電池與模組新技術的新問題-IEA Task 13新年度專題

林敬傑/ 首席顧問
PV Guider

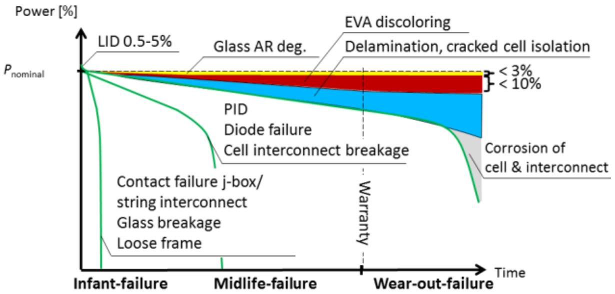
Keep Green Gold Shining!

內容

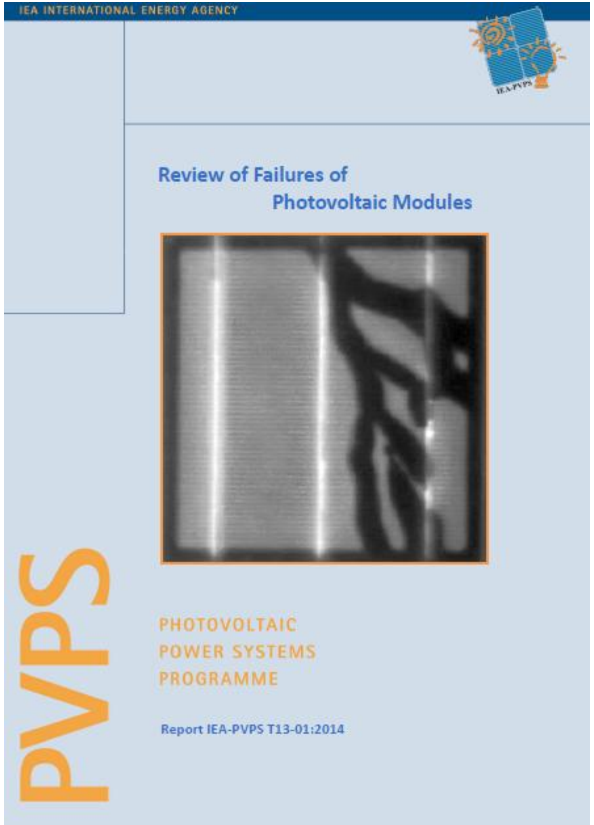
- IEA PVPS與Task 13簡介
- 2022-2025計畫
- 新技術的新問題

IEA PVPS?

最有名的模組功率衰減圖



出自2014年Task 13報告


IEA INTERNATIONAL ENERGY AGENCY

Review of Failures of
Photovoltaic Modules

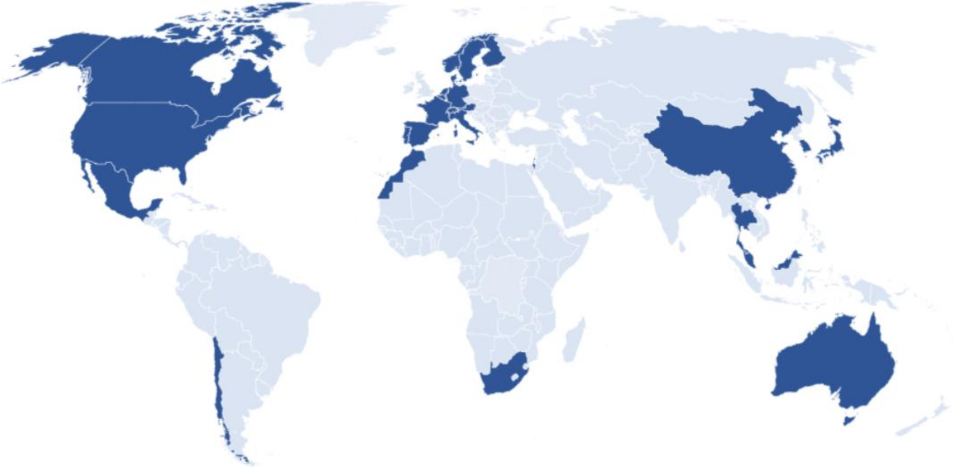
PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

Report IEA-PVPS T13-01:2014

IEA-PVPS Task 13簡介

- IEA-PVPS(Photovoltaic Power Systems) 是國際能源署 (IEA)合作研發計劃之一，成立於 1993 年。
- 目前有 31 個 PVPS 成員，包括 27 個國家和 4 個組織。有8 個Task活躍進行中，每個Task有多達 100 名專家參與。
- Task 13 的目標是改善太陽光電模組和系統的性能、可靠度和品質。



Task 13 2022-2025

Subtask 1: 新材料、元件與模組的可靠度

1.1 新電池及模組技術的性能衰退模式（傑博擔任共同主持人）
1.2 修復模組的性能與可靠度
1.3 針對特定負載的測試策略之影響
1.4 PV+儲能的可靠度

Subtask 2: 太陽光電系統的性能與耐久性

2.1 Floating PV
2.2 Agrivoltaics
2.3 雙面追日系統
2.4 數位整合與Digital Twinning
2.5 模組功率電子（優化器等）的效率與遮蔽效應

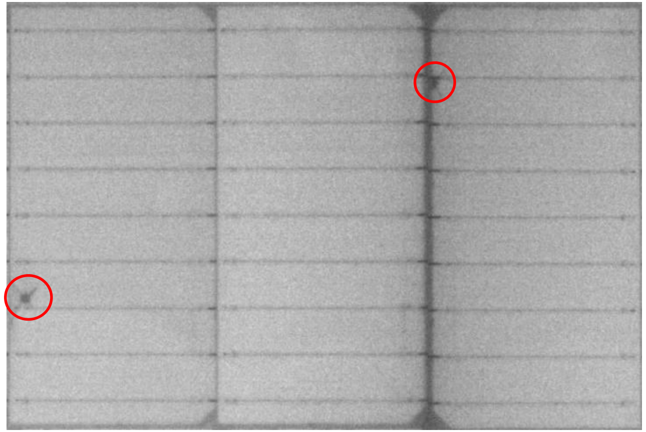
Subtask 3: 技術-財務性能指標

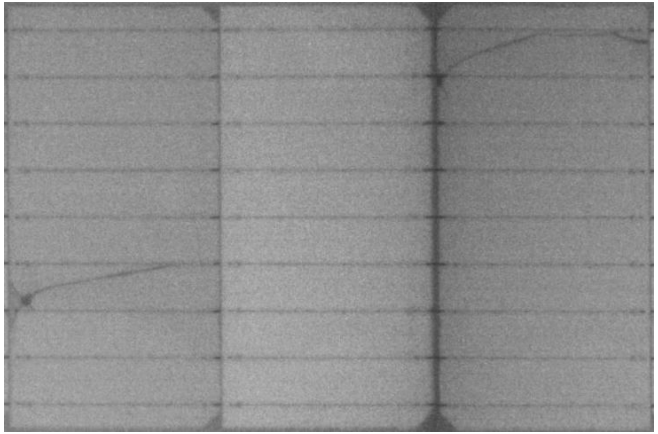
3.1 極端氣候及其對PV性能KPI的衝擊
3.2 針對特定氣候的KPI優化指引
3.3 PV電站財務KPI的影響
3.4 財務與可靠度KPI的連結

