OXFORD PV™

The Perovskite Company

Standards – a silicon-perovskite tandem perspective

David Bushnell, 21st April 2023

Outline

- Oxford PV at a glance
- Tandem solar cells
- Qualification
  - Safety
  - Performance
- Measurement
  - Stabilisation
  - Multijunction
  - Bifaciality
- Energy rating

Oxford PV at a glance

First commercial

Perovskite cell manufacturing line to start production in 2022

c. 20%

Saving on system costs from increased cell efficiency and lower balance of system costs per watt

c. $400 billion

Addressable market size (2030)

No.1 IP portfolio

530+ filed or granted patents. Largest perovskite patent portfolio in the world

29%

Certified Oxford PV solar cell efficiency and roadmap to >33% efficiency

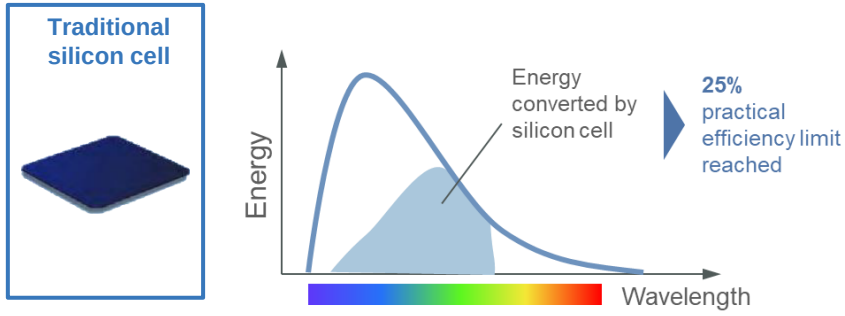
Largest group

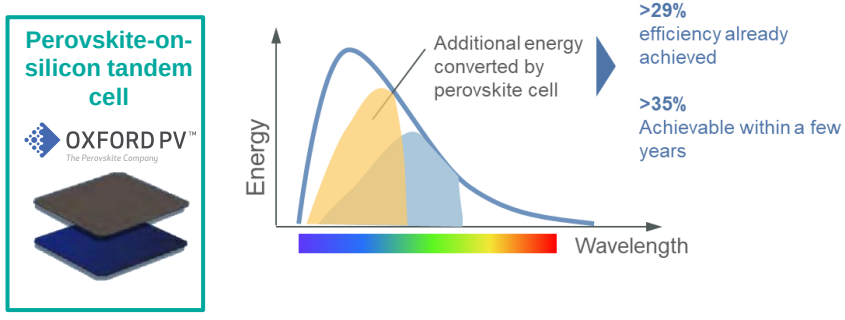
Of scientist and engineers working to bring the perovskite product to market

OXFORD PV™
The Perovskite Company

Tandem solar cells

- Two junctions, two terminals
  - Top cell with wide bandgap
  - Bottom cell with narrow bandgap
- Bottom cell illumination passes through the top cell
- Top and bottom cell must pass the same current
  - Performance strongly dependent on photocurrent matching
- In practice, usually one junction *limits* the other
  - By design, varying spectrum or both





Standards landscape

Qualification (safety)

IEC 61730 series

- IEC 61730 defines:
  - Part 1: Design rules that the module must adhere to
  - Part 2: Stresses that a module must pass without creating an unsafe condition
- Appears that IEC 61730 safety testing can be used as-is
- Except that it (and IEC 61215) cites the testing and bifaciality standards…


Standard fine, can be used as-is


Standard can be only approximately followed and requires adjustment to yield sensible results

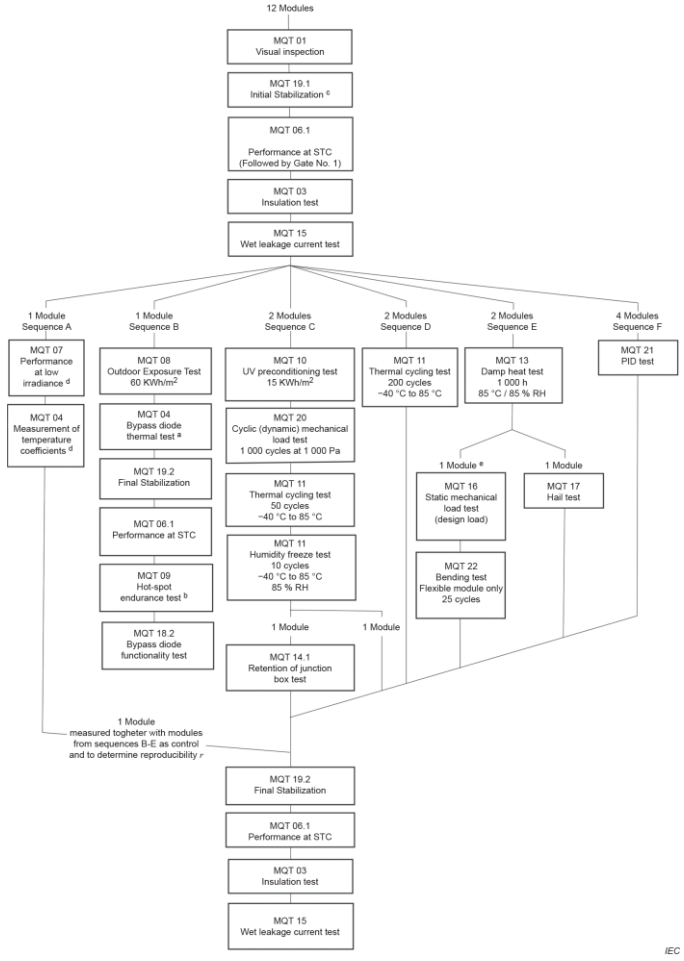

Standard does not exist

Qualification (performance)

IEC 61215 series including technology-specific parts

- IEC 61215 defines stresses that a module must pass with minimal performance loss
- Technology-specific parts provide refