NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Silicon Heterojunction Field Performance

Silicon Heterojunction Workshop

Virtual

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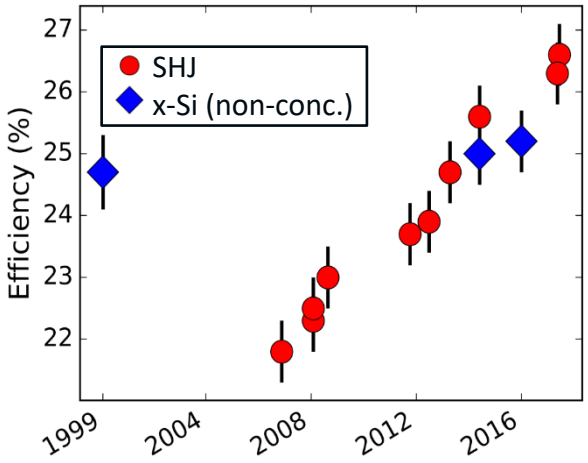
10/20/2020

Outline

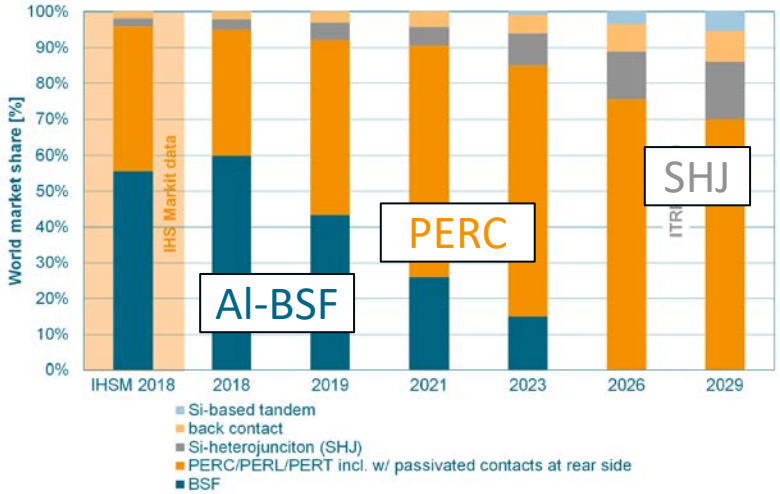
- Introduction
- Compare silicon heterojunction (SHJ) system performance loss to other high efficiency systems such as PERC, IBC
- 10-year-old SHJ system characterization
- More recent SHJ installation
- Conclusion

Motivation

World record cell efficiency



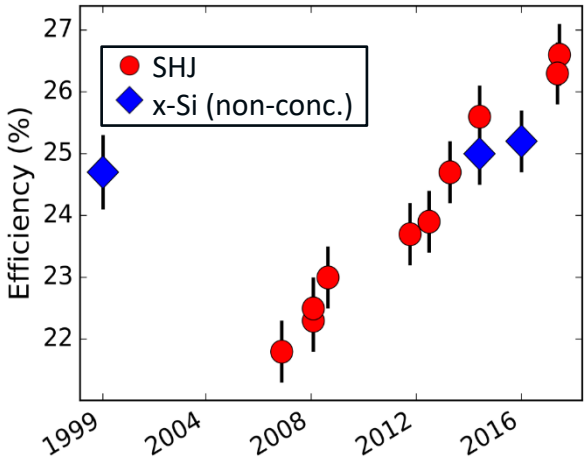
ITRPV 2019



- World record cell efficiency
- Market share projected to grow
- Good bifaciality factor
- Circular economy: may be some advantages

Motivation

World record cell efficiency



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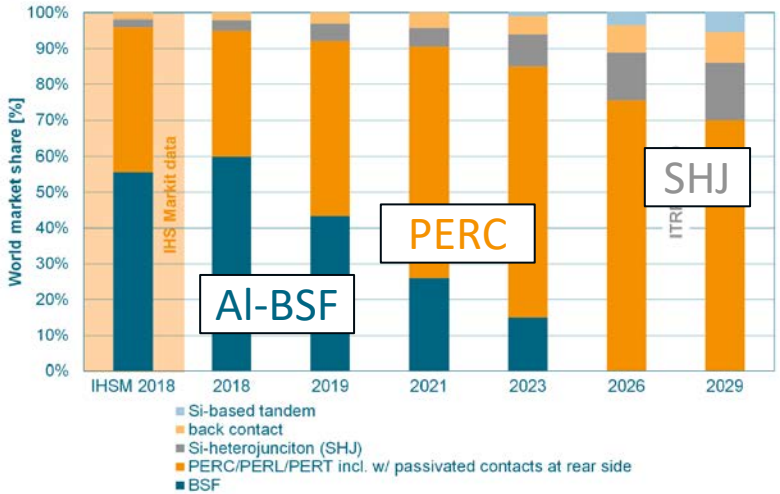
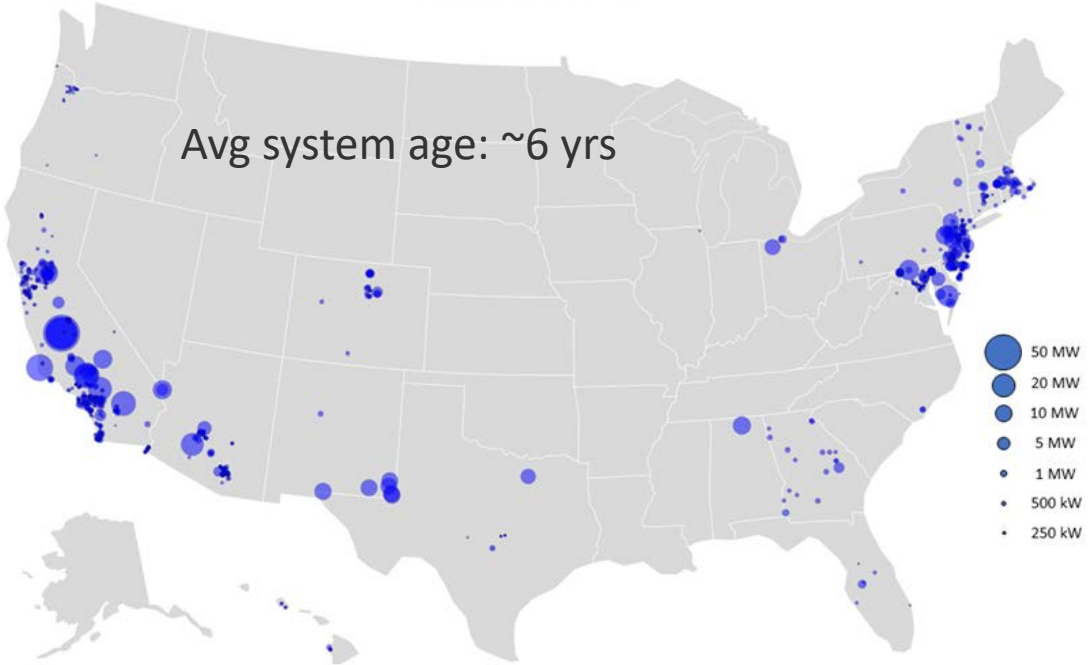


- World record cell efficiency
- Market share projected to grow
- Good bifaciality factor
- Circular economy: may be some advantages

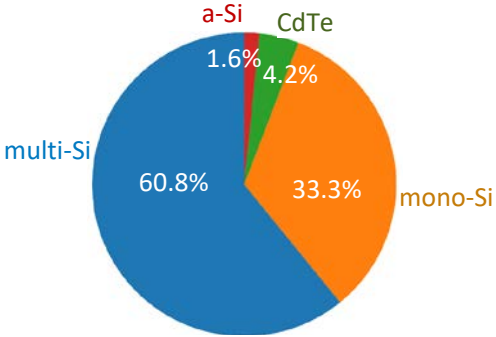
Yet, our field performance knowledge is limited

PV Fleet Project

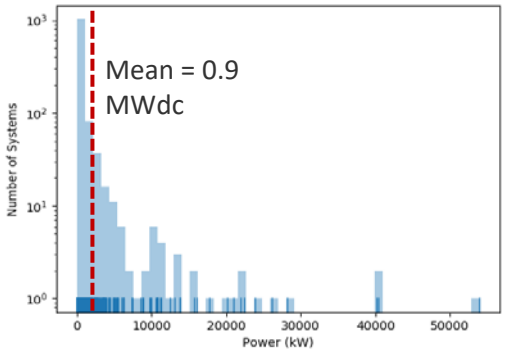
>1400 systems, > 13,600 Inverters, >2.4 GWdc capacity



Module technology breakdown



System Power Distribution



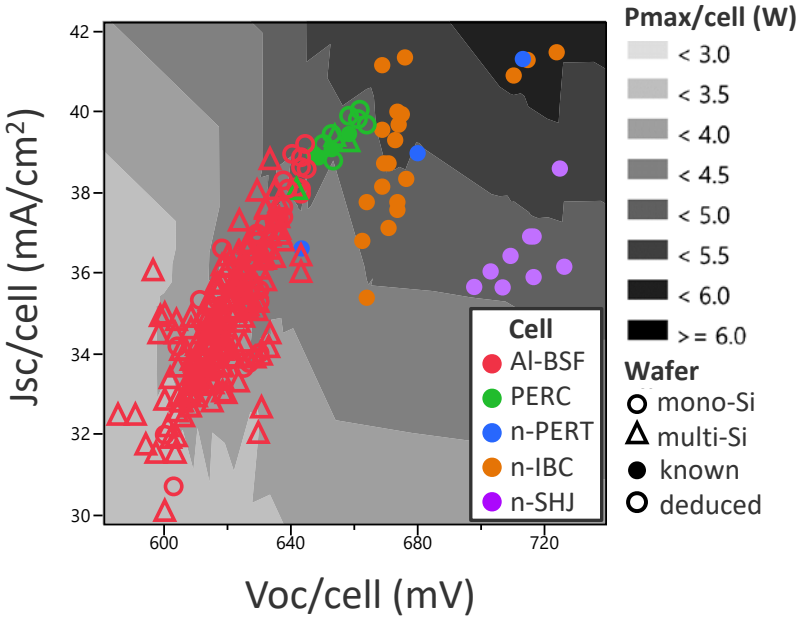
How many systems with high-efficiency modules?

C. Deline et al., *PVSC* 2020

Silicon cell technology in PV Fleet+

Problem: often used cell technology not specified on datasheet

Scale IV parameters to the same number of cells & cell area

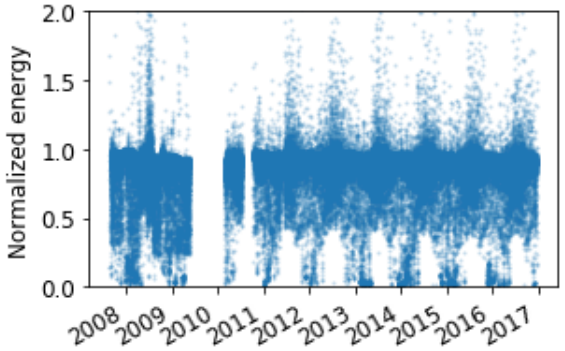


Al-BSF: Aluminum back surface field
PERC: passivated emitter & rear cell
PERT: passivated emitter rear, totally-diffused
SHJ: heterojunction
IBC: interdigitated back contact

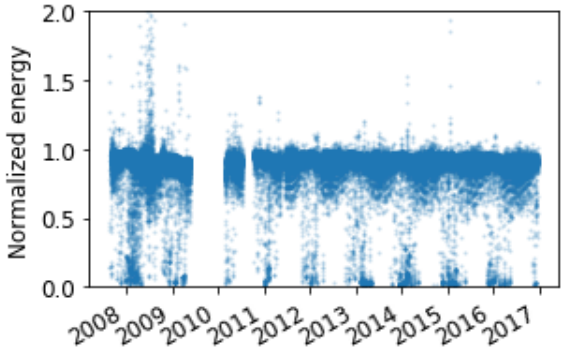
Can reasonably well identify cell technologies from datasheet entries
(although a few systems in the PERC/Al-BSF transition region may be misidentified)

RdTools workflow

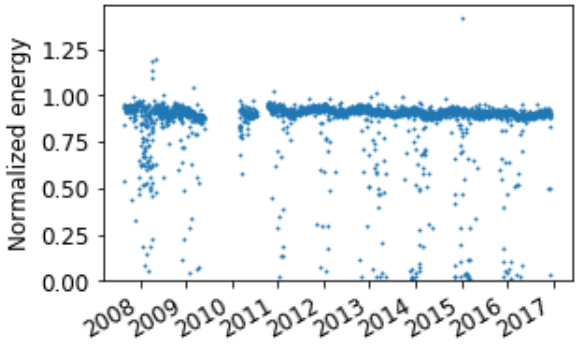
Normalized



Filtered



Aggregated



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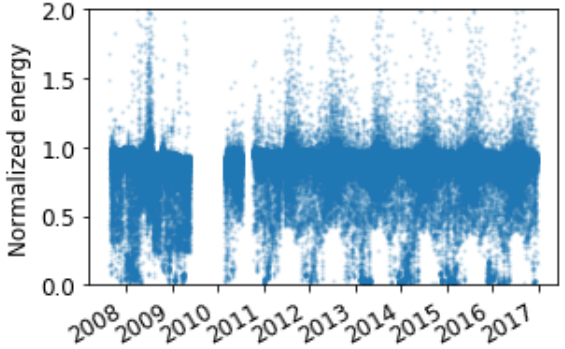

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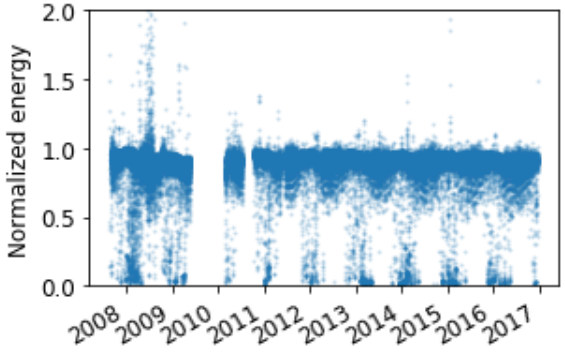

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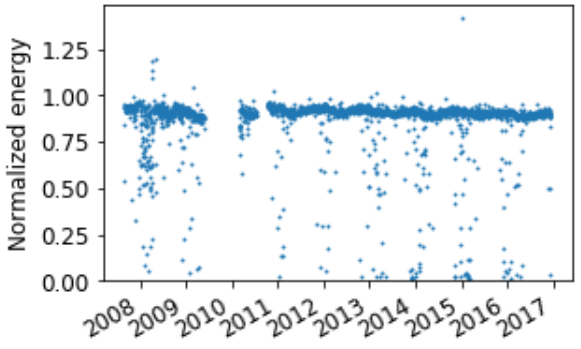
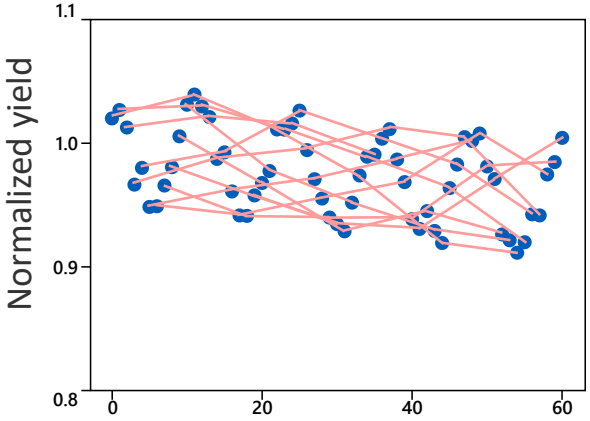
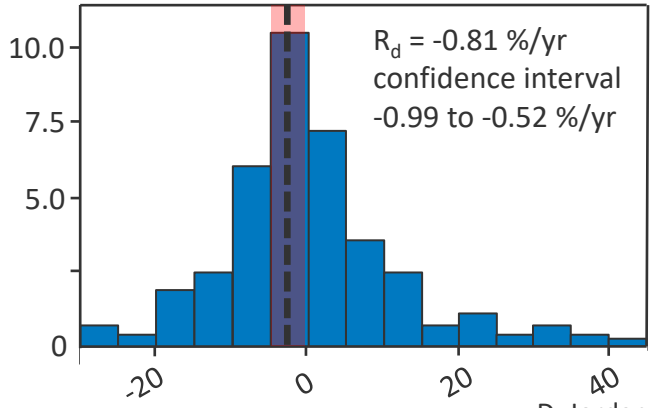




