Australian National University

The Impact of Perovskite/Silicon Tandem Module Design on Hot-Spot Temperature

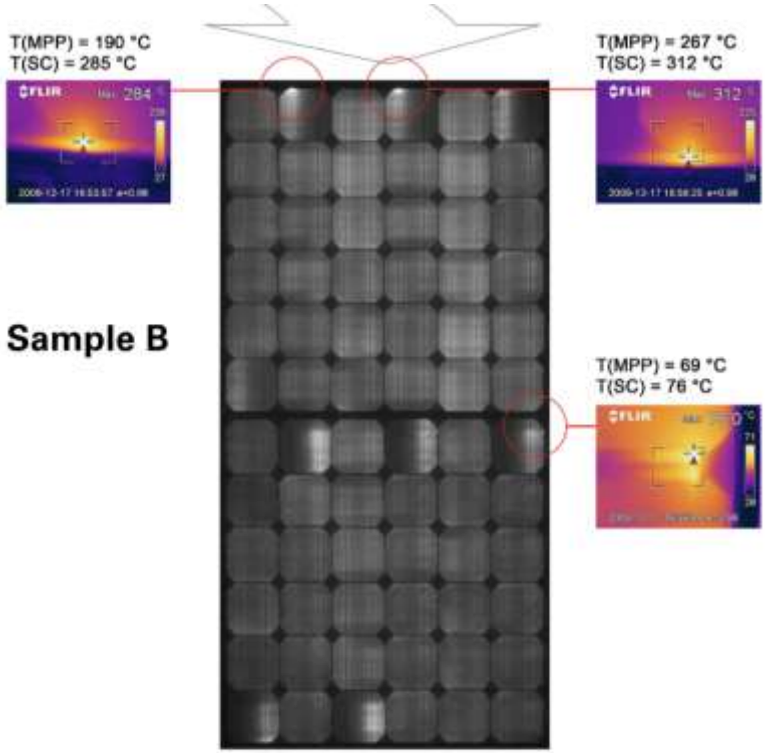
Jiadong Qian, Andrew Thomson, Yiliang Wu, Klaus Weber, Marco Ernst and Andrew Blakers

Australian National University, Canberra, ACT 0200

E-mail: jiadong.qian@anu.edu.au

Hotspot effect in Si module

- Mismatch of current generation capacity within a module causes reverse biased cell(s)
- Reverse biased cell dissipates heat if:
  - partially illuminated
  - allows leakage current to flow
- Shading, cell cracking, bad soldering, inhomogeneous cell degradation etc. can lead to current mismatch



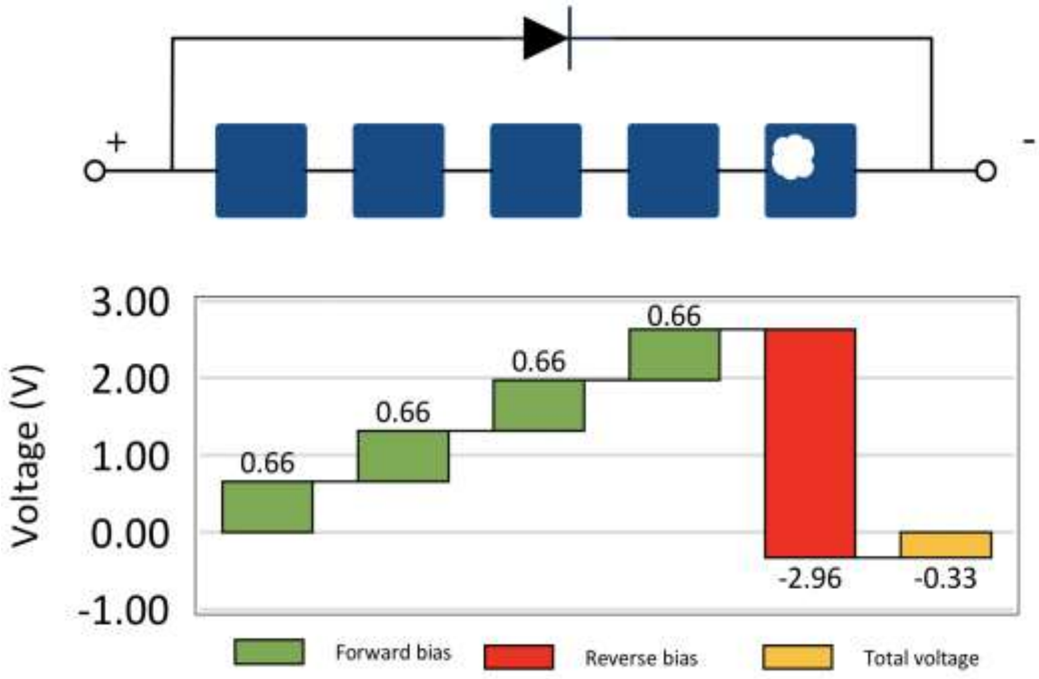
Experiments by BP solar showed a maximum module temperature of 267 ℃ under realistic conditions[1]