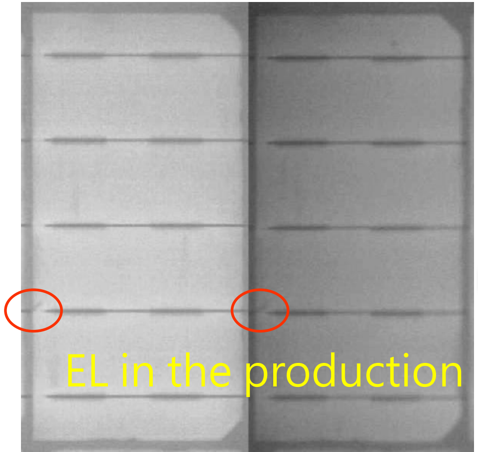
電池與模組新技術的新問題

Cell cracks of half cut cells and failures in shingled modules

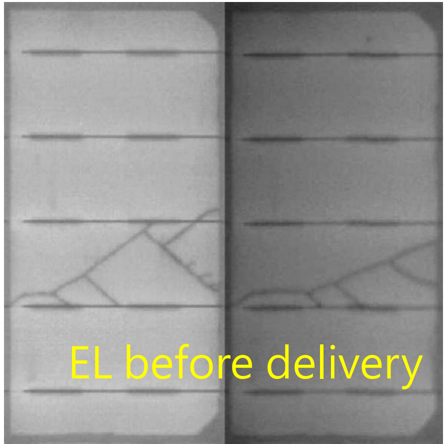
Cell cracks of half cut cells



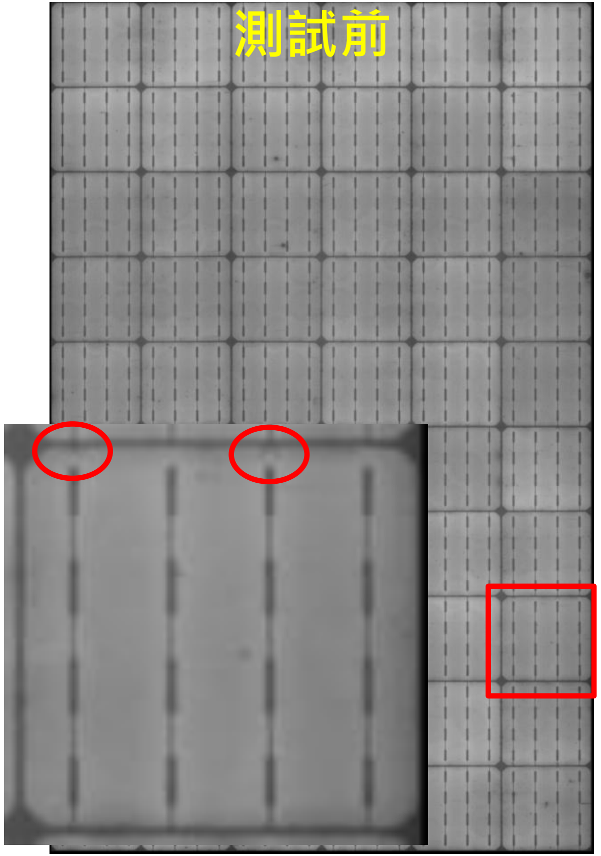




⇨ 包裝+內部運輸 ⇨

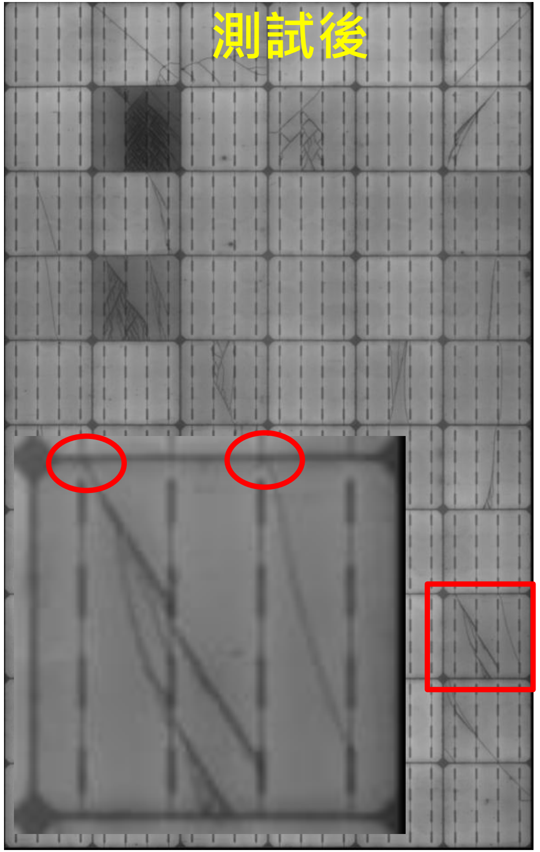


小V裂的成長

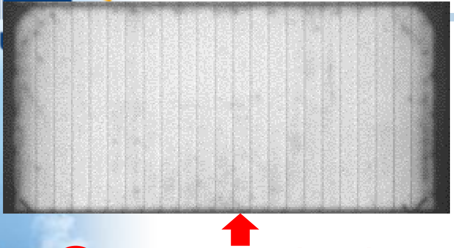


機械負荷測試

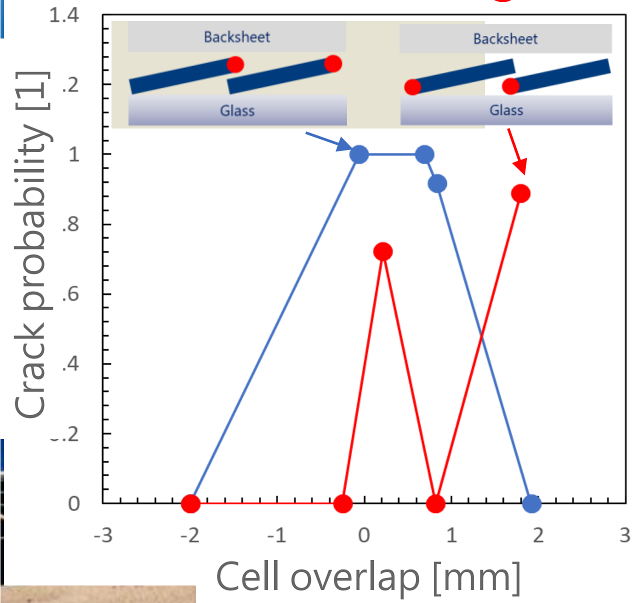
Mechanical Load



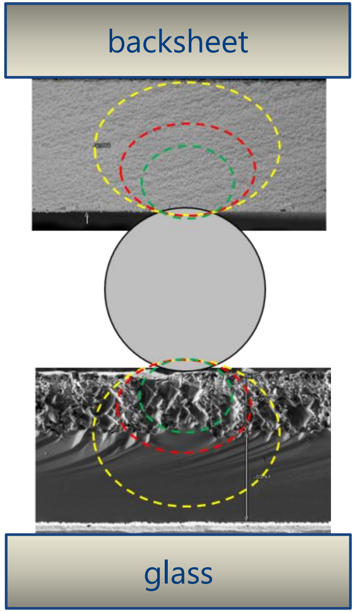
與cell的方向有關



● Lasered edge

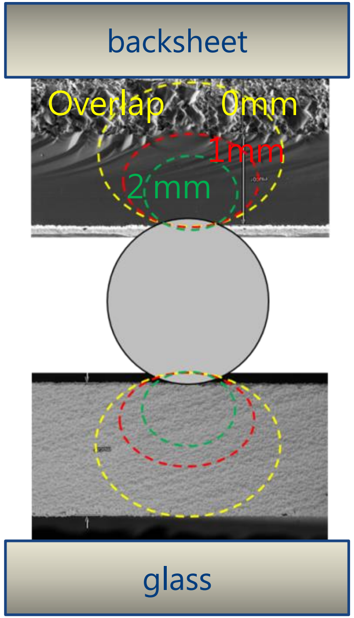


Lasered edge to glass



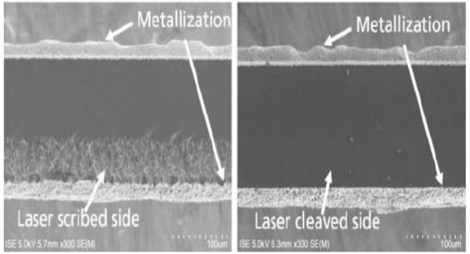
- Crack-free shingle: only 1 mm overlapp

Lasered edge to backsheet



- Crack-free shingle: 2 mm overlapp

Laser cleaved

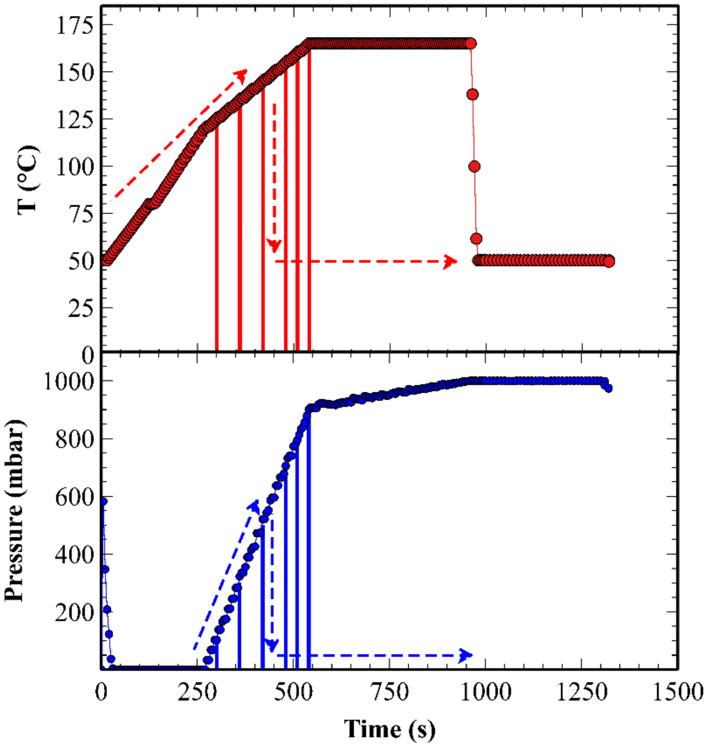


R.P. A. Muenzer, et al.,
EU PVSEC Proc. (2020), pp. 394–399.

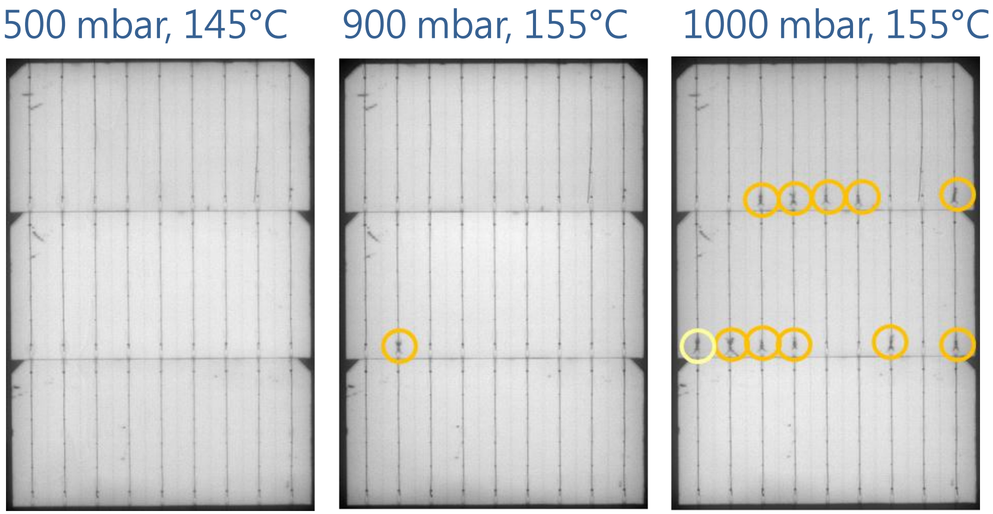
- Laser cleaved silicon show less defects
- Probably less cracks

- Possible reduction of the risk of crack by stress volume optimization

與封裝壓力有關

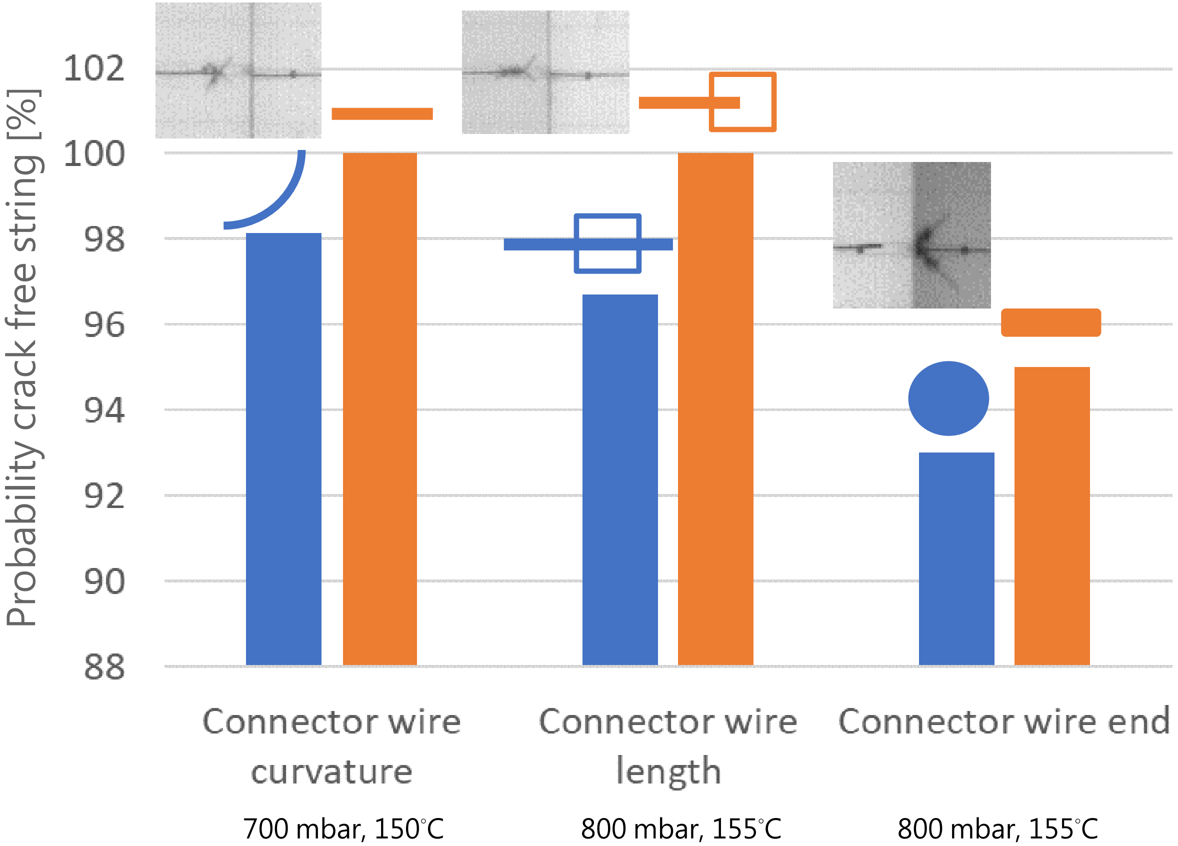


- M6 PERC half cells+ 380 µm cell interconnect wires
- Interruption of lamination at specified pressures and temperatures followed by EL for crack detection

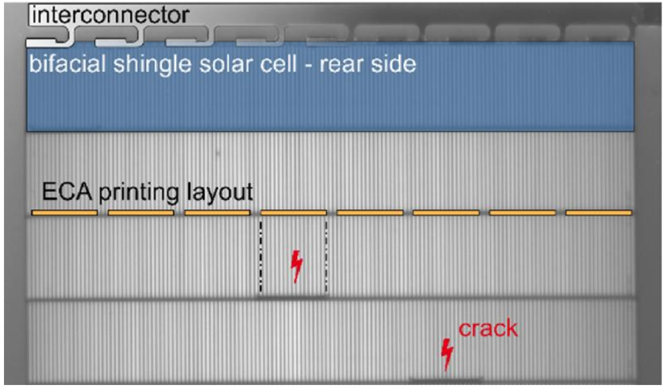


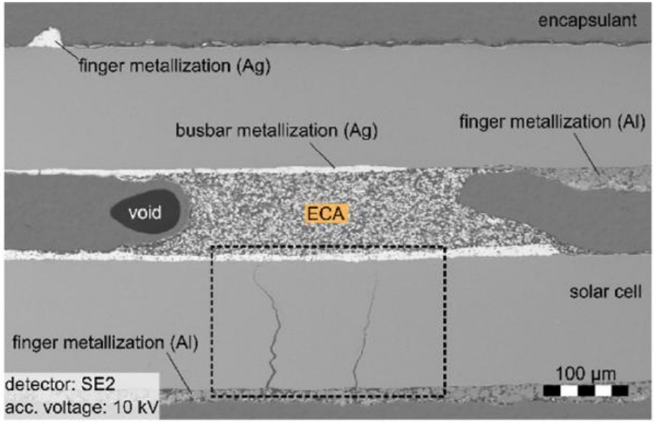
- Test reveals critical lamination conditions

與ribbon有關


Probability crack free string [%]
102
100
98
96
94
92
90
88
Connector wire curvature
Connector wire length
Connector wire end
700 mbar, 150°C
800 mbar, 155°C
800 mbar, 155°C

疊瓦隱裂





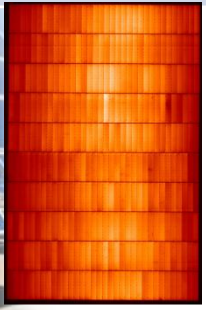
N. Klasen, et. al , *Sol. Energy Mater. Sol. Cells* 238, 111590 (2022).

