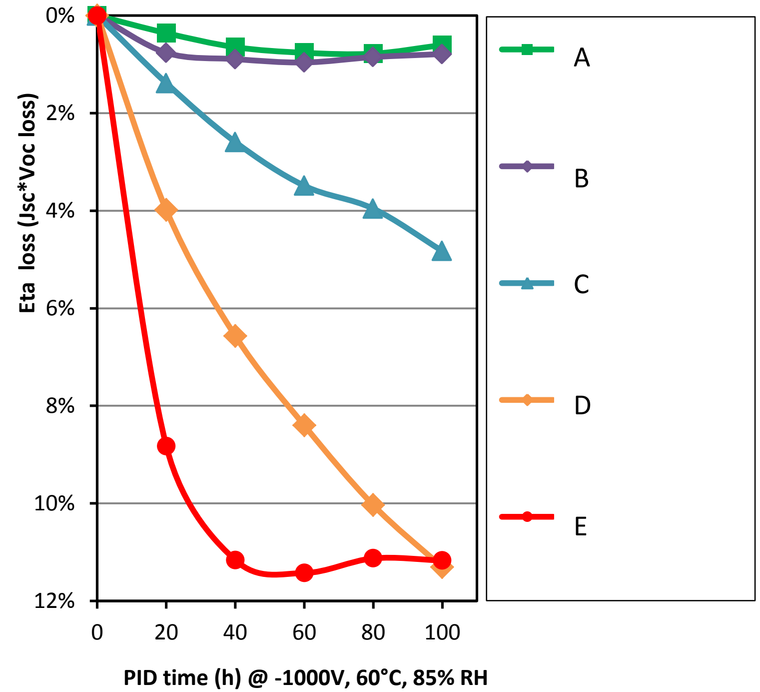


ECN PID tests with different encapsulants and susceptible cells / modules

- Solution can be to use more insulating encapsulant - expensive
- This is not a sufficient solution for all types of cells and modules

ECN PID free modules

- ECN have developed cells and modules that are intrinsically PID free
- Engineered PID sensitive modules to fully understand the PID process
- Result: A full understanding of the PID process in these cells and modules
- Industrial low cost method to produce PID free cells and modules – available to industry



Reference: Stodolny et al, *PID-and UVID-free n-type solar cells and modules*, SiliconPV Conference 2016

Fretting Corrosion

Fretting Corrosion of Electrical Contacts

- Fretting Corrosion
  - Fretting corrosion causes failures at contact points – Safety issue
  - Defined as:
    - *"Fretting is a special wear process that occurs at the contact area between two materials under load and subject to minute relative motion be vibration or some other force."*
  - If movement is less than 80µm when wear occurs – this is termed "fretting"
- Current IEC tests do not test for fretting corrosion in junction boxes
  - Being discussed in standards circles

Fretting Corrosion – what is it?

