

# CFV Labs

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## Flash Testing Capability

Daniel Zirzow, CTO

CFV Labs, Albuquerque, New Mexico

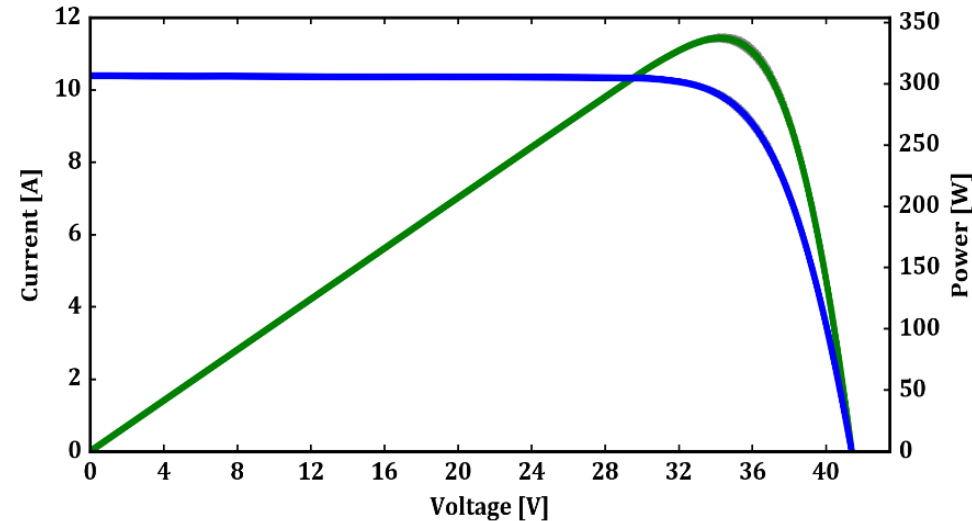
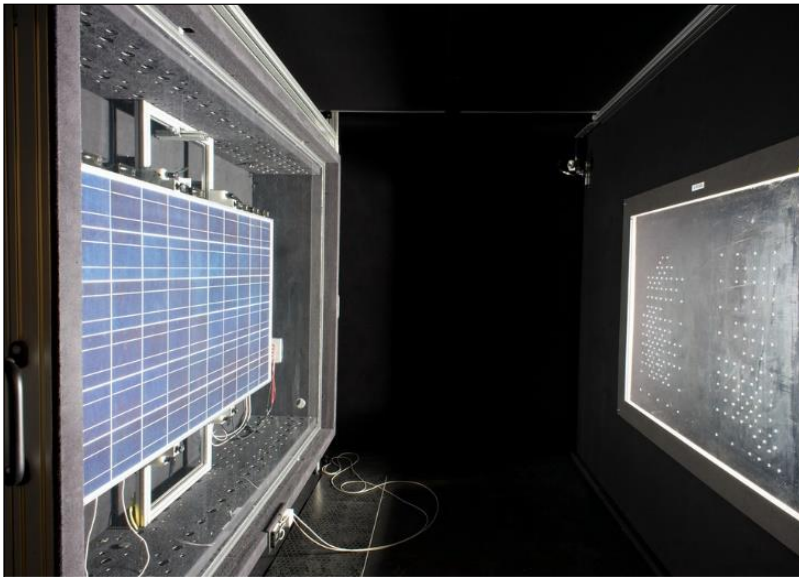


# Main Takeaways

- CFV Labs has a Class A+A+A+ tunnel-type h.a.l.m. indoor flasher, nearly identical to the flasher at Fraunhofer ISE CaLab.
- Accurate measurements of PV modules require precise calibration and characterization of test equipment as well as rigorous measurement process control.
- CFV follows the industry-best practices to achieve top-tier uncertainty in its I-V measurements.
  - PTB-calibrated reference cell for in-plane irradiance measurement
  - Separate flasher room continuously maintained at 25°C
  - Quarterly measurement of the flasher spectrum and uniformity
  - Daily quality control with p-type Si modules;  
Weekly quality control with n-type Si and CdTe modules
  - Quarterly checks with reference p-type, n-type (IBC and n-PERT), and CdTe modules
  - Yearly check of the reference modules at Fraunhofer ISE CaLab
  - Routine interlaboratory measurement comparisons with modules of varied technologies

# Class A+A+A+ Halm Flasher

- Class A+A+A+ flasher with the latest optics upgrades
- Single flash is 35ms with a 25ms measurement window. By default, CFV takes three forward- and reverse-sweep measurements and averages the data.
- Sectional sweeps allow accurate analysis of n-type modules.