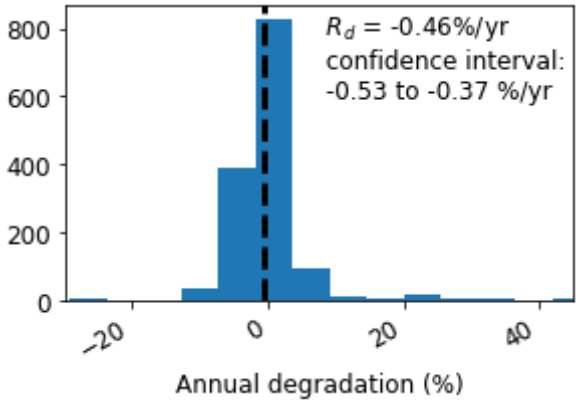


https://github.com/NREL/rdtools

D. Jordan et al., JPV, 2018
M. Deceglie et al, JPV , 2019

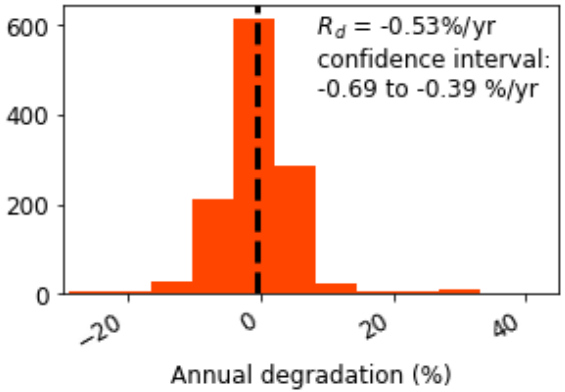
Normalization of PV performance with irradiance

1. Local sensor(s)



- ☺ More precise
- ☹ Sensors are prone to drift b/c lack of calibration

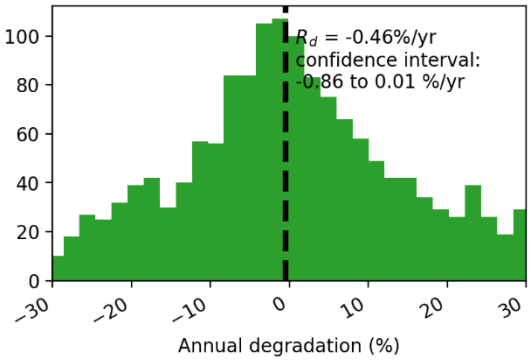
2. Clearsky



Use modeled clearsky irradiance to normalize & use local sensor to determine when it the sky is clear

- ☺ Robust to sensor drift
- ☹ Less precise (higher uncertainty)
- ☹ Assumes local irradiance does not change (Δ air pollution)

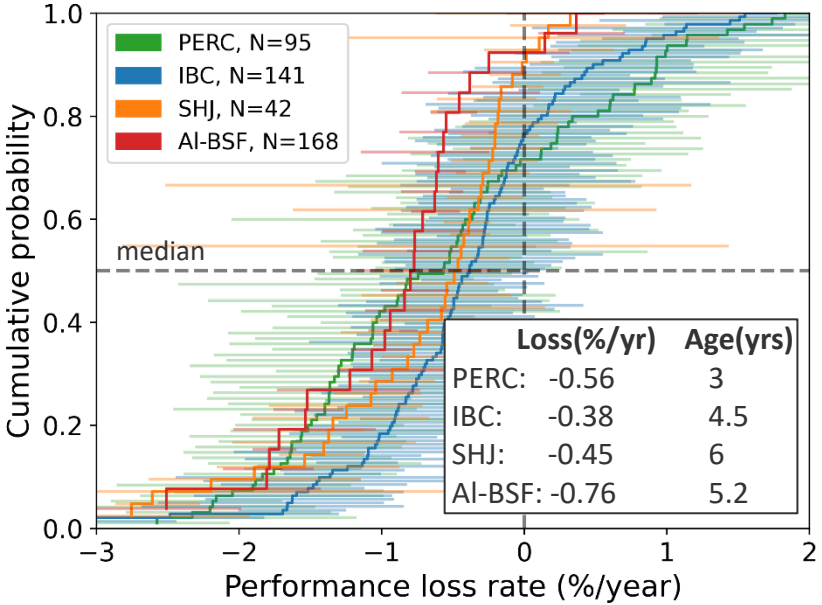
3. Satellite



- ☺ Robust to local irradiance changes for < 5 years
- ☹ Less precise
- ☹ Availability

Performance loss rates for high-efficiency systems

Cumulative distribution function (CDF) of high-efficiency systems



"Degradation rate" can be ambiguous → performance loss rate

Satellite data used for irradiance

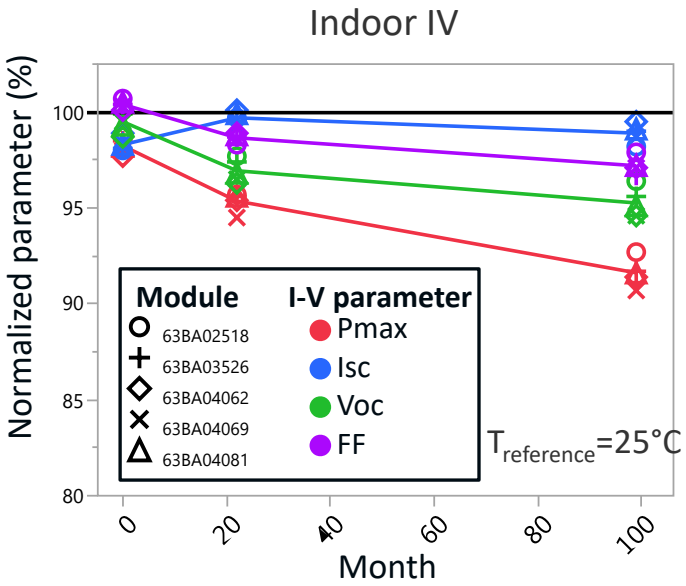
AC power results

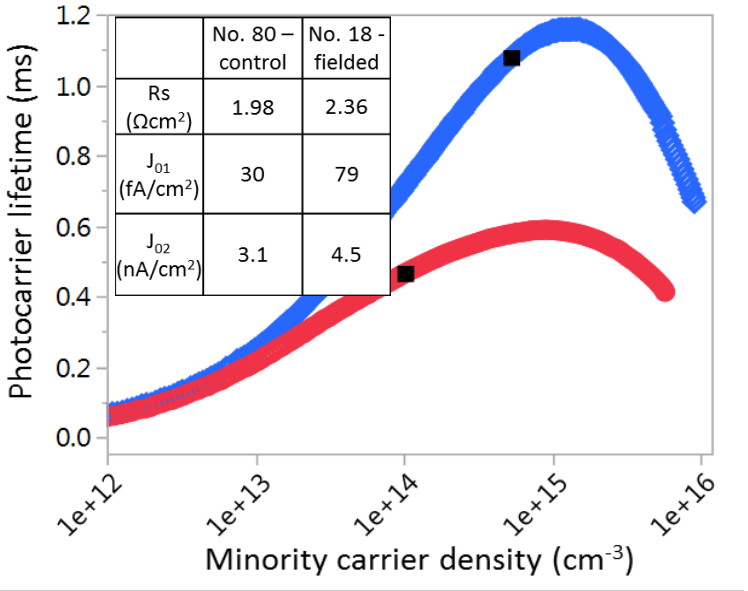
Installation in Southern California

Ground-mounted installations

At the median, performance loss rates for SHJ, IBC, PERC are at least as good as Al-BSF