- **主要與疊瓦連接及層壓有關**
- 導電膠的剛性與溫度膨脹係數似乎很重要
- 大部份發生在背面
- 實驗顯示對功率影響不大
- 50 % 導電膠位置有隱裂

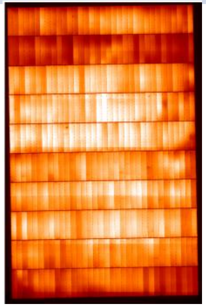
→ TC1000 後功率損失~= (- 2.3±1.5) %

加速測試

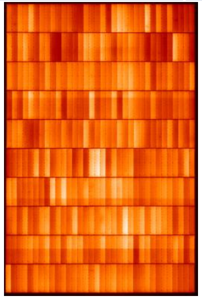
	TC (-40~85)	XTC (↑ΔT°C)	DML+XTC
Failure mode	FF ↓ String interconnection failure	Same as TC	Same as TC
EL image	➢String disconnection (ribbon failure) ➢No problem on the shingle structure	Same as TC	Same as TC
Impact of DML	-	-	➢DML has slight impact (ΔPmax < 1%) ➢Accelerated FF ↓ caused by TC ➢The number of cycles has no impact on post-TC aging



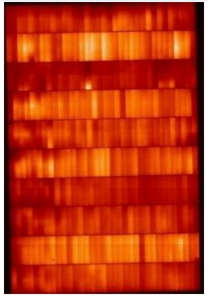
T_0



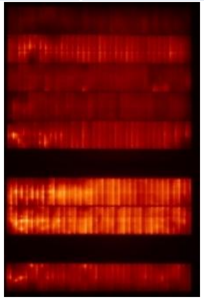
600 TC



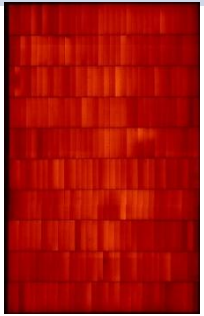
T_0



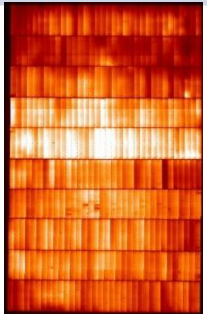
300 XTC



500 XTC



200 XTC

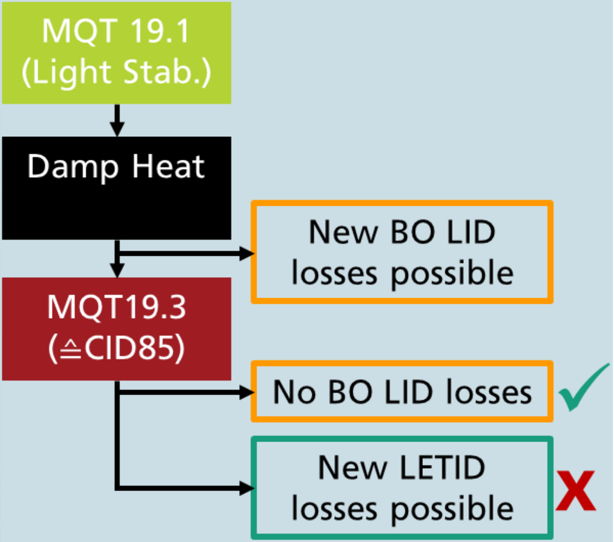


DML 1000/1000 & 200 XTC

LID & LETID

BO-LID與LETID糾纏不清

In IEC 61215:2021



MQT 19.1 (Light Stab.)

Damp Heat

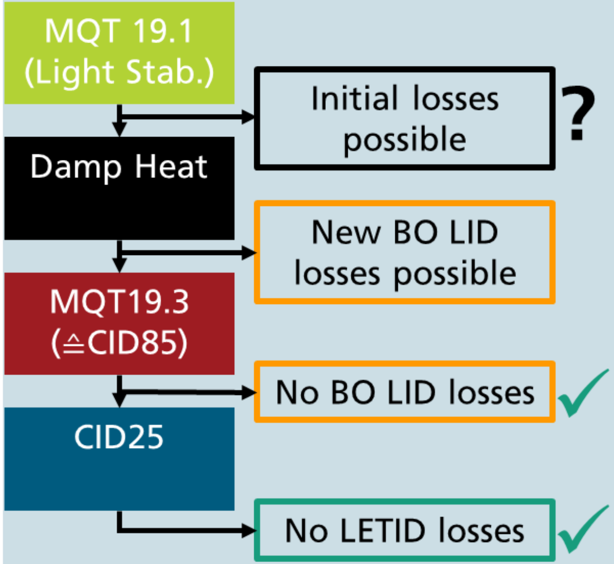
New BO LID losses possible

MQT19.3 (≙CID85)

No BO LID losses ✓

New LETID losses possible X

Possible Workaround



MQT 19.1 (Light Stab.)

Initial losses possible ?

Damp Heat

New BO LID losses possible

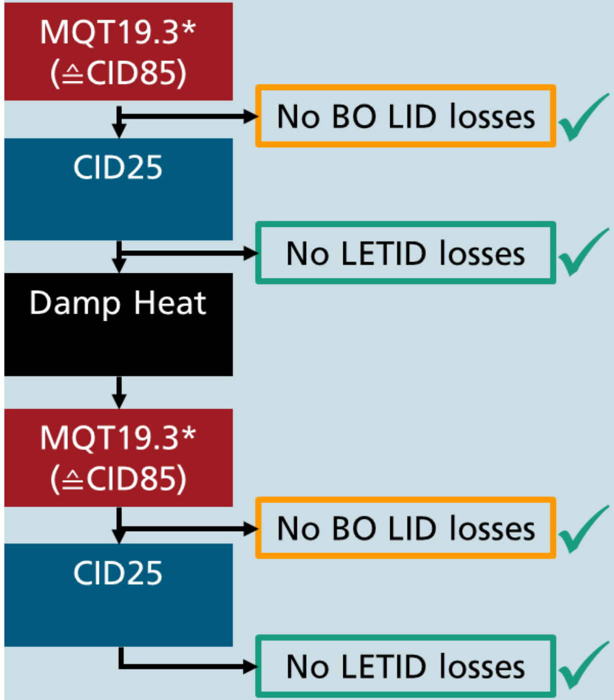
MQT19.3 (≙CID85)

No BO LID losses ✓

CID25

No LETID losses ✓

Most precise comparison



MQT19.3* (≙CID85)

No BO LID losses ✓

CID25

No LETID losses ✓

Damp Heat

MQT19.3* (≙CID85)