I-V data of a 19.7%-efficient module;  
Graph shows an overlay of forward and reverse sweeps of 3 sections each.

# Measurement Uncertainty Drivers for PV Module Measurements

- Identification, quantification, and mitigation of uncertainty drivers is crucial for understanding the accuracy of PV module measurements.
- Primary uncertainty drivers for measurements of PV modules include:
  - Test plane irradiance and uniformity
  - Spectral mismatch effects
  - Module temperature and uniformity
  - Test equipment measurement accuracy
  - Test reproducibility

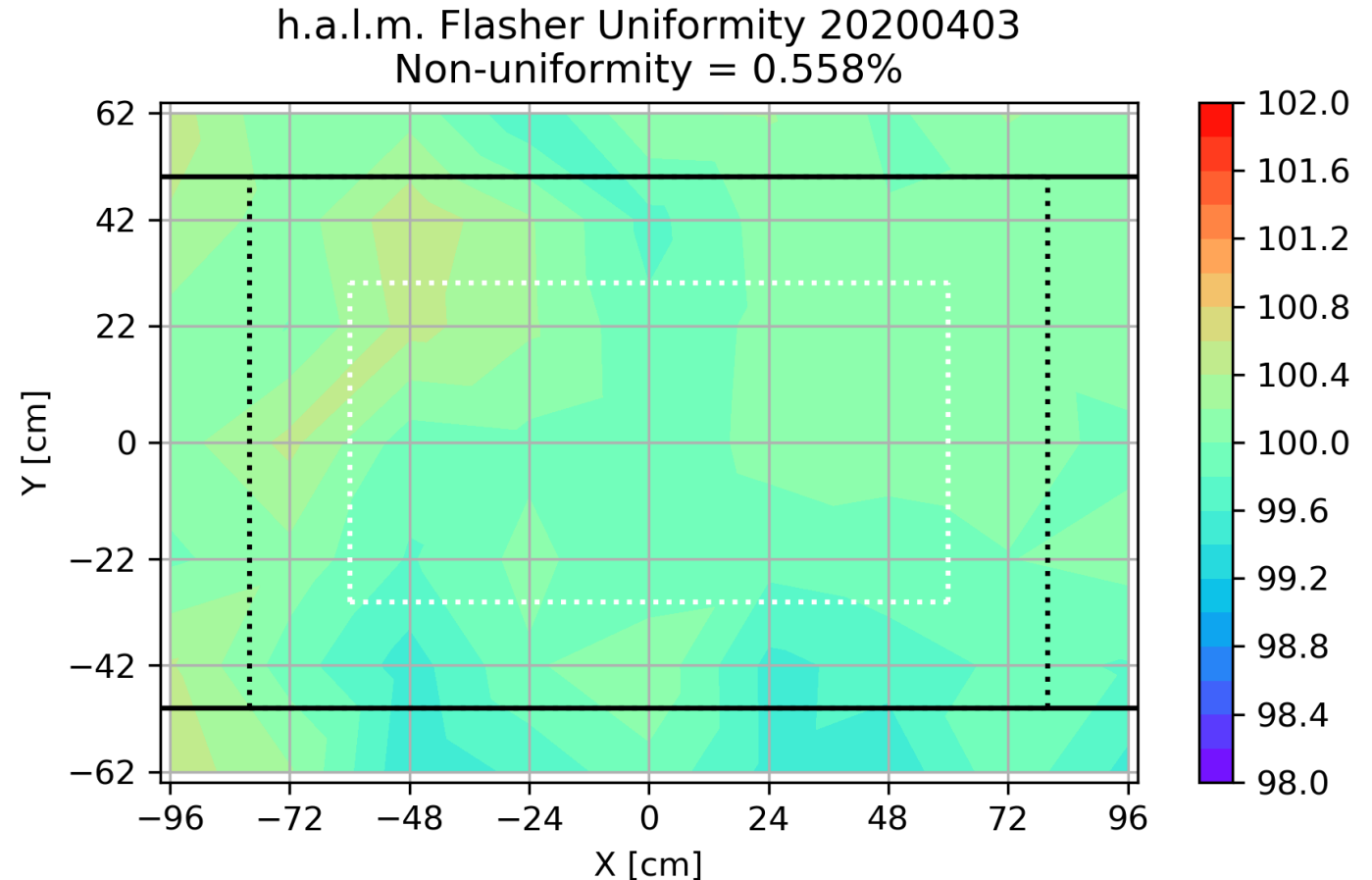
# PTB-Calibrated Reference Cells

- CFV uses Fraunhofer's WPVS (World PV Scale) reference cells for the in-plane and real-time irradiance measurement.
- Each data point in the I-V curve is individually corrected with the simultaneously measured reference cell Isc data, to correct errors from temporal instabilities of the flasher (short-term instability < 0.5%).
- Using a calibrated reference cell for the irradiance measurement is superior to using a reference module in terms of the measurement uncertainties.
- The reference cell is calibrated regularly at PTB, the German calibration institute (calibration uncertainty ~0.5%).