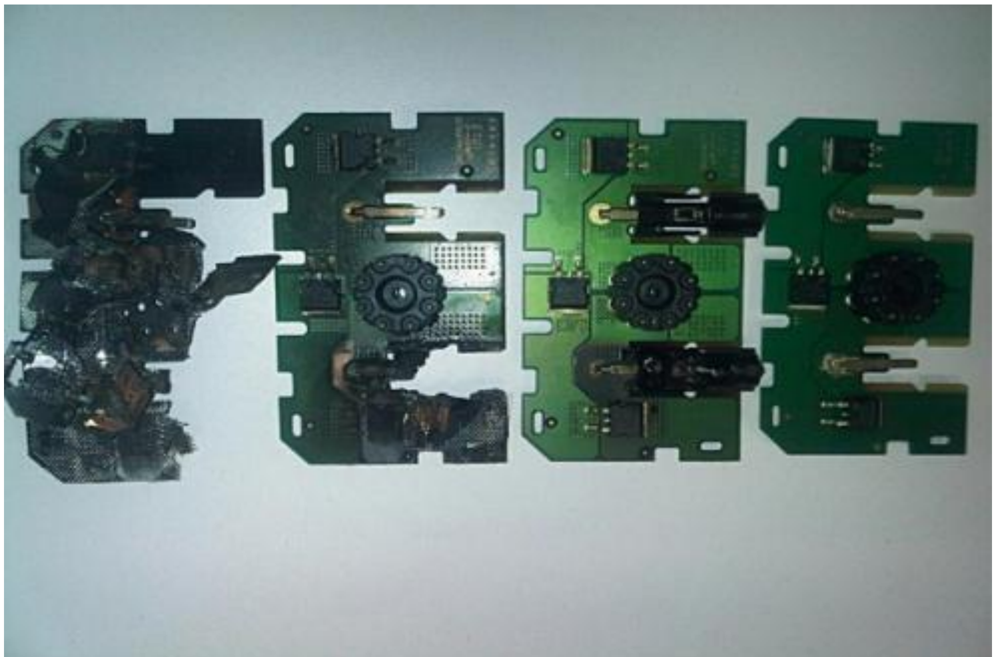


Image Source: PV magazine – S. Ali Oettinger, 11/2003
www.pv-magazine.com

Different Thermal expansion coefficients of contacts

Friction at contact surfaces (small movement)

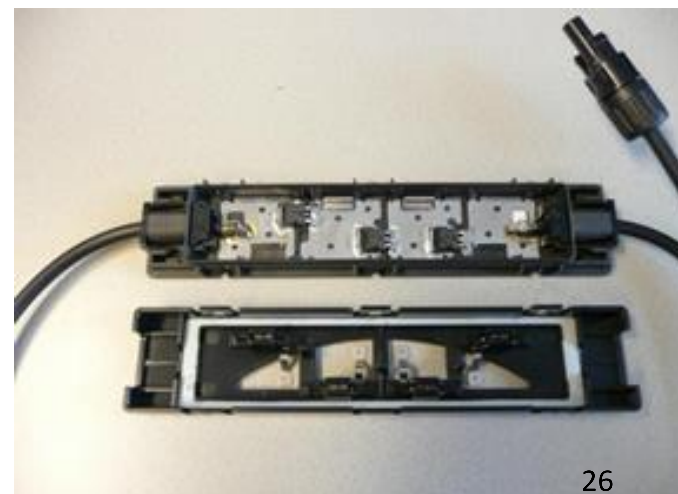
Higher contact resistance

Local heating and melting / failure of J-box

Fretting corrosion test approach

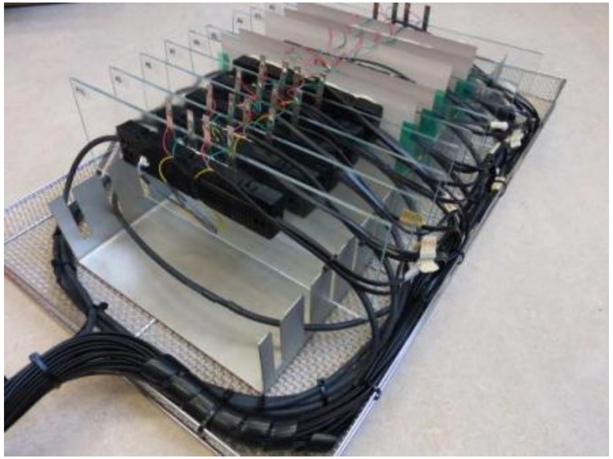
- ECN and Solned designed a test regime
- Tests were carried out at ECN
- Approach: Simulate conditions for fretting corrosion
- Junction boxes subjected to thermal shock –
  - -40 °C - + 85 °C
  - Different thermal expansion coefficients cause displacements
  - More severe than thermal cycle
- Junction boxes under load during test
- Contact resistance measured on line during test – sample frequency 5sec -
- Length of test 7 days / 144 cycles.