SHJ NREL installation: Nonlinear decline in V_{oc}





Installed: 2007
Size: 1kW, 5 modules
Age: 10 yrs
Mounting: ground

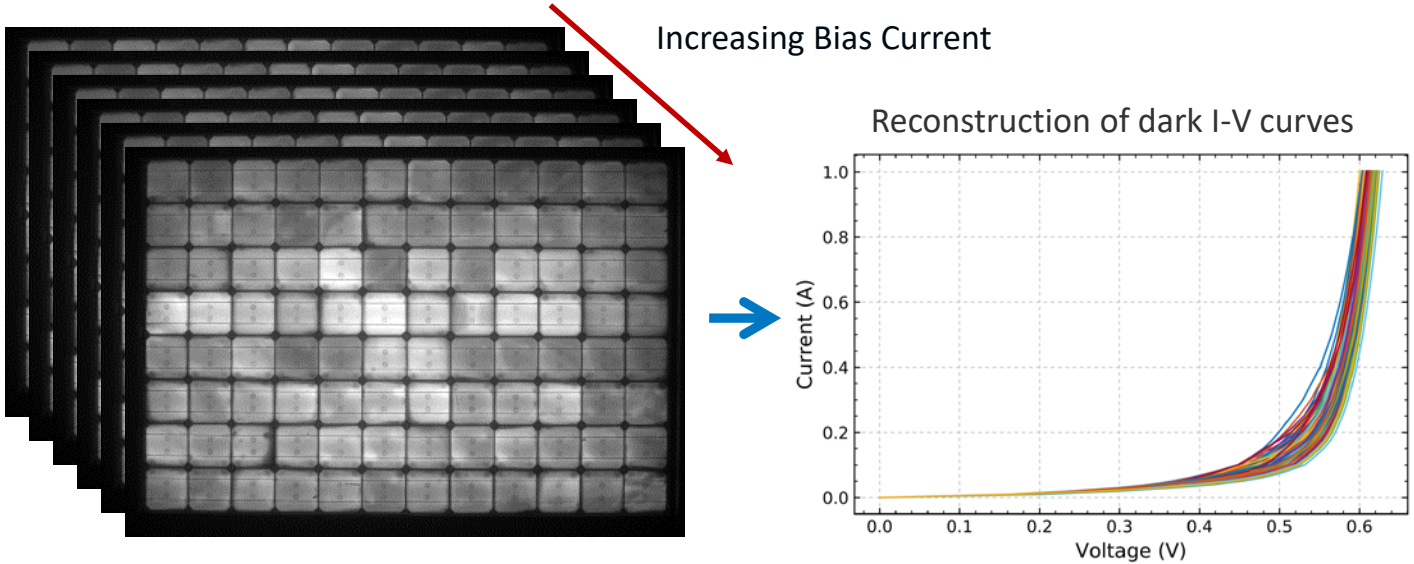
Voc: most of the decline in first 2 years
FF: small decrease, Rs increase (no solder bond problems, corrosion, cell breakage)
Isc: within measurement uncertainty

Degradation 0.4-0.6 %/year range, within warranty

D. Jordan et al., *JPV*, 2018

Electroluminescence (EL) mapping

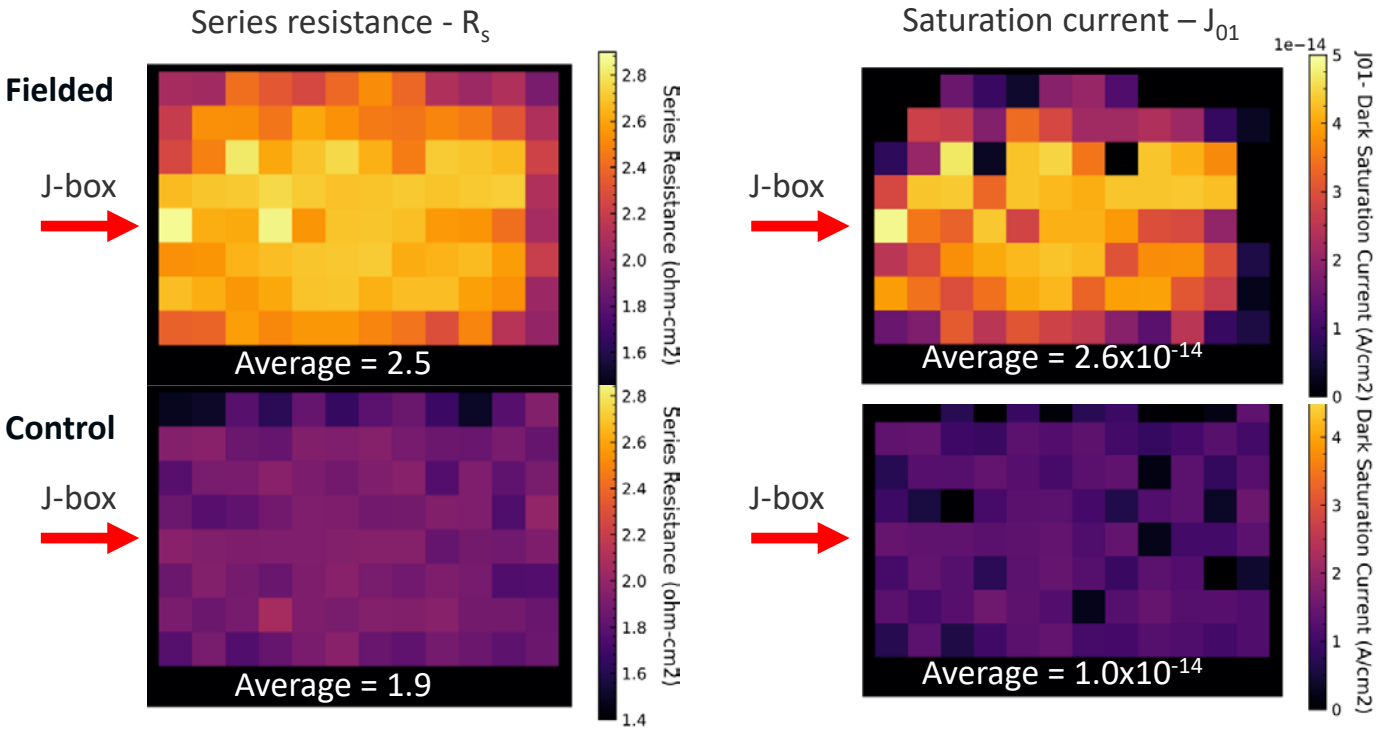
Take images under a range of bias currents
($<10\%\ I_{sc} - I_{sc}$)



Fit 2-diode model → can map diode parameters for each cell within the module

T. Potthoff et al. , *Prog. in PV,* 2010

Fairly uniform increase in J_{01} & R_s

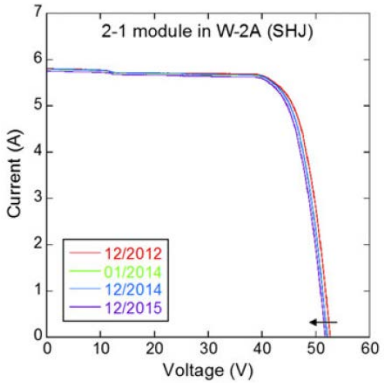


Cell over the J-box shows highest increase in J_{01} & R_s → temperature may play a role

D. Jordan et al., *JPV*, 2018

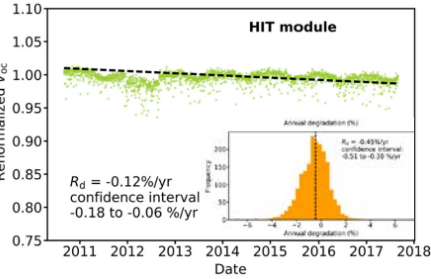
Similar findings in 2 publications

Japan



Installed: 2012
Age: 5 yrs
Mounting: ground

Singapore



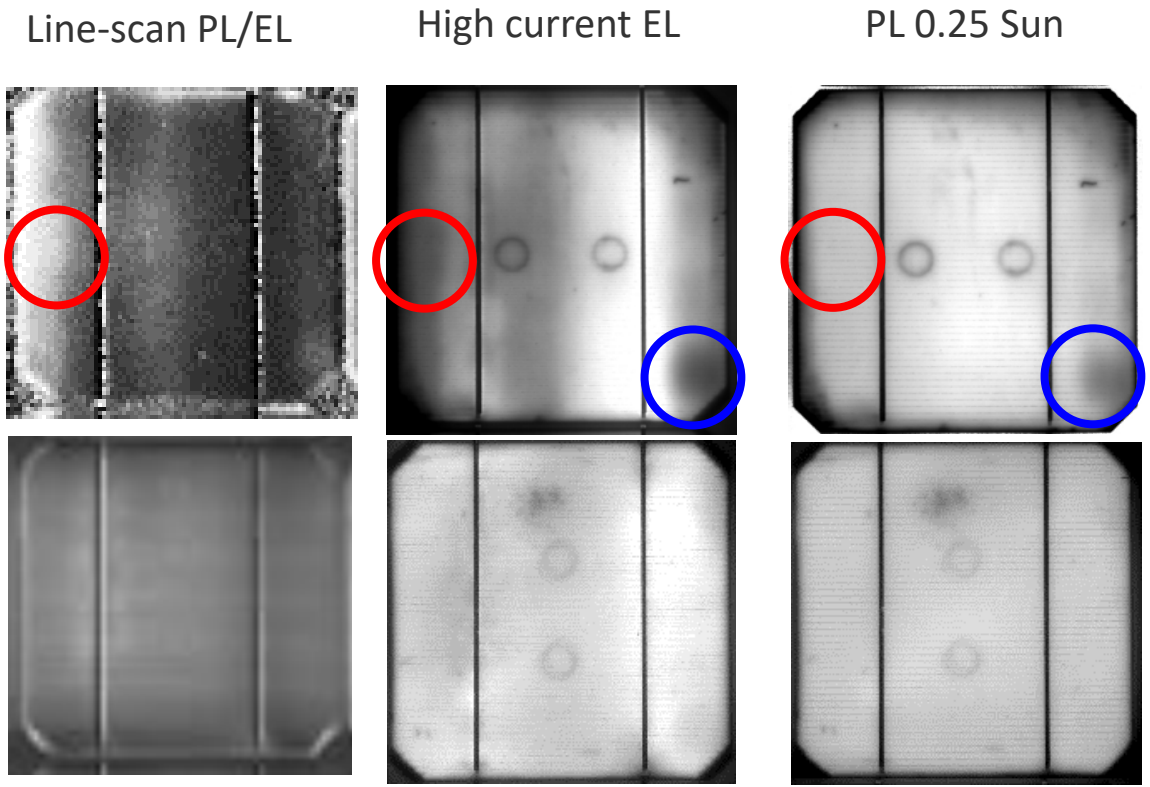
Installed: 2011
Age: 7 yrs
Mounting: rack on roof

Loss in V_{oc} over several years

Ishii et al., *Prog. in PV* ,2017

Luo et al. *JPV*, 2018

Degraded cells are primarily located along the module edge



Dark in EL, bright in PL → resistive

Dark in EL & PL → material

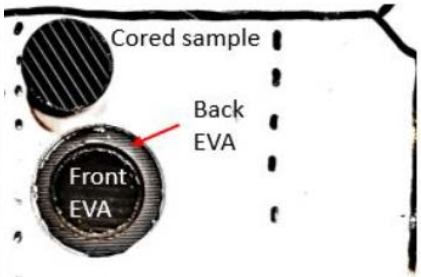
EL: electroluminescence,
PL: photoluminescence

Control module showed ca. 2x intensity of fielded module

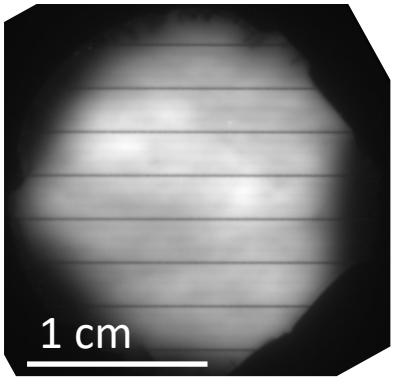
Coring of the modules

Backsheet removal

Metal stubs to remove cell pieces



PL shows no defects

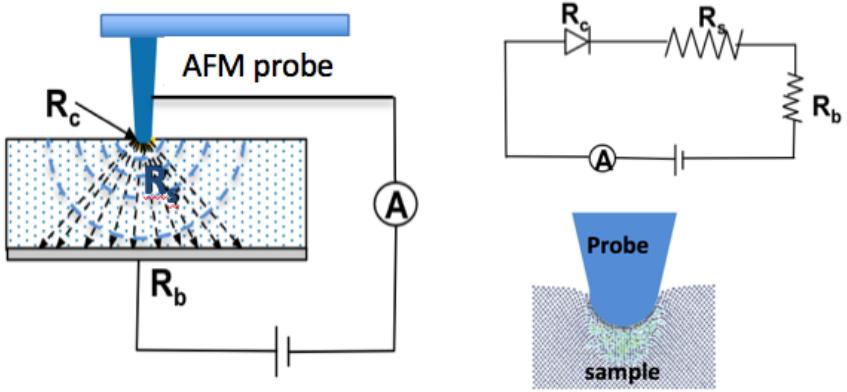


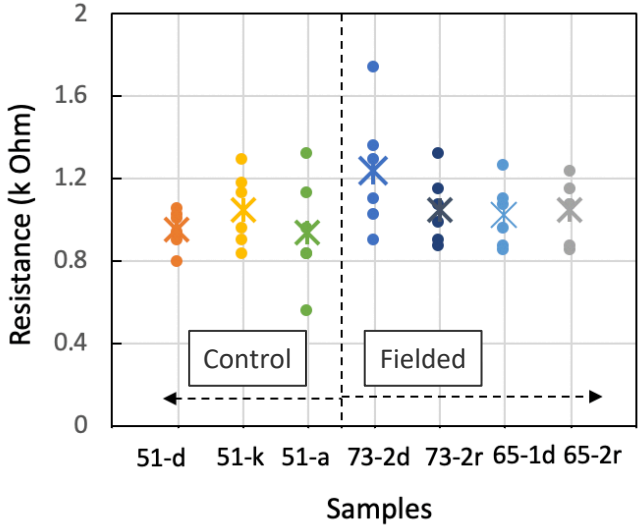
Available for materials characterization

H. Moutinho et al., *PVSC*, 2020

Scanning spreading resistance measurements (SSRM)

SSRM setup





Use atomic force microscope (AFM)

Small contact area → resistance is limited to directly below the probe

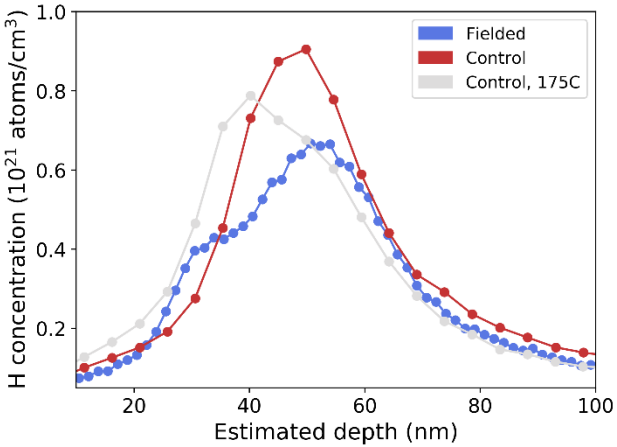
No significant difference between control & fielded sample

TCO does not appear to have degraded (at least the surface)

CS. Jiang et al., PVSC 2020

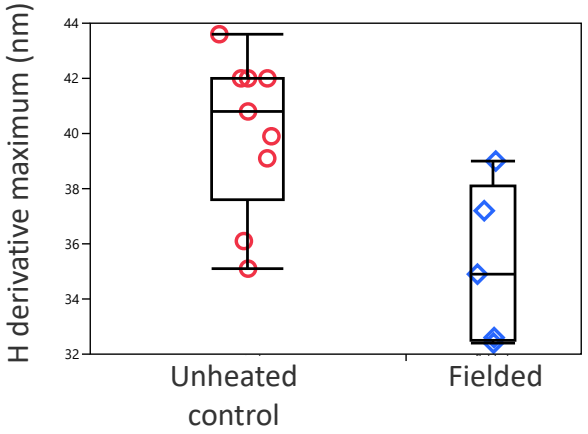
Hydrogen (H) redistribution in SHJ?