Current solution to the hotspot effect

- To use bypass diodes to limit the reverse bias of the compromised cell

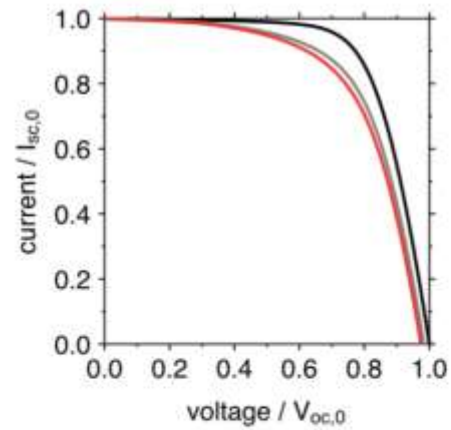
- Reverse bias $\geq -\sum V_{mp}$ (illuminated cell)

- Commercial 72-cell Si module with 3 bypass diodes typically have a reverse bias of -14V at a shaded cell.



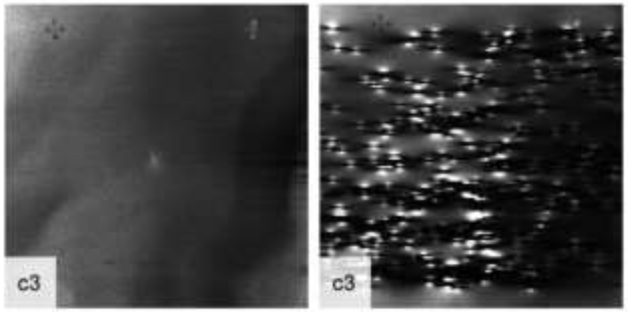
Thin-film modules

- The electrical and thermal impact of the hot spot effect revealed in 2015[2]
- Experiment results show permanent P_{mp} loss between 4% and 14% caused by brief partial shading events