# Test Plane Irradiance Uniformity

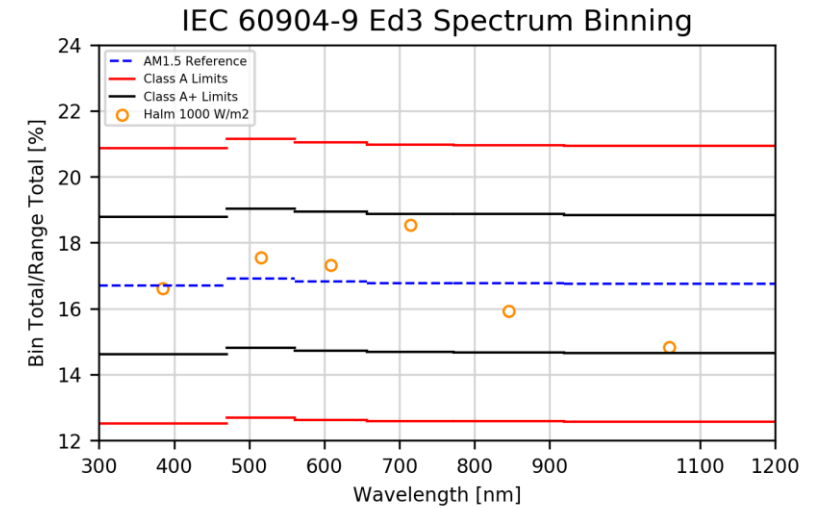
- CFV carries out quarterly uniformity measurements.
- Latest non-uniformity was 0.6% (Class A+ limit: 1%)
- After the irradiance uniformity mapping, the PTB-calibrated reference cell is placed at a location that matches the average irradiance of the test plane.



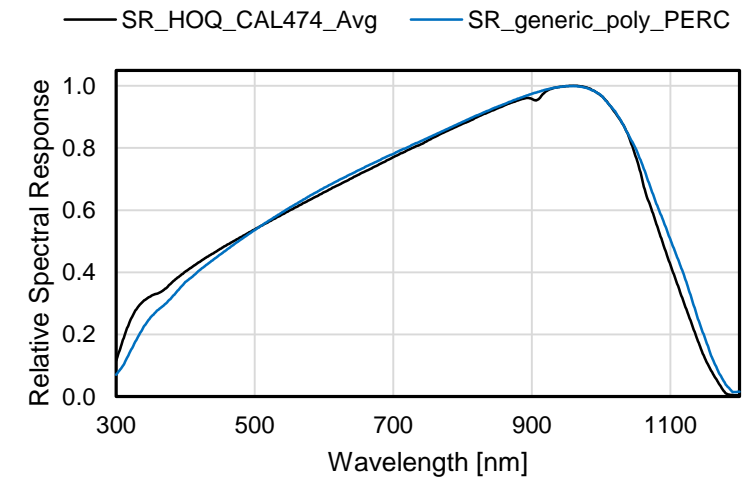


# Spectral Mismatch Effects – Module EQE Data

- CFV carries out quarterly spectrum measurements with a calibrated spectroradiometer at better than 1nm wavelength resolutions.
- Latest spectrum measurement (2020-03-31) shows Class A<sup>+</sup> spectral match.
- Measurement uncertainties are generally higher in the absence of module EQE or SR data.
- CFV has partnerships with Fraunhofer ISE and NREL for module EQE/SR measurements.