Dynamic secondary ion mass spectroscopy (d-SIMS)



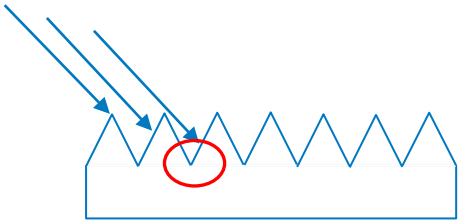
Orientation of samples was close

All samples



Statistically significant (though we could use more samples) p = 0.011

Sample orientation can impact the shape & location of the peak



Shadowing due to anti-reflective texturing

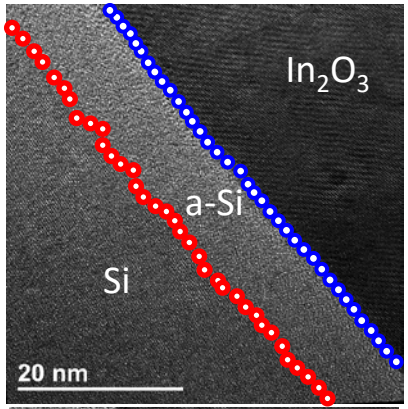
- Hydrogen from SIMS influenced by sample orientation → need more samples
- Follow up includes atom probe tomography

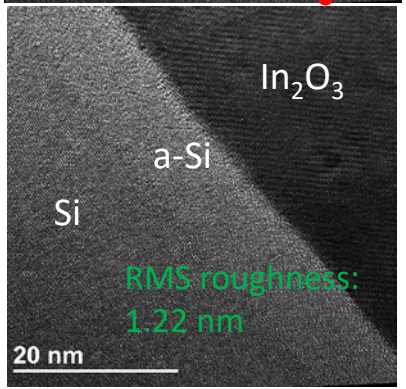
J. Clenney et al., PVSC 2020

TEM cross section - interface roughness

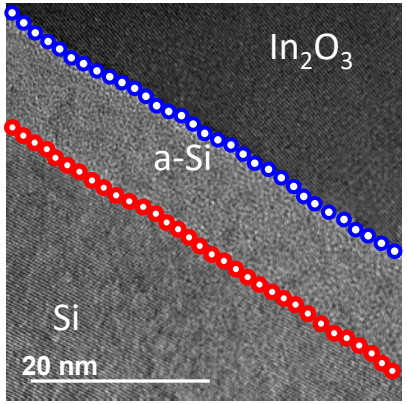
High resolution transmission electron microscopy (TEM) images to determine interface roughness

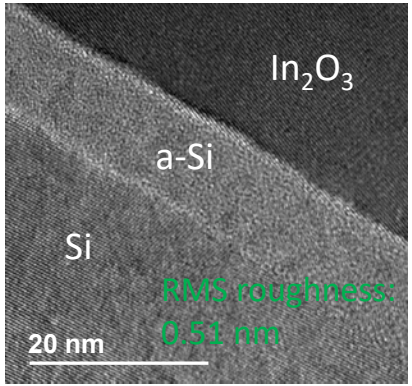
Fielded



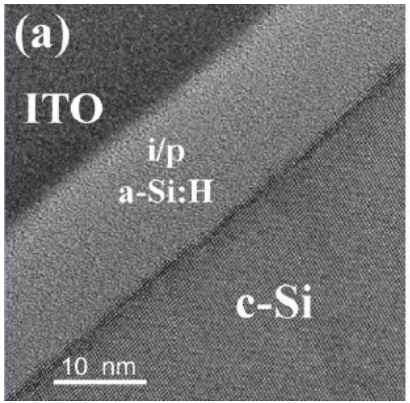


Control



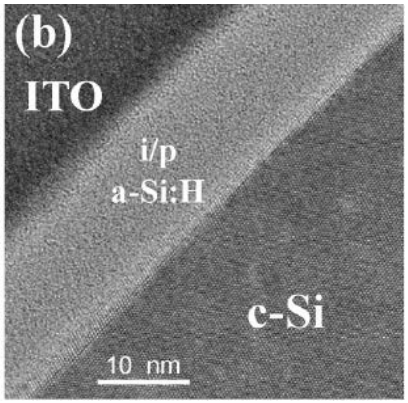


a-Si deposition by RF-PECVD



RMS roughness:
0.33 nm

a-Si deposition by VHF-PECVD



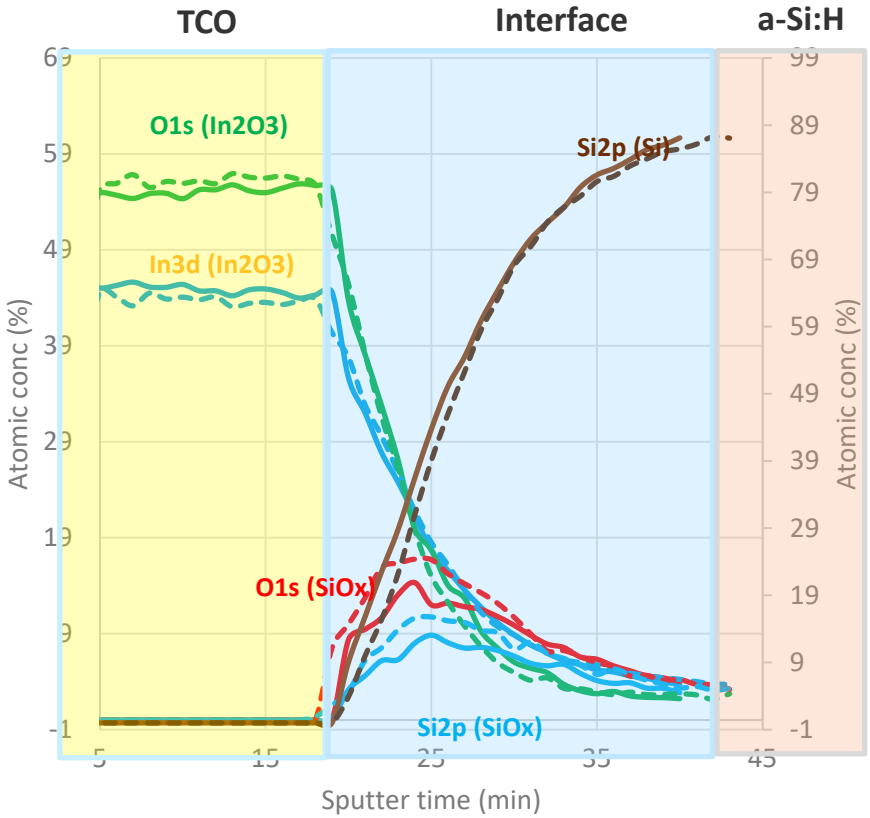
RMS roughness:
0.37 nm

Ru et al., 25.11% SHJ, *SEM&SC* 2020

Interface a-Si/Si of fielded module appears rougher but alignment issues could impact it

Sputtering X-ray photoelectron spectroscopy (XPS)

Collaboration with SLAC (Stanford Linear Accelerator)

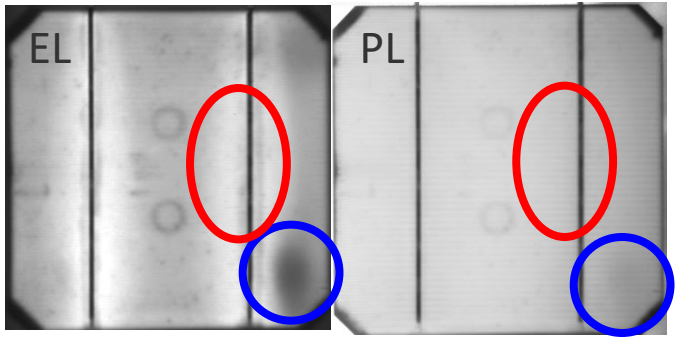


- The profile of aged sample was shifted to match the onset of Si
- In 3d atomic conc% (In_2O_3) mostly remains same in TCO region of both samples, indicating minimal degradation of TCO layer
- Within the interface region, the %O1s (SiOx) of aged sample is higher than that of control sample

SHJ installed in Florida (hot & humid climate)

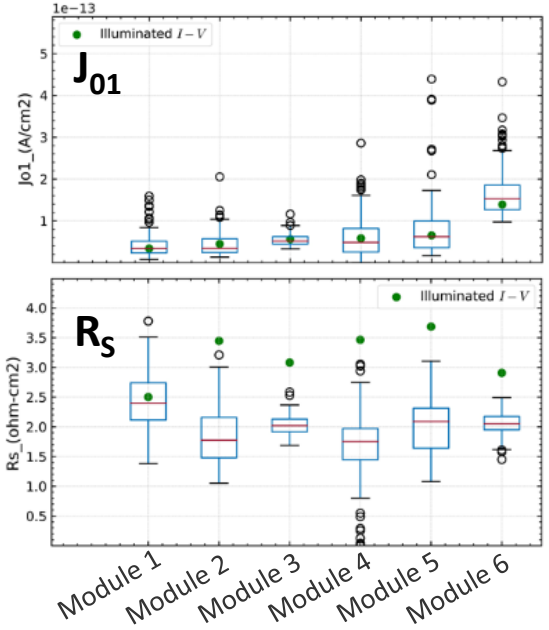
Collaboration with University of Central Florida (UCF)

Residential system: same module type
10 years, more severe climate & mounting
No control module, no baseline measurements



Dark in EL & PL
→ material

Dark in EL, bright in PL
→ resistive



	UCF	NREL	ctrl
J_{01} (fA)	60	26	10
R_S (Ωcm^2)	2.15	2.5	1.9

See increased J01 & Rs compared to our control module

UCF

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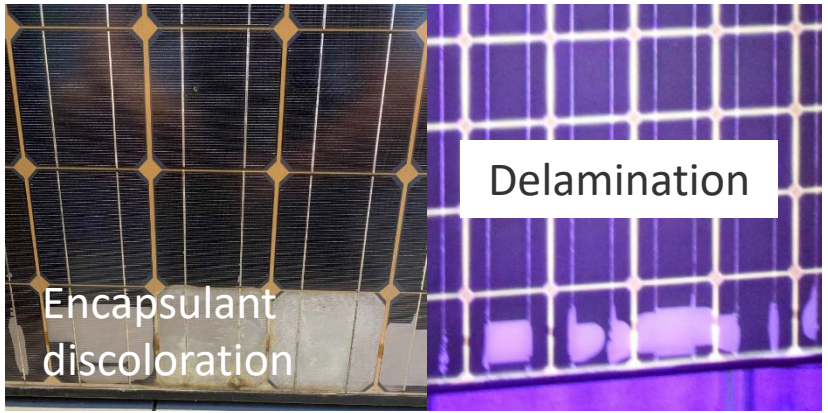


Some modules have bypass diode turned on

More severe climate & mounting → additional module packaging issues

UCF

PV Lifetime project - NREL

Heterojunction installation,
size = ca. 10 kW, installed 2018

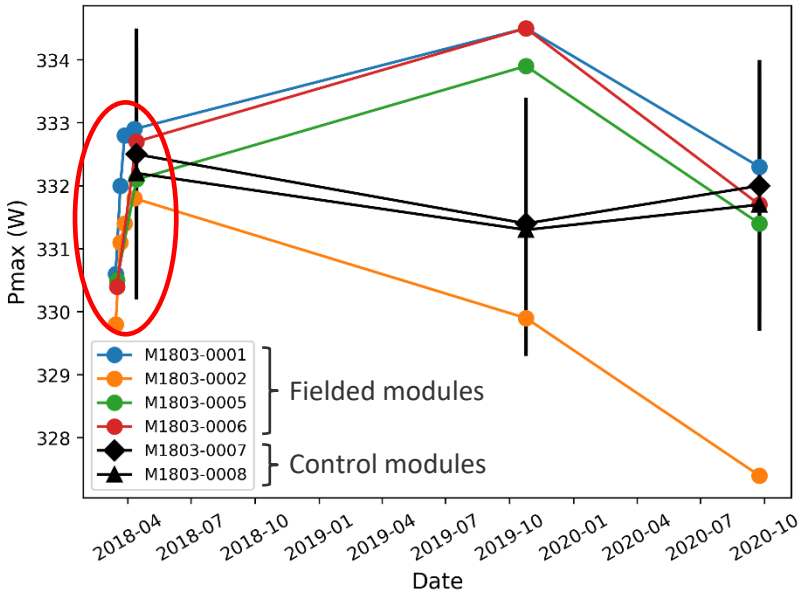
- Sample of 4 modules is brought inside for IV measurements once a year
- 2 control samples are kept indoors

Connected to energy storage unit

7kWh Li-Ion PV

Pmax & Isc performance

Probably insufficient light-soaking



- Initial light-induced changes can be seen in Pmax
- Control modules are stable
- One module degrading, the rest appears w/in uncertainty

E. Kobayashi et al., APL, 2016

Pmax & Isc performance

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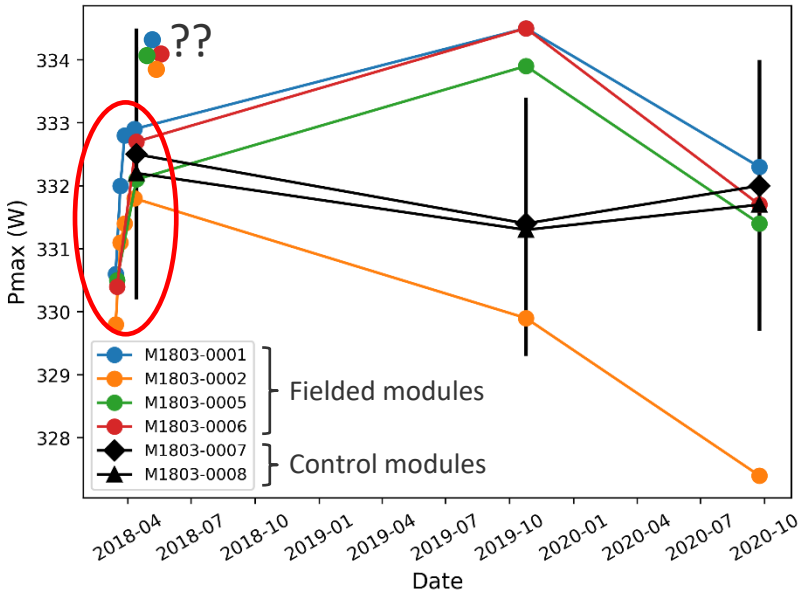