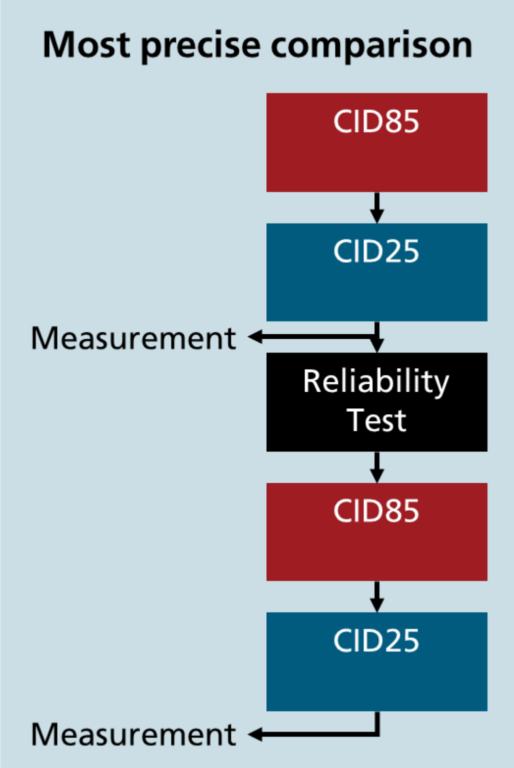
No BO LID losses ✓

CID25

No LETID losses ✓

精準量測

- B-doped Cz-Si PERC cells小模組試驗結果：
  - DH1000: BO LID **destabilization**
  - TC200 沒有電流注入: BO LID **destabilization**
- 要免除BO LID的影響：
  - BO LID regeneration (CID85)
  - **會引發LETID**
- 結合CID85 與 LETID recovery
  - ➢ 得到最精準量測, 例如應用於R&D目的



Most precise comparison

CID85

CID25

Measurement

Reliability Test

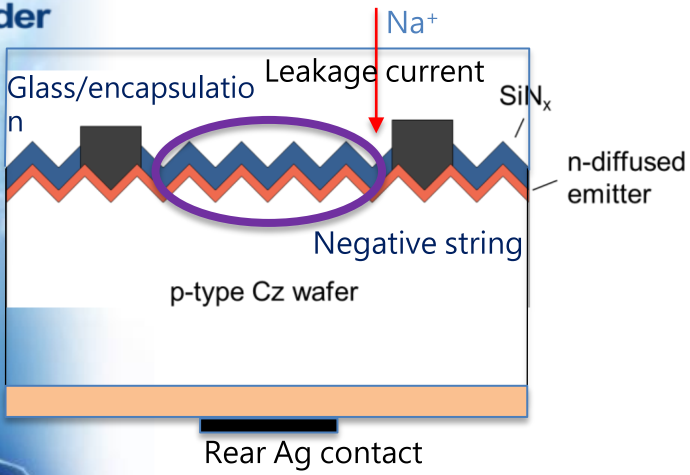
CID85

CID25

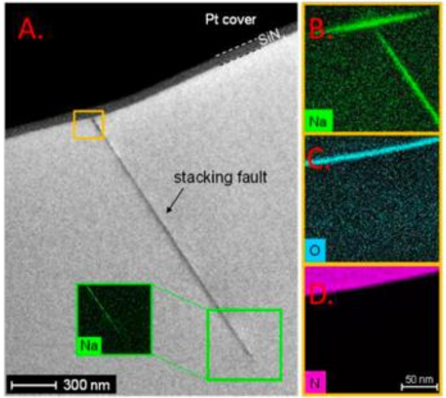
Measurement

Rear PID for PERC+, front PID for PERT & TOPCON

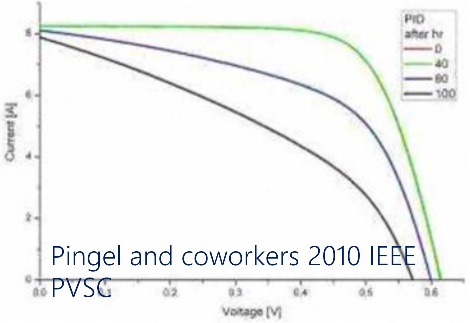
PID-Shunting



PID type	PID-shunting (PID-s)
Cell types	Cells with junctions (all)
Mechanism	Na+ 被電場帶到cell，然後擴散至類缺陷中 Shunting降低FF
Sensitivities	系統負偏壓, shallow junctions
Mitigation	SiO_2/SiNx 堆疊AR coating, 高折射率SiNx, 阻抗更大的封裝材 減少矽晶裡的類缺陷, UV irradiation

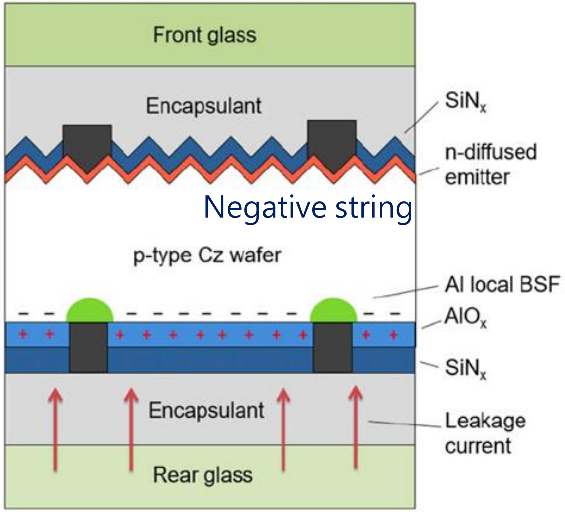


V. Naumann, D. Lausch, A. Hähnel, J. Bauer, O. Breitenstein, A. Graff, M. Werner, S. Swatek, S. Großer and J. Bagdahn,
Solar Energy Materials and Solar Cells, 2014,



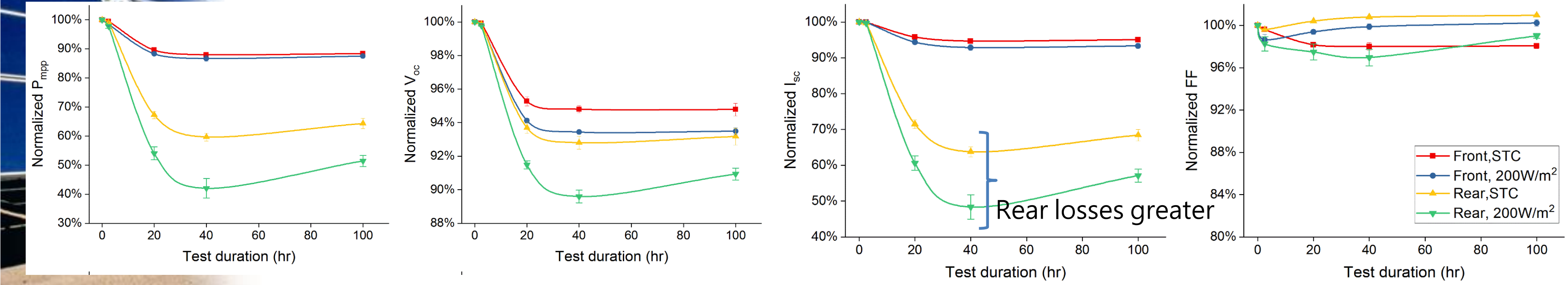
Pingel and coworkers 2010 IEEE PVSC

PID-Polarization



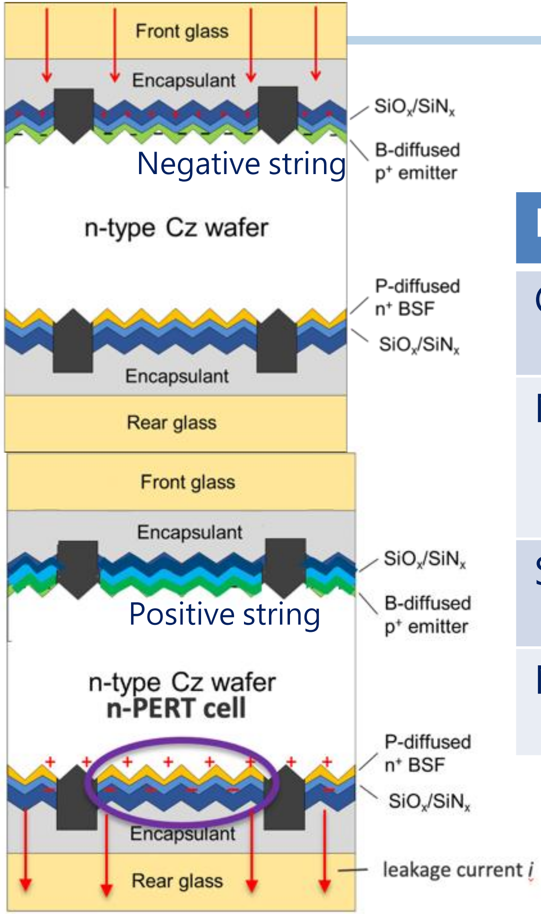
Negative string

PID type	PID-polarization (PID-p)
Cell types	Bifacial PERC (PERC+)
Mechanism	正電荷聚集在背介電層，吸引p型的少數載子電子聚集，導致再複合損失
Sensitivities	系統負偏壓, undoped surfaces
Mitigation	背面使用AlOx/SiO2/SiNx 結構, 阻抗更大的封裝材與透明背板 UV irradiation