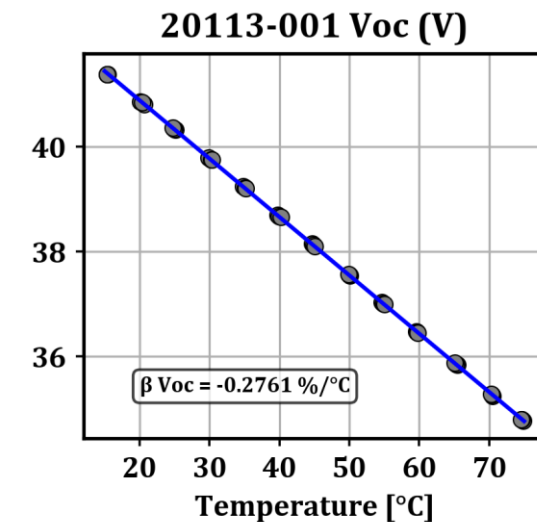
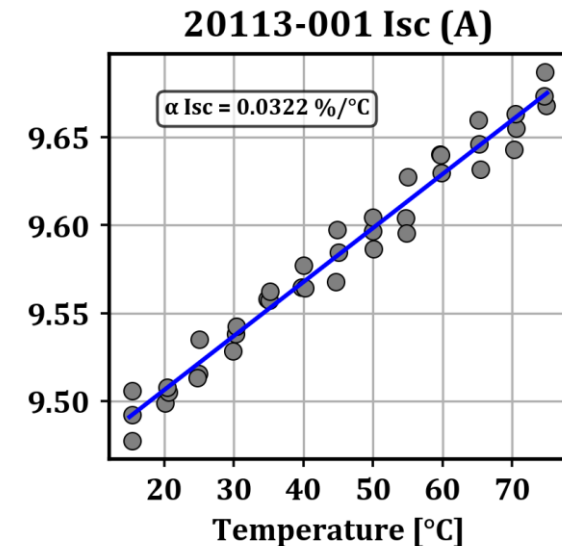


Reference Cell and Module Spectral Response



# Module Temperature Measurements

- Both voltage and current have measurable temperature coefficients, e.g. for silicon modules.
  - $\alpha_{Isc} \sim +0.04\% / ^\circ C$
  - $\beta_{Voc} \sim -0.28\% / ^\circ C$
- Temperature errors arise from several sources
  - Module temperature measurements
  - Module temperature uniformity
  - Module temperature coefficients (because data is corrected to 25°C)
- Flasher room is maintained at a constant  $25.0 \pm 1.0^\circ C$  temperature.
- Modules are stored in the flasher room for a minimum of 1 hour prior to measurement to ensure module temperature stability and uniformity.
- Module temperatures are measured with Class A four-wire RTDs with low uncertainties.

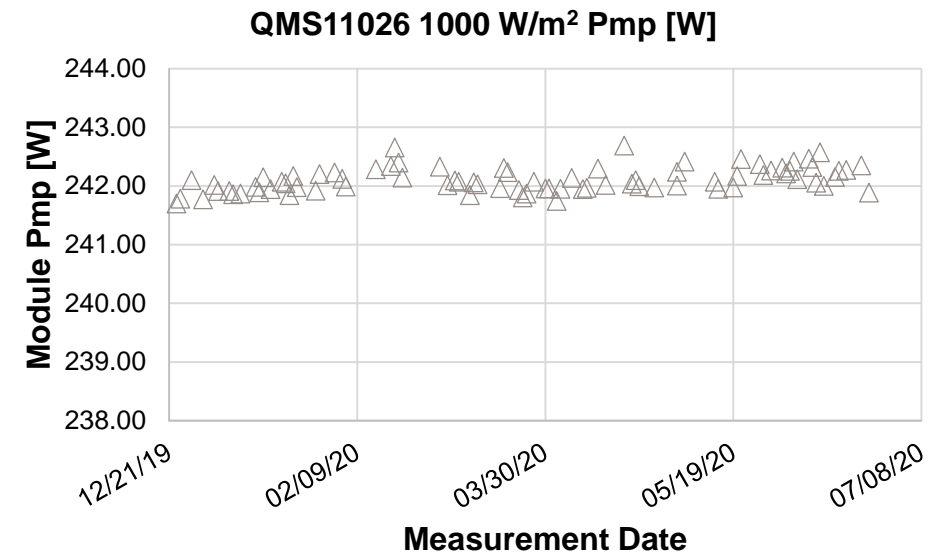
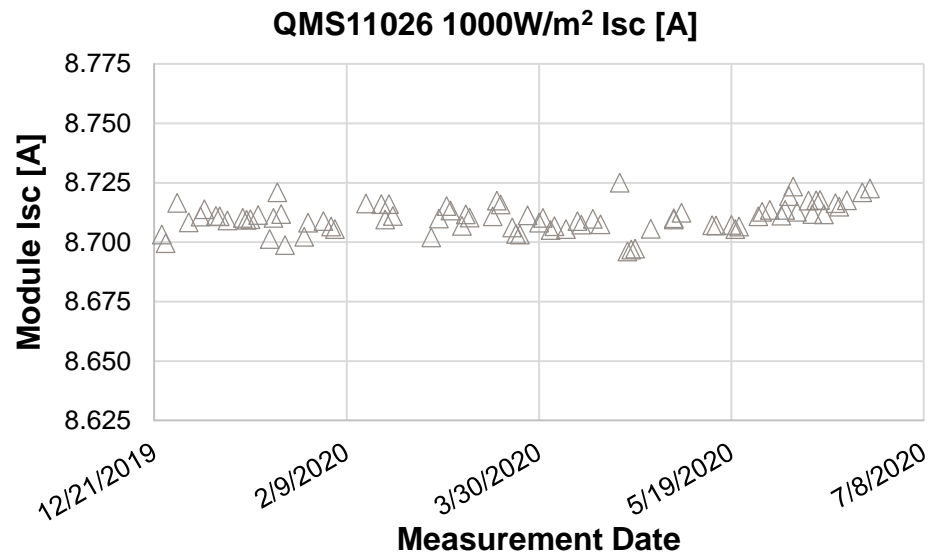




# Measurement Repeatability (Daily Silicon Control Module Data)

- The latest six months of daily control module data shows excellent repeatability. The table below lists the standard deviation of each STC IV parameter for a silicon control module for the last six months.

Isc [A]	Voc [V]	Imp [A]	Vmp [V]	Pmp [W]
0.07%	0.02%	0.09%	0.08%	0.08%



# Latest Control Module Measurements (2020 Q1)

Module ID	Cell Technology	Last CFV Measurement Date	Last CFV Measured Pmp [W]	Last Fraunhofer ISE Measurement Date	Last Fraunhofer ISE Measured Pmp [W]	Difference (CFV/Fraunhofer) – 1
CFV009	Mono PERC	2020-04-06	261.0	2018-11-27	261.2	-0.09%
CFV010	n-PERT	2020-04-06	303.1	2018-11-27	301.7	+0.45%
CFV012	IBC	2020-04-06	315.5	2018-12-13	315.3	-0.02%
CFV013	Poly AI-BSF	2020-04-06	281.2	2018-11-28	281.9	-0.19%
CFV014	CdTe	2020-04-07	109.8	2018-12-06	109.8	+0.03%
<i>Average</i>						+0.04%

CFV014 (CdTe) measurements were carried out after chamber preconditioning procedures specified by the manufacturer, at both CFV and Fraunhofer ISE CalLab.

## CFV's STC I-V Measurement Uncertainties (k=2)

Cell Technology	Isc [A]	Voc [V]	Imp [A]	Vmp [V]	Pmp [W]
Crystalline Silicon, Monofacial*	± 1.4 %	± 0.7 %	± 1.8 %	± 1.2 %	± 1.9 %
Crystalline Silicon, Bifacial*	± 1.6 %	± 0.75 %	± 2.1 %	± 1.3 %	± 2.2 %
CdTe**	± 2.0 %	± 2.5 %	± 2.4 %	± 2.3 %	± 3.3 %
CIS/CIGS*	± 1.7 %	± 1.6 %	± 2.1 %	± 1.8 %	± 2.6 %

\* With module EQE data, uncertainties are higher for measurements in which EQE/SR data is not available

\*\* Depends on stabilization method

## Summary

- CFV has a best-in-class tunnel-type flash tester.
- Starting with the technical guidance of Fraunhofer ISE CaLab, and through seven years of experience, CFV has developed practices to guarantee top-tier measurement uncertainty.
- The quality control practices, and the measurement setup allows sub 2.0% STC Pmp [W] measurement uncertainty for silicon monofacial modules with module EQE/SR data. Measurements of bifacial modules have slightly higher STC Pmp [W] uncertainties of 2.2%.
- CFV Uses PTB-calibrated reference cells for in-plane irradiance measurement.
- Interlaboratory round robin tests on show very good match between CFV and other top-tier labs such as Fraunhofer ISE, NREL and SERIS.

# CFV Labs

# Thank you.

CFV Labs

5600A University Blvd SE

Albuquerque, NM 87106, U.S.A.

505-998-0100

Project inquiries: [jim.Crimmins@cfvsolar.com](mailto:jim.Crimmins@cfvsolar.com)

[www.CFVLabs.com](http://www.CFVLabs.com)