Solned Junction Box



Fretting corrosion test set-up

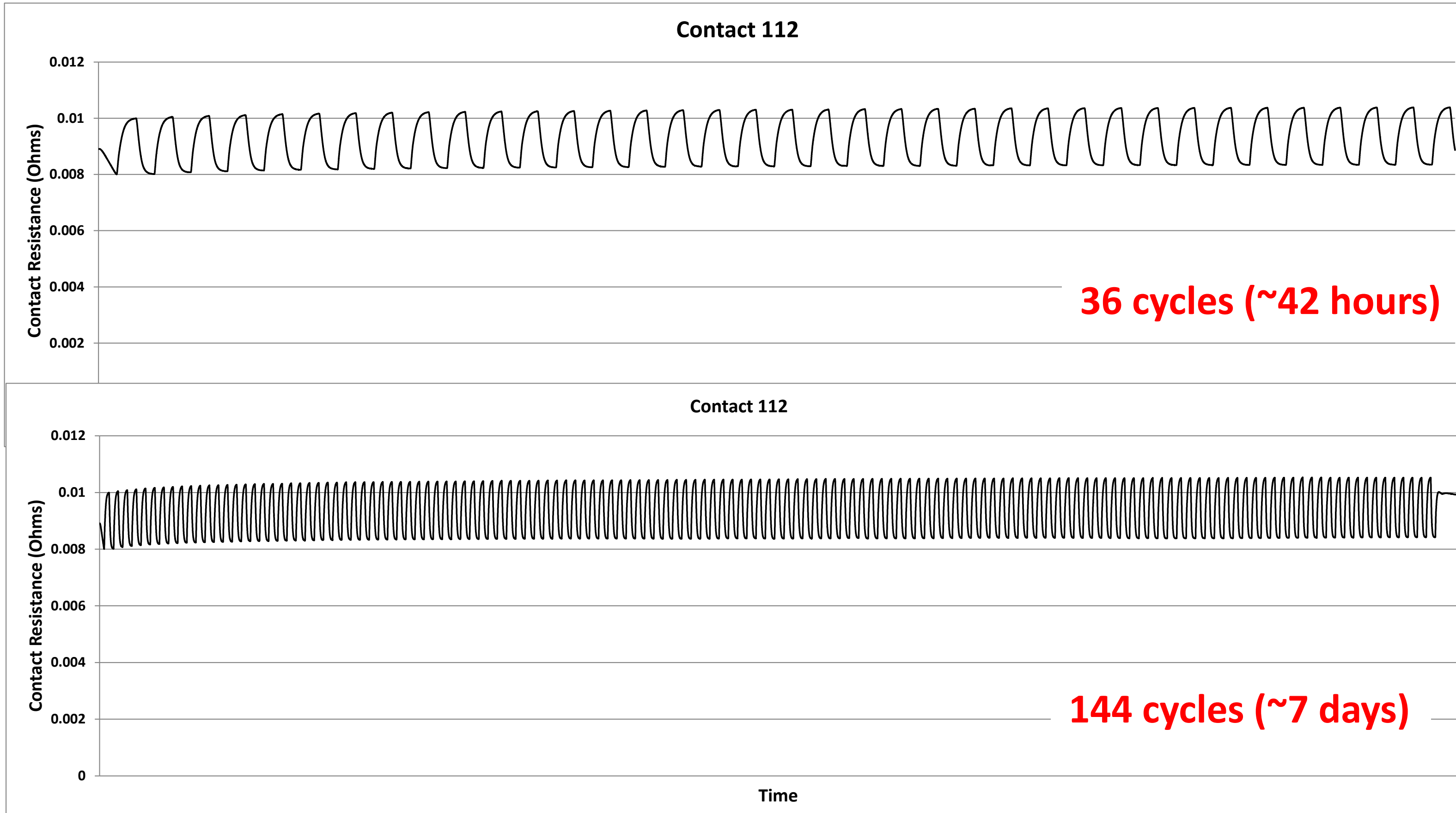
Data cables & Power Supplies



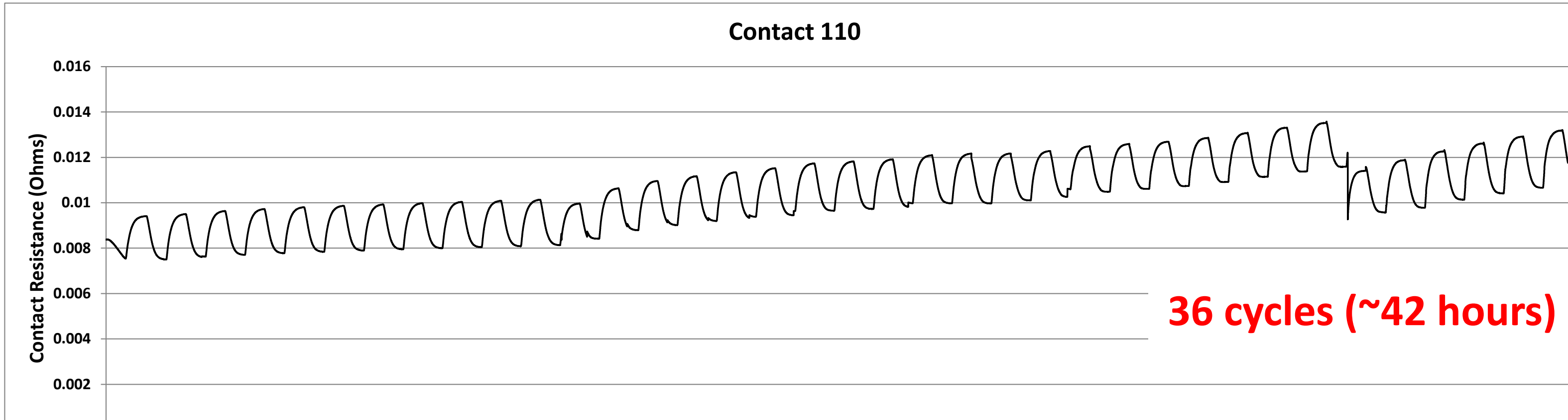
Wired up samples

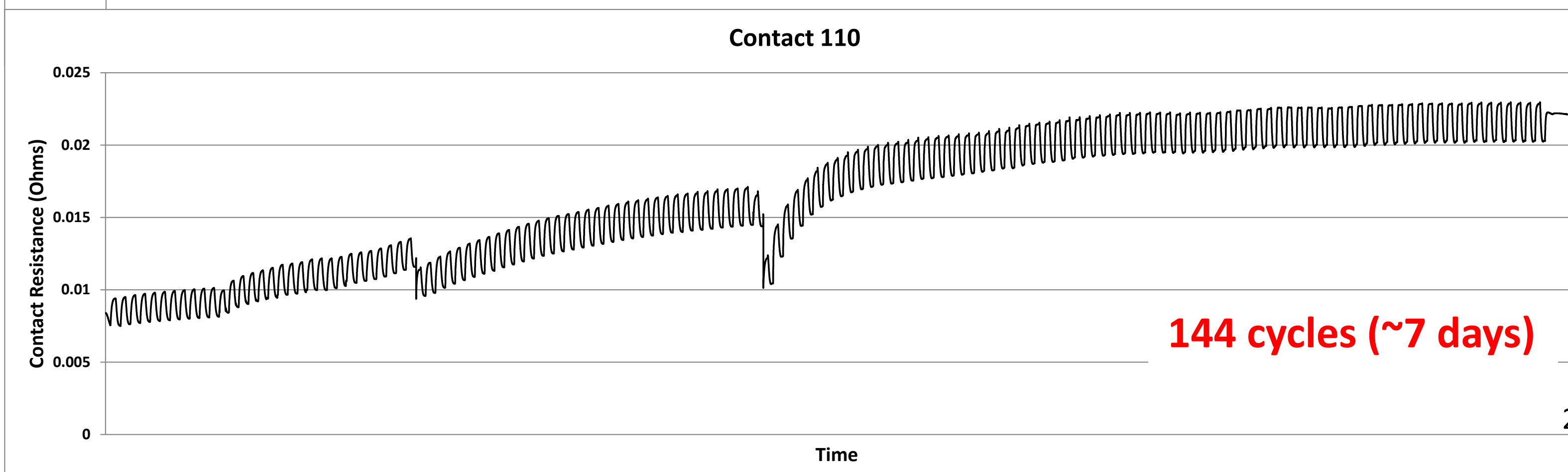
Thermal Shock Chambers

Results –
Stable contact resistance



Results – Contact showing escalating resistance





Conclusions of fretting corrosion tests

- Fretting corrosion test successful - sufficiently stresses susceptible j-box contacts to induce escalating contact resistance over time – start of fretting corrosion
- First run of tests – some instability observed in some contacts
- Based on results contact design changed by Solned
- Follow up tests on new contact design showed that it was stable
- Fretting corrosion test provides a simple and effective way to test electrical contact designs for safety