Rear losses greater

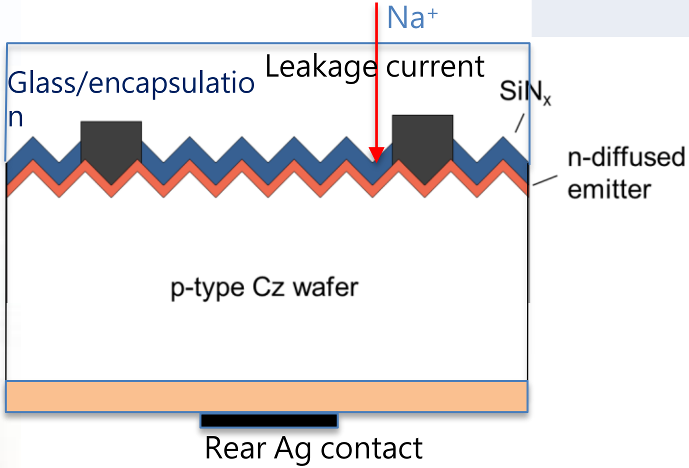
PID-Polarization

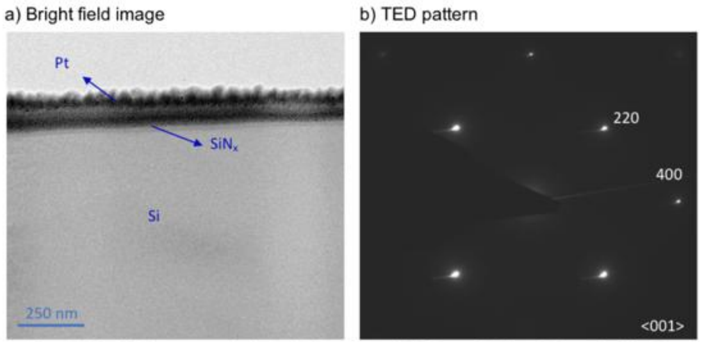


PID type	PID-polarization (PID-p)
Cell types	PERT & TOPCON front; SunPower type n$^+$/n front IBC and PERT rear
Mechanism	正電荷聚集在正面介電層，吸引p-emitter的少數載子電子聚集，導致再複合損失（IBC front 與PERT rear相反）
Sensitivities	系統負偏壓（IBC front 與PERT rear相反）, lightly doped emitter
Mitigation	選擇AR coating的介電層 減少矽晶裡的類缺陷, UV irradiation

PID-Penetration

PID type	PID penetration
Cell types	Various
Mechanism	Na+電荷遷移擴散到矽，穿越介電層導致表面再複合速度上升 (沒有達到造成junction短路)
Sensitivities	系統負偏壓 , lightly doped emitters
Mitigation	選擇AR coating的介電層 阻抗更大的封裝材





TEM results: a) bright-field image on a typical area showing no extended defects on PID-degraded area; b) diffraction pattern showing that Si is crystalline.

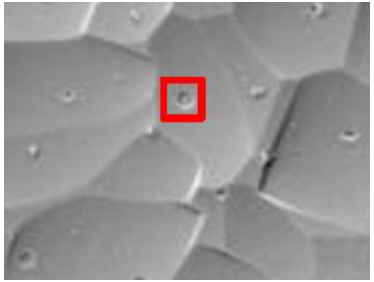
PID-Corrosion

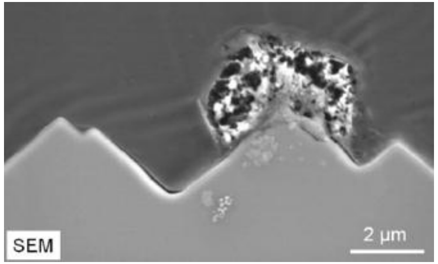
85°C/85%RH/+600V/2000 h
結果顯示SiN層退化

4年戶外1500V系統有類似症狀

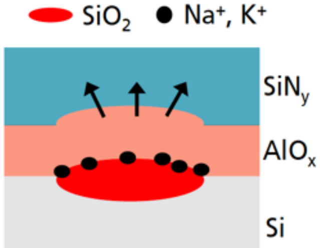
P. Hacke et. al,
2014 IEEE PVSC

PID type	PID corrosion
Cell types	Various
Mechanism	對cell的負偏壓：矽的陰極反應 ，產生NH_3和 hydrous silica
Sensitivities	高濕度、高系統電壓
Mitigation	研究不多，但是預期阻抗更大的封裝材有幫助



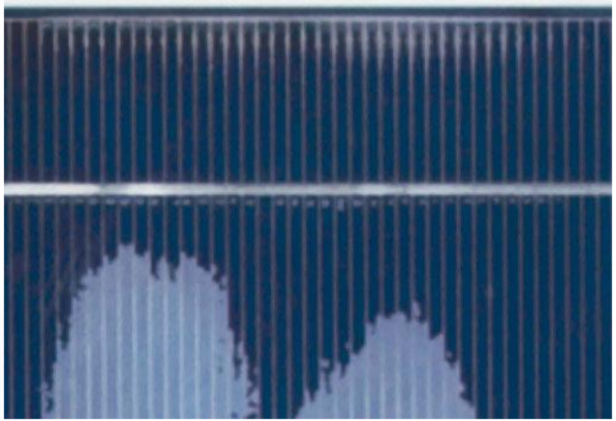


Ohdaira et. al. EUPVSEC 2019
Sporleder et al Phys. Status Solidi RRL2019,13, 1900163

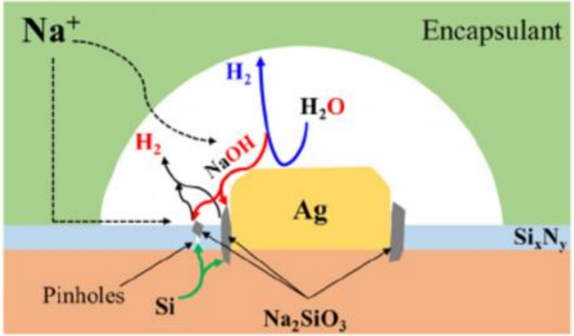


Na-based domes which partly destroys the surface SiN_x. -1000 V to cell

PID-Delamination

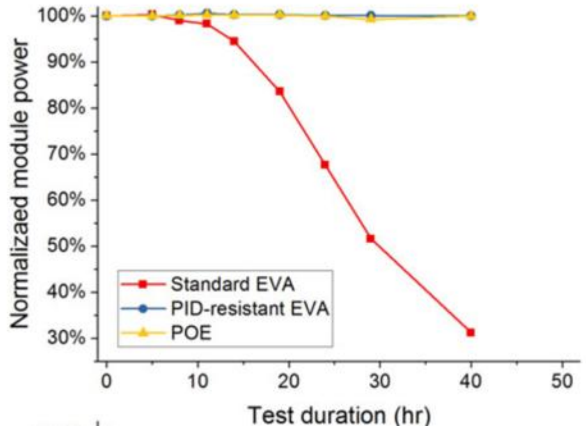


PID type	PID-delamination
Cell types	Various
Mechanism	負偏壓、Na累積在cell表面導致腐蝕與脫層,與副產物氣體的電化學反應
Sensitivities	高濕度, UV light
Mitigation	研究不多，但是預期阻抗更大的封裝材有幫助