Before

After stabilized



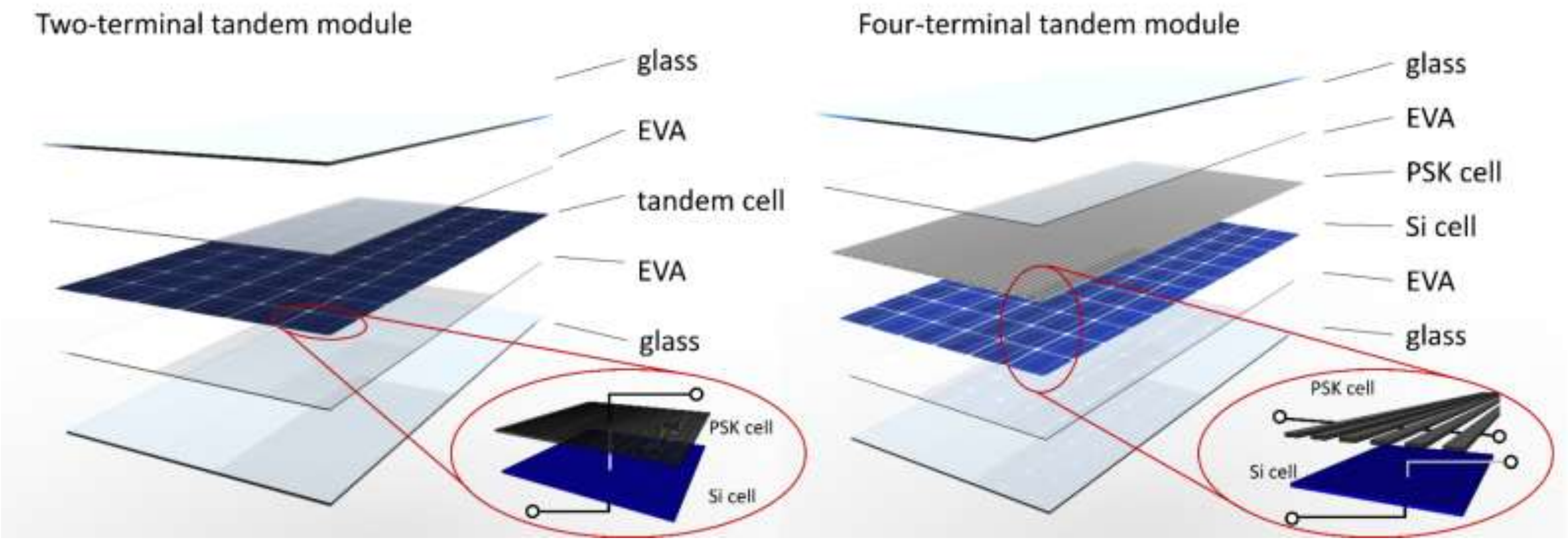
Studied tandem module configurations

Two-terminal module

- 72 tandem cells with 15.6 x 15.6 cm^2 dimension
- Power conversion efficiency of 23.7%

Four-terminal module

- 48 PSK top cell strips with 191.6 x 2 cm^2 with efficiency of 16.4%
- 72 Si bottom cells with 15.6 x 15.6 cm^2 dimension with filtered efficiency of 10.4%
- Mono c-Si and IBC Si bottom cells simulated