Anti Soiling Coatings

ECN

Challenges for PV in desert regions

Challenges for PV in desert regions

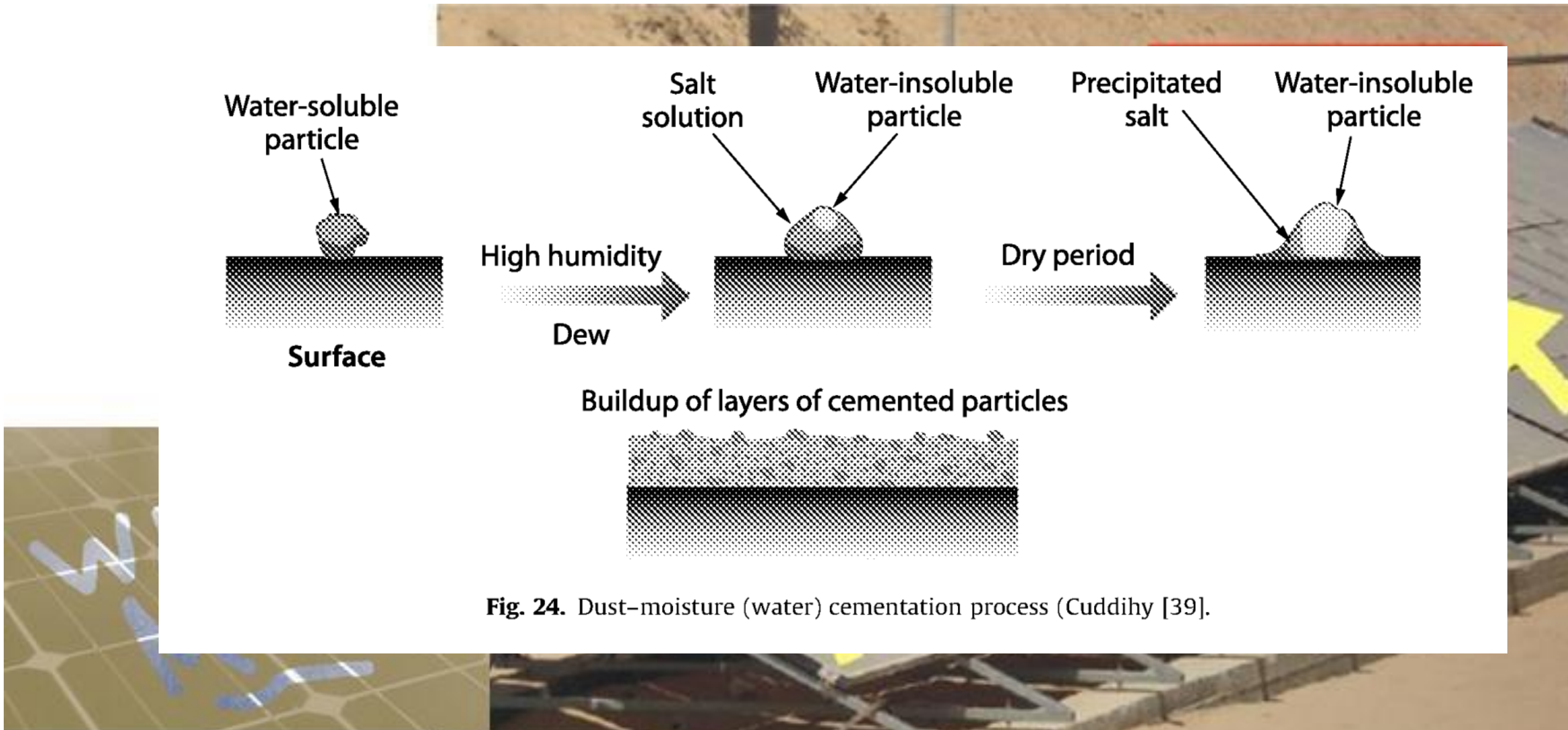


Fig. 24. Dust–moisture (water) cementation process (Cuddihy [39].

Assessment of anti-soiling coatings

- Developed a fast and conclusive method for artificial (accelerated) soiling/cementation and testing of anti-soiling coatings
- Tested the performance of anti-soiling coatings from several suppliers
- Durability tested: abrasion resistance test following standard (EN 1096-2)
- Assessment techniques not restricted to PV applications – applicable to any coating

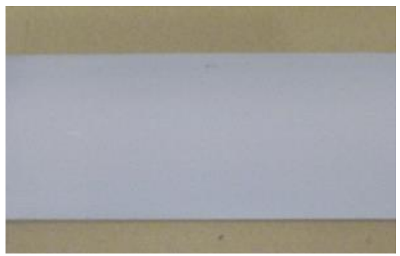
References

Travis Sarver, Ali Al-Qaraghuli, Lawrence L. Kazmerski, Renewable and Sustainable Energy Reviews Volume 22, June 2013, Pages 698–733

Thomas Weber et al., Proceedings 29th European Photovoltaic Solar Energy Conference and Exhibition (2014), Page 2499

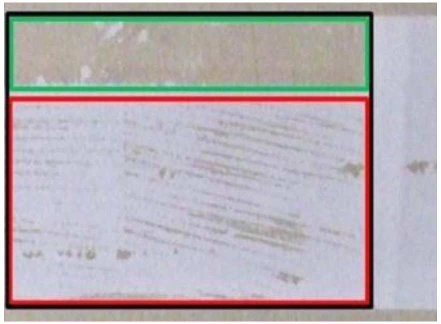
Approach

- Local abrasion of glass sample with anti-soiling coating
- Artificial soiling (white) within and outside the abrasion zone
- Removal of soiling by pulling off using adhesive tape (black square, very good performing AS coating in this case)
- Visual inspection: between red lines AS coating still OK after abrasion > 10000 strokes (Very good abrasion resistance for this sample)



Results for a representative coating

- All white parts: soiled area