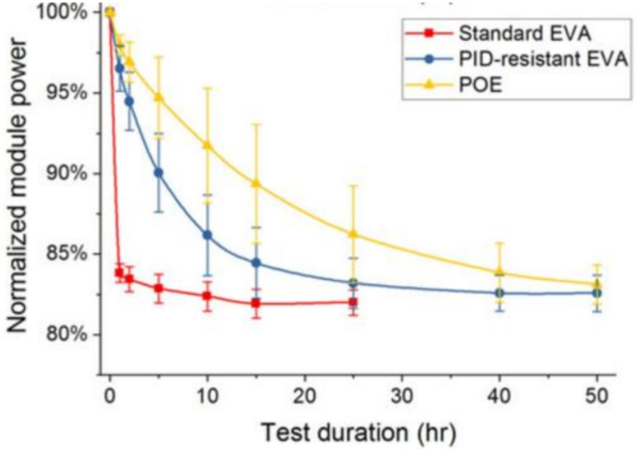


J. Li, Yu-C. Shen, P. Hacke, M. Kempe
Solar Energy Materials and Solar Cells 188
(2018)

Encapsulant



傳統電池片的PID-s fronts



PERT cell的PID-p front

50 °C, 30% RH, and −1000 V with test configuration

Luo and coworkers IEEE J. PHOTOVOLTAICS, 8(1), 2018

背面POE/glass沒有完全避免PID-p

Degradation Modes of HJT and TOPCon Cells

Silicon Heterojunction Degradation

Jordan *et al.*:

- 顯著的V_{OC} 衰減
  - ○ 特別是最開始兩年
- 戶外模組顯示增加：
  - ○ Series resistance (R_S)
  - ○ Diode one recombination current density (J_{01})

Subsequent studies [2, 3]

- 證實 R_S and J_{01} increases

提出的機制:

a-Si:H 衰退 → Non-radiative recombination → Increased J_{01}

TCO衰退 → Increased R_S → Reduced FF

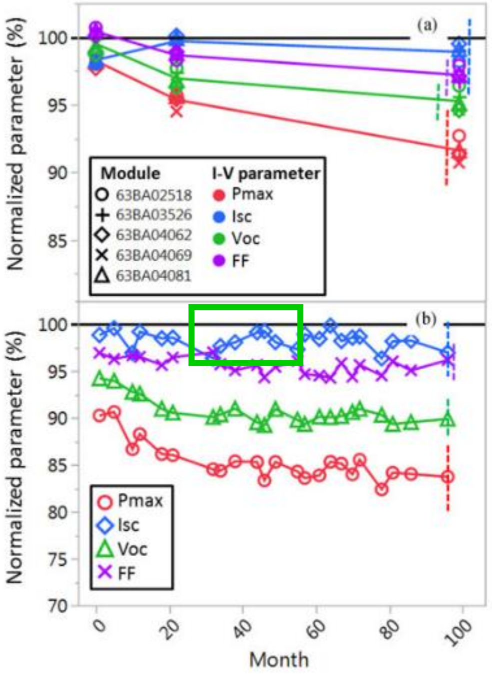


Fig. 4. Indoor I–V measurements on the LACSS for all 5 modules (a), and outdoor I–V measurements on the system adjusted to a module temperature of 45° (b) and normalized by nameplate value. Uncertainty bars, only shown for one data point, are indicated by dashed vertical lines and are offset for better visibility.

結論

PERC

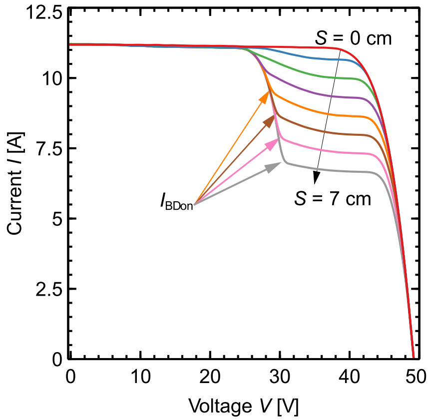
- 濕氣/熱沒有造成明顯cell衰退
    - I_{sc}衰減
- 對醋酸造成的衰退大都有抵抗力，發生在正面導體

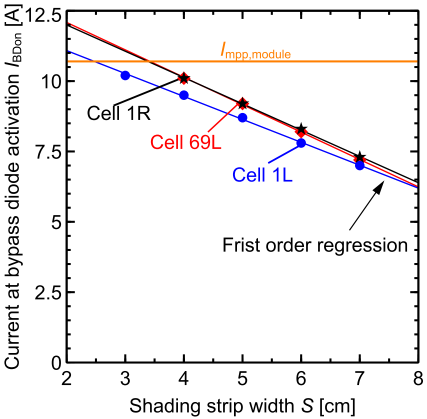
SHJ cells

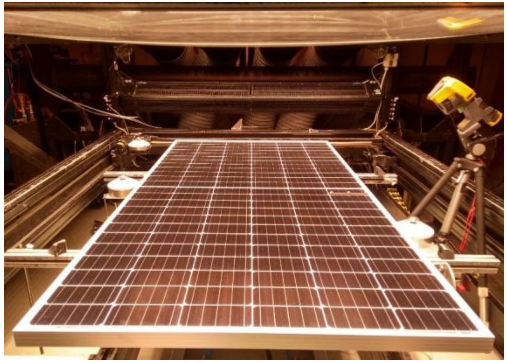
- 濕氣/熱沒有造成明顯cell衰退 (1700 hrs DH)
- 醋酸造成的衰退大都與再複合相關
    - 即使長時間測試後，正面導體都維持得很好
- DH造成ITO表面改變是一致的
    - with increased sheet resistance;
    - 部份銀氧化發生，這些改變沒有導致Isc損失
- 只有DH不會造成Voc因為再複合損失而衰減
    - 醋酸才會