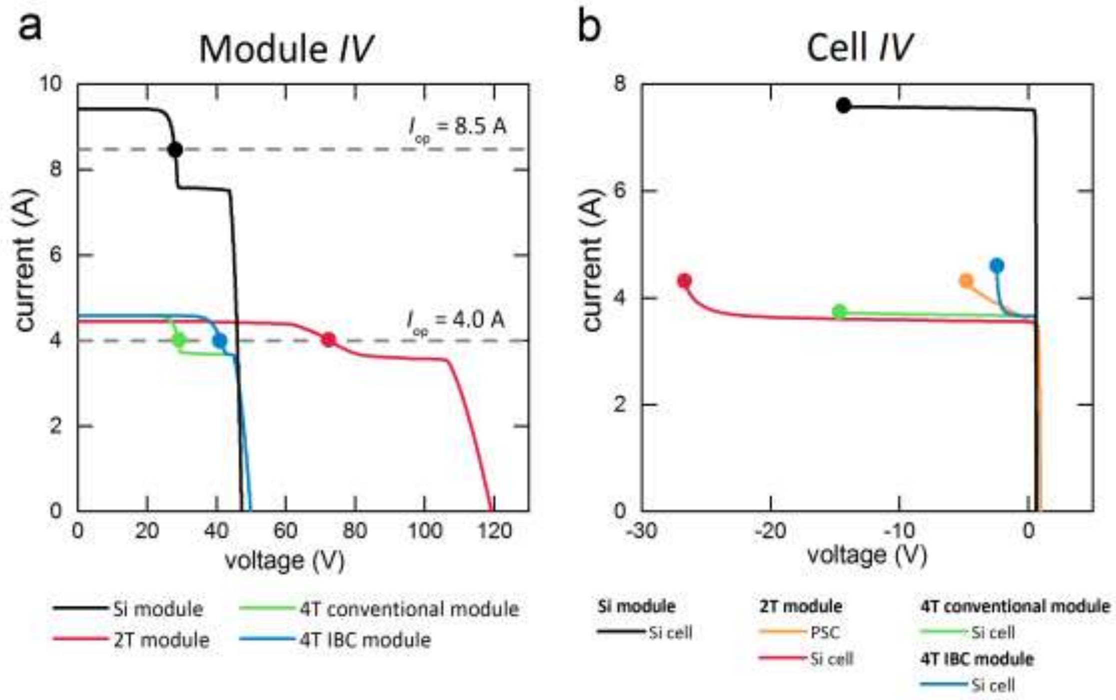


Simulation Method

- Assumption
  - Forward and reverse bias behavior taken from latest best cells
  - Homogenous heat dissipation
  - Steady state cell temperature
  - Only spot shading (<15.6 x 15.6 cm^2) effect is considered
- Electrical modelling
  - MATLAB based PV module mismatch simulator
  - Current Si diode model and breakdown model to fit the PSK cell *IV* characteristics
- Thermal modelling
  - One-dimensional heat transfer model

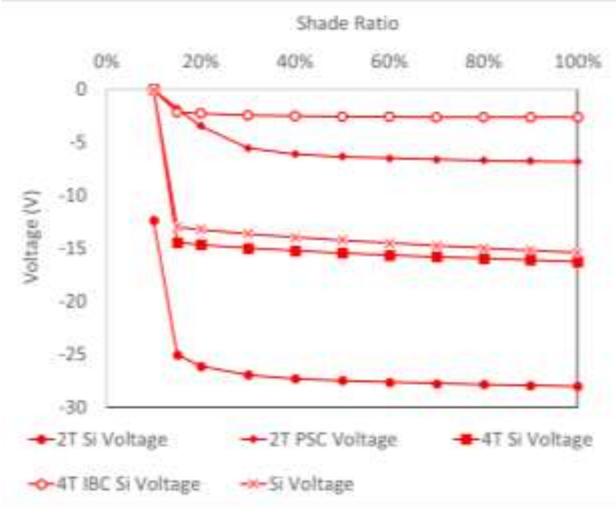
Results – Impact of a shade on module and cell

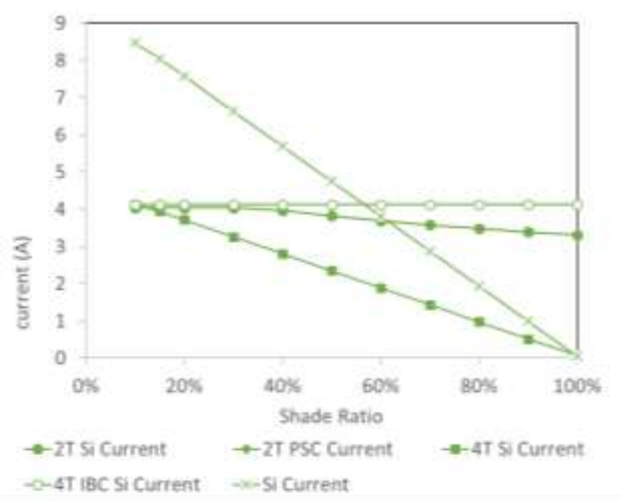
- A shade area equivalent to 20% of a Si cell is applied to modules
- Modules operate at their maximum power current when no shade is applied
- Shade causes bending of module *IV* and reverse bias of cells