- Red marked area: surface subjected to abrasion test (prior to soiling), soiling strongly adheres
- Green: surface not subjected to abrasion test, low adhesion of soiling
- Black: all loosely adhered soiling pulled off
- Anti-soiling effect largely annihilated after abrasion test for this sample



Relative performance of anti-soiling coatings

ECN

- Ranking of 3 different anti-soiling coatings with respect to effectiveness and abrasion resistance.
- Pass criteria 500 strokes (EN 1096-2 standard)
- Abrasion resistance of coatings can vary substantially (by factor >20)

sample	AS activity	
	initial	after abrasion (no. of strokes)
Ref glass	- -	No test
1	++	- (500-1000)
2	- -	No test
3	++	++ (>10000)

	Legend AS activity ranking	
	- -	non visible
	-	low
	+	good
	++	excellent

Conclusions

Conclusion

- ECN Solar are active in the bulk of the photovoltaics value chain
- PV Module developments require testing both at IEC standards and outside the standards
- PID testing at ECN enabled a full understanding of the PID mechanism in our high efficiency cells and modules – resulting in a lower cost industrial process for PID free cells and modules
- Fretting corrosion test method for junction box contacts is developed – can be applied to any electrical contacts
- Fast assessment of anti-soiling coating developed, and coatings tested for durability following abrasion standard – not restricted to PV applications


Want to know more?
Contact me: carr@ecn.nl