HOT CELLS in new PV modules

熱斑測試的最不利遮蔽條件

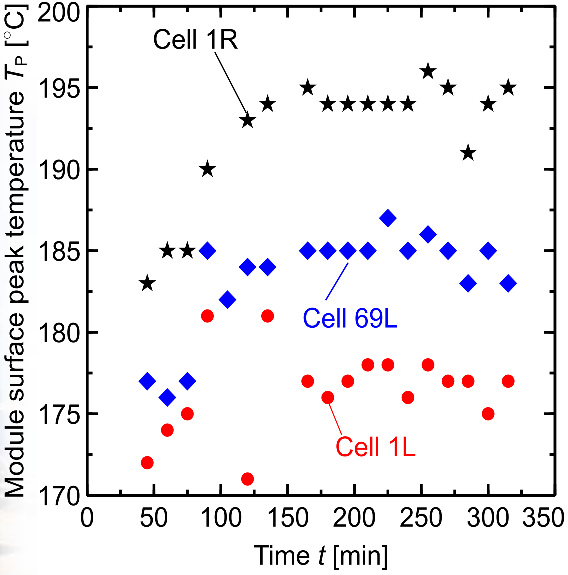




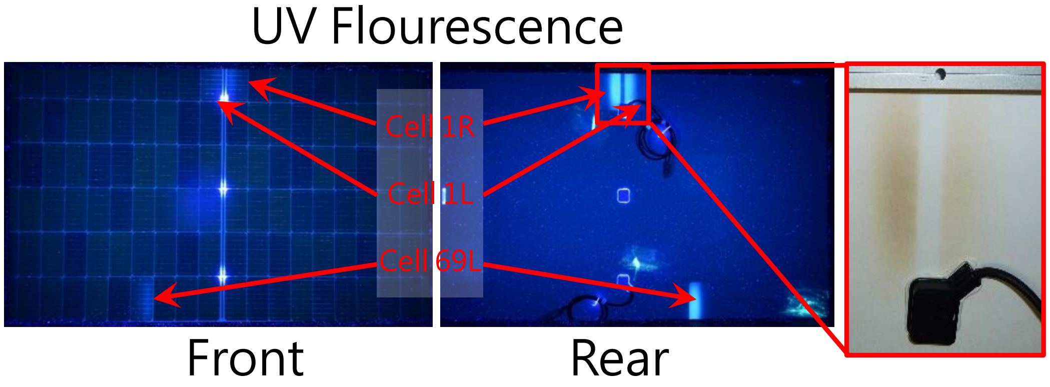


R. Witteck, et al., EUPVSEC 2021, 4AV.1.25

模組溫度



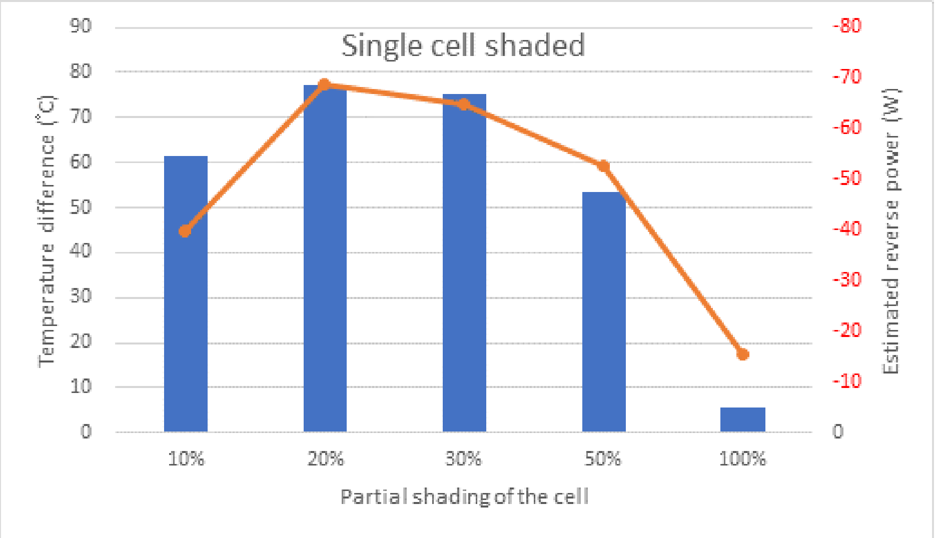
R. Witteck, et al., EUPVSEC 2021, 4AV.1.25



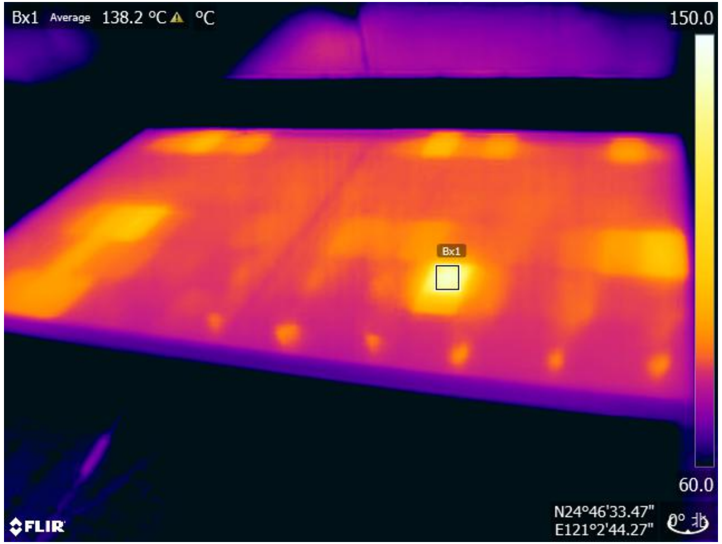
- 同時遮被左右各一片 1L+1R
- 最高溫cell 1R 196°C

A. Morlier, et al., *IEEE JPV*, vol. 7, nr. 6, pp. 1710-1716, 2017

溫度與逆偏壓功率

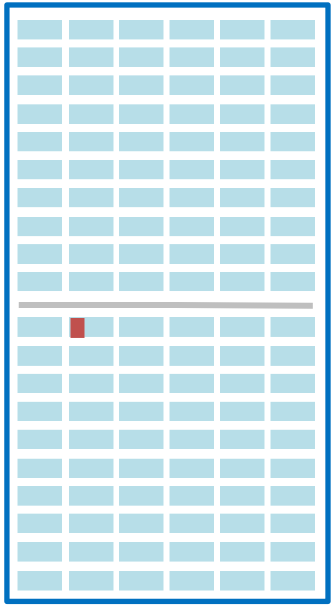


遮蔽電池的逆偏壓功率與溫度相關性高



ITRI量測中心/PV Guider合作測試

半切模組不同運行模式下的最不利狀況

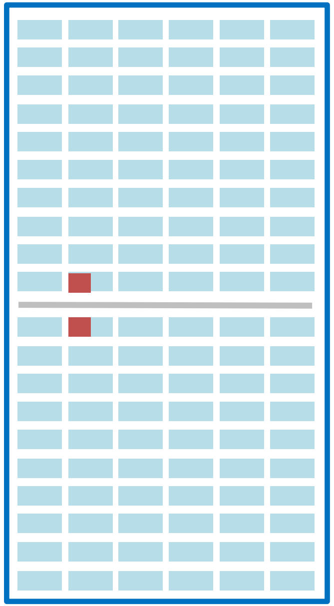


Short circuit

1 cell

20% shading

$P_{revse} = 68.87$ W

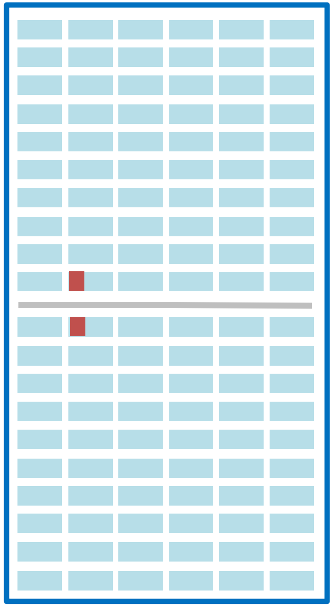


MPPT

2 cells

50% shading

$P_{revse} = 52.67$ W



Imp

2 cells

25% shading

$P_{revse} = 64.99$ W

Perovskite and tandem degradation challenges and mitigation strategies

Degradation Modes for Perovskite PV

Perovskite PV 材料的特性：

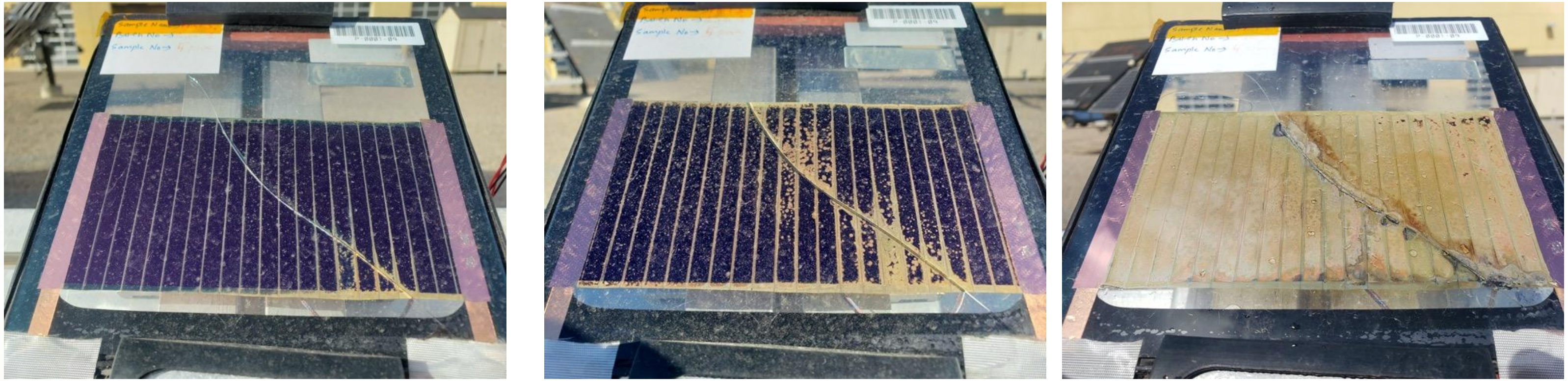
- **弱鍵結**讓離子隨電場移動
- 暴露在**濕氣**、**氧氣**、**熱**、**光**的衰退可能性高

封裝需要與水汽隔離且留住氣體

- 產生氣體的化學反應是可逆的

衰退模式分類：

- **外在因素Extrinsic**（water, oxygen, mechanical stress, PID）
- **內在因素Intrinsic**（相穩定性,鹵化物偏析, 分解, 離子遷移）
- **裝置因素Device specific**（電極擴散, 導電層反應, 逆偏壓）



Keep Green Gold Shining

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