Results – cell operating conditions

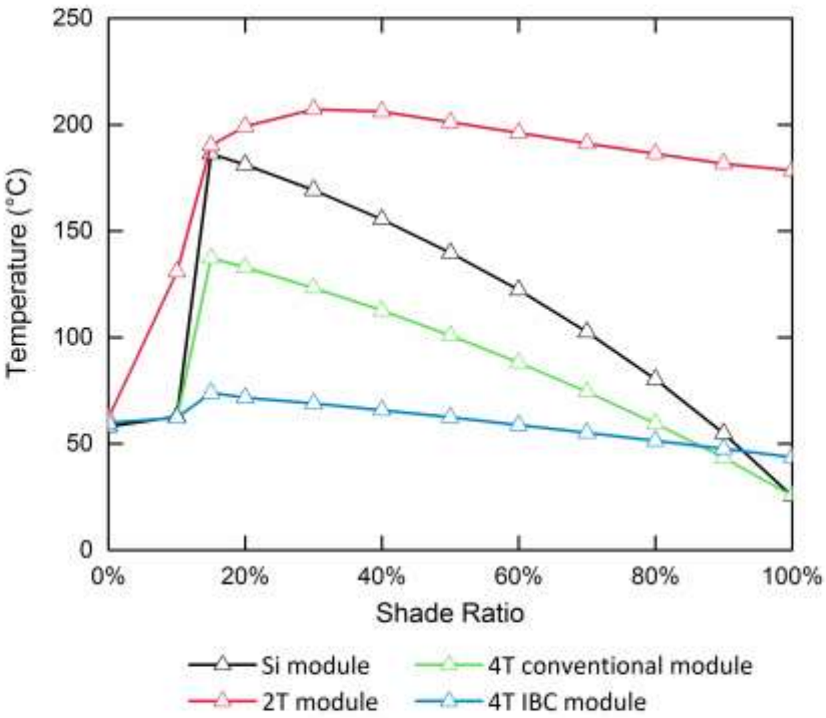
- Si cells in all four modules are reverse biased, as well as the PSK cell in the 2T module
- Simulate shading conditions from 0% to 100% of a 15.6 x 15.6 cm^2 cell area
- Si cells in 2T module are most reverse biased due to high cell voltage





Results – Simulated temperature

- Peak temperature of 207℃ found in the 2T module at shading ratio = 30%
- Benefiting from the PSC filter, Si cells in 4T modules have lower hot spot temperatures compared with conventional Si module
- ‘Leaky’ reverse bias behavior keeps reverse bias and temperature very low in the 4T IBC module



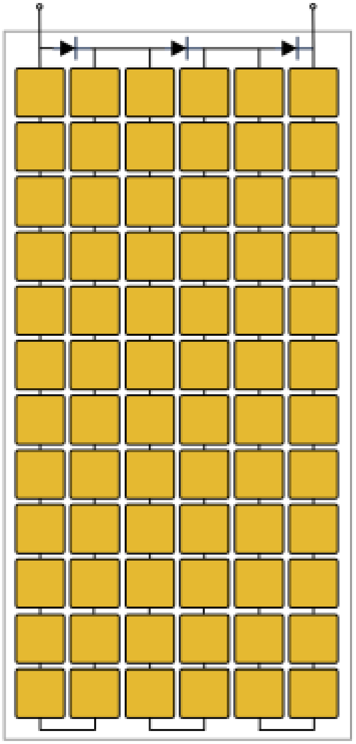
Comparison with the critical temperature for PSC stability

- 2T 72-cell module :
  - 207℃ at 30% shading
  - 178℃ at 100% shading
- 4T PERC module
  - 137℃ at 15% shading
  - ≤90 ℃ at shading ≥ 60%
- 4T IBC module
  - ≤75 ℃ for all conditions