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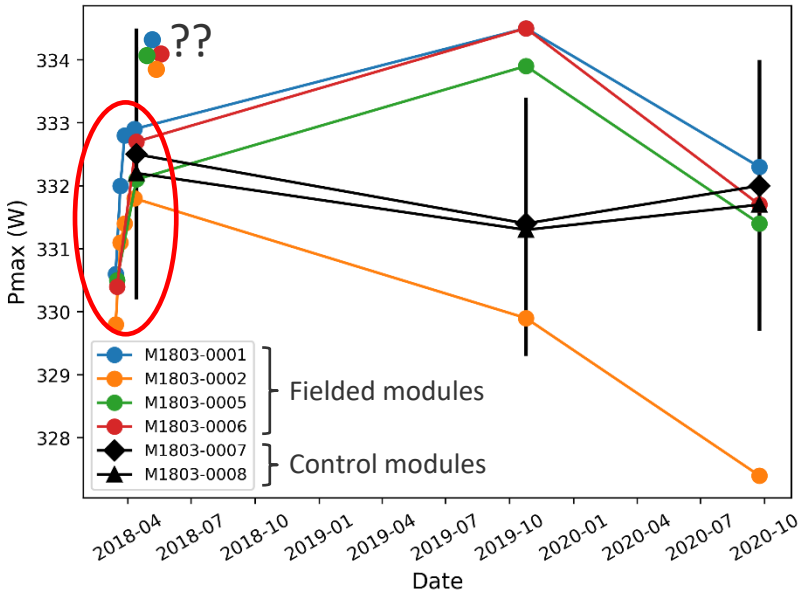
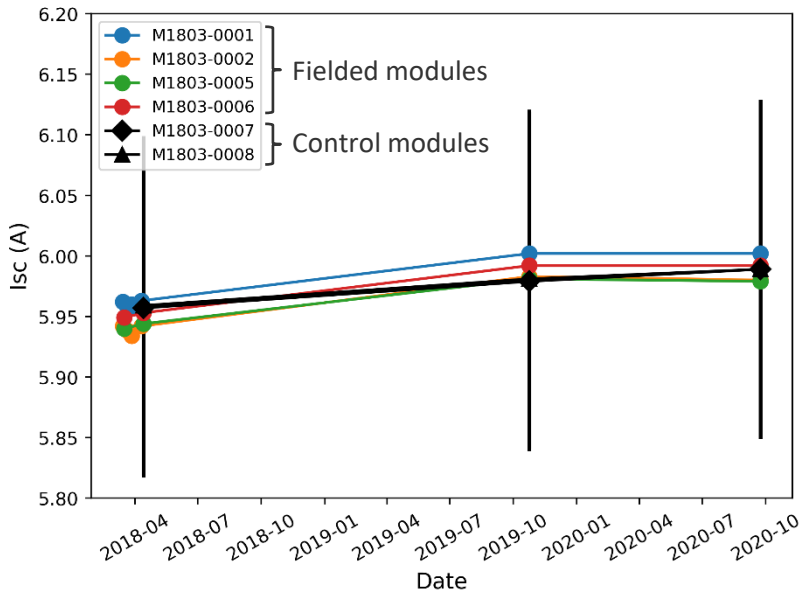
Probably insufficient light-soaking

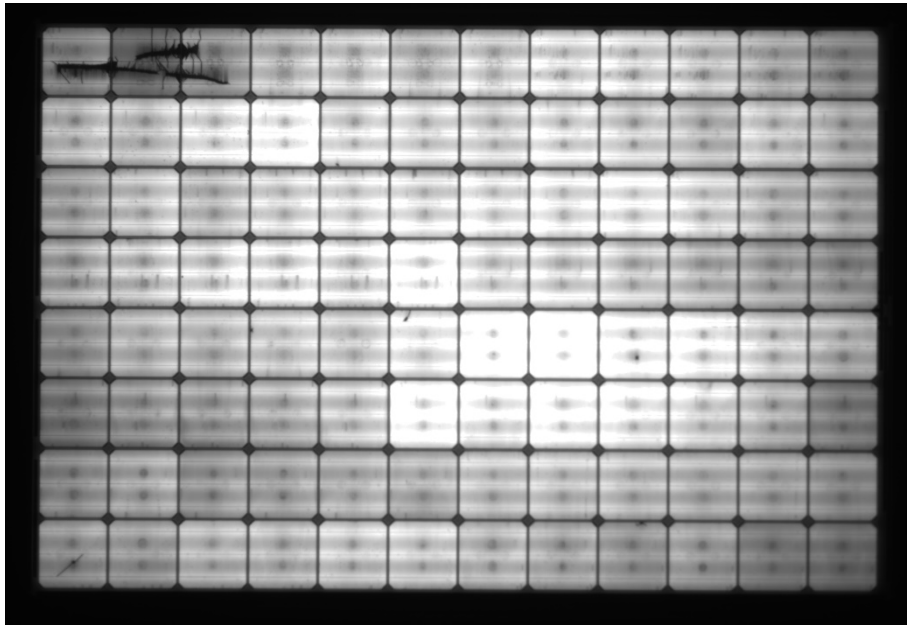




- Initial light-induced changes can be seen in Pmax
- Control modules are stable
- One module degrading, the rest appears w/in uncertainty
- Isc appears stable

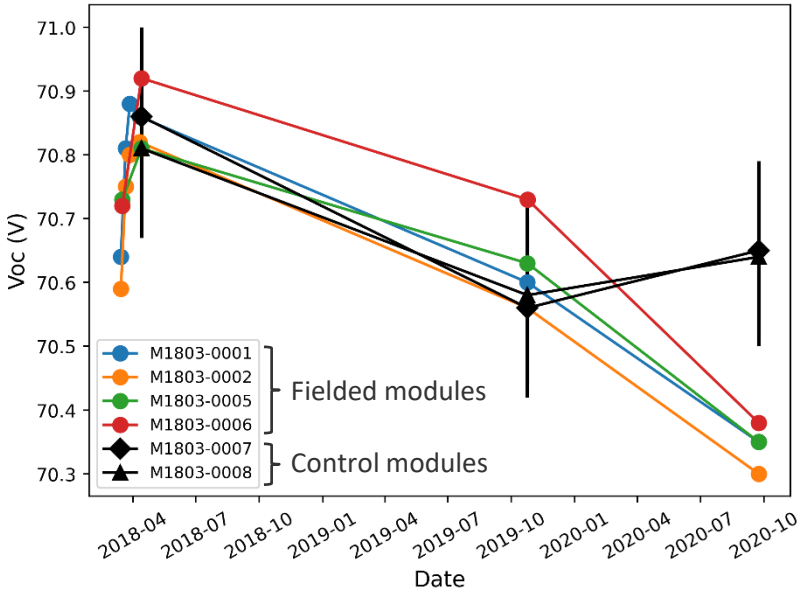
E. Kobayashi et al., APL, 2016

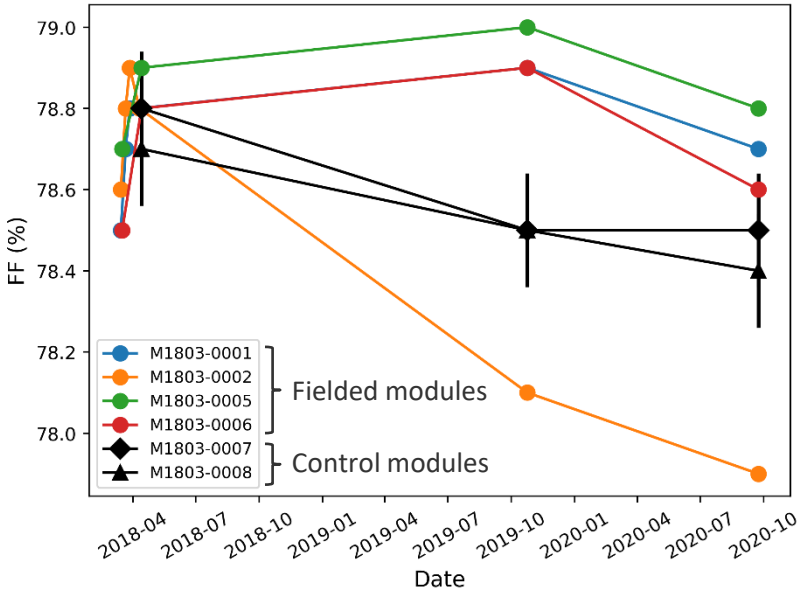
Degrading module



- Back shows a scratch mark
- EL image shows damage to 3 cells

Voc & FF performance





- Voc appears to be degrading, although uncertainty bars are barely overlapping
- Median degradation in 0.3%/year range
- FF appears stable with the exception of the module with scratch (M1803-0002)

Conclusion

- High-efficiency modules show performance loss rates at the median not worse than conventional Al-BSF based technology
- SHJ: Voc loss, several possible mechanisms: H redistribution, interface roughness, oxide layer formation
- Understanding the fundamental degradation mechanism is still important for today's products
- Degradation from system components & module packaging added to cell degradation
- Patent expiration in SHJ has led to many more entrants into the market
- Use of quality assurance programs at manufacturer, installation level important (IS6001, IEC 62941, IEC 61215, IECRE etc.)

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