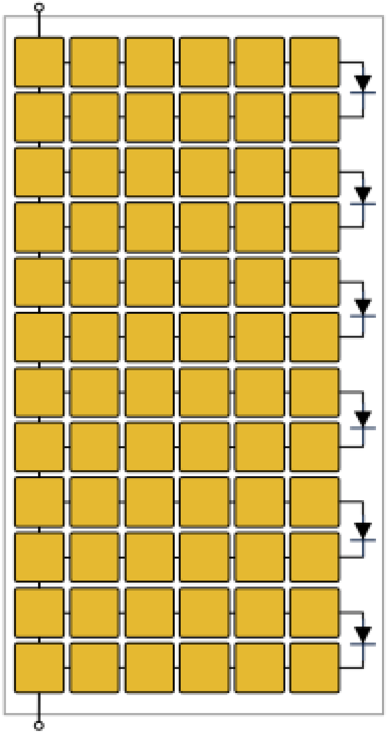
- Light harvester for high-efficiency PSCs, ($MAPbI_3$) begin decomposition between 234 °C and 300 °C [3,4]
- Hole-transport material spiro-OMeTAD and PTAA) degrade between 90 °C and 100 °C [5,6]
- Temperatures above 100 °C could cause interfacial degradation[6]
- High temperature induced mechanical stress

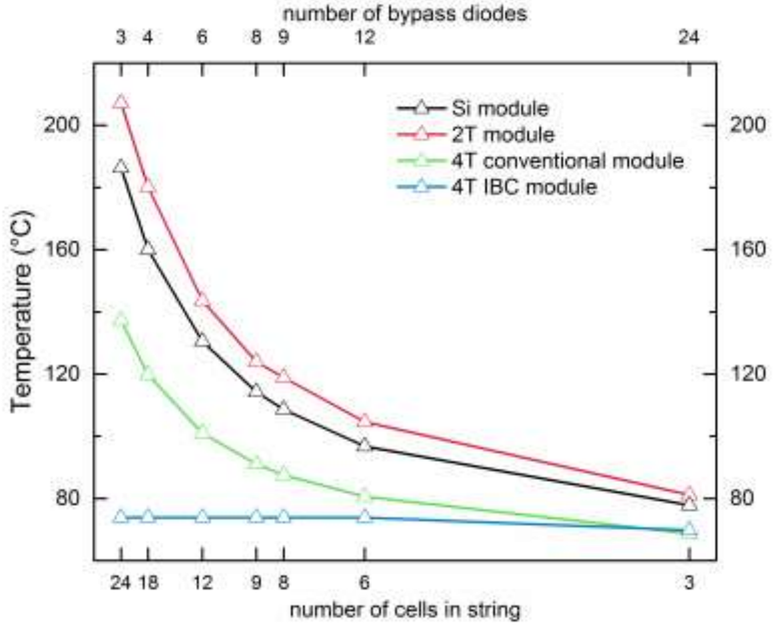
More bypass diodes/shorter cell strings

Three-bypass-diode configuration



Six-bypass-diode configuration

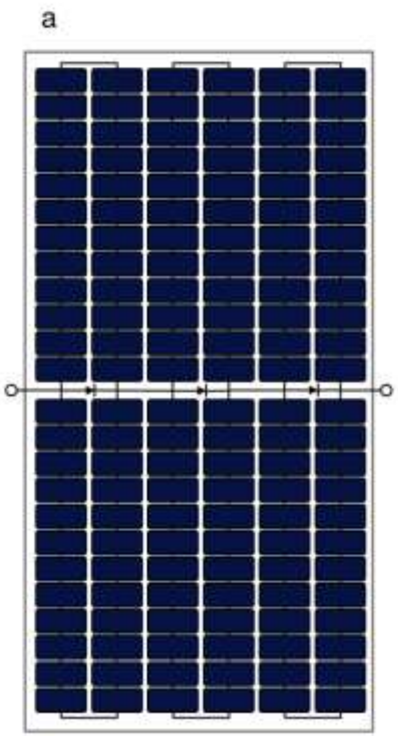




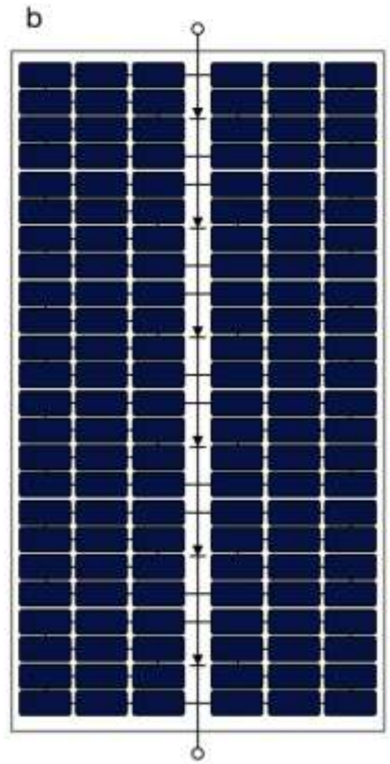
Peak PSC temperature simulated in the four modules using 3-24 bypass diodes in a 72-cell module

Cut cells in half + series-parallel-series connections

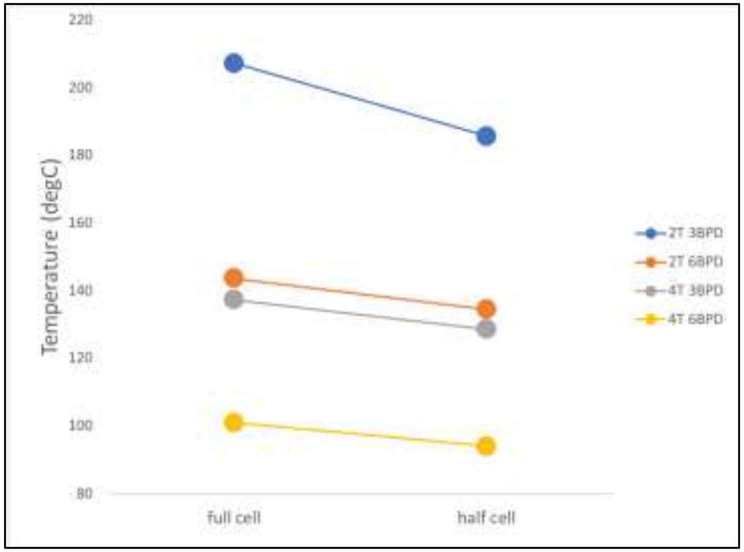
Three bypass diodes half-cell



Six bypass diodes half-cell



- Current compensation between parallel connected strings
- 22 ℃ temperature reduction in 2T module using 3 bypass diodes
- 73 ℃ temperature reduction to 134 ℃ if double the bypass diodes



Thank you

Reference

1. Cunningham, D. W. (2011). Analysis of Hot Spots in Crystalline Silicon Modules and their Impact on Roof Structures. Photovoltaic Module Reliability Workshop 2011, Denver Colorado, National Renewable Energy Laboratory.
2. Silverman, T. J., et al. (2015). "Thermal and electrical effects of partial shade in monolithic thin-film photovoltaic modules." IEEE Journal of Photovoltaics 5(6): 1742-1747.
3. Conings, B., et al. (2015). "Intrinsic Thermal Instability of Methylammonium Lead Trihalide Perovskite." Advanced Energy Materials 5(15).
4. Dualeh, A., et al. (2014). "Thermal Behavior of Methylammonium Lead-Trihalide Perovskite Photovoltaic Light Harvesters." Chemistry of Materials 26(21): 6160-6164.
5. Divitini, G., et al. (2016). "In situ observation of heat-induced degradation of perovskite solar cells." Nature Energy 1: 15012.
6. Kim, Y. C., et al. (2017). "Engineering interface structures between lead halide perovskite and copper phthalocyanine for efficient and stable perovskite solar cells." Energy & Environmental Science 10(10): 2109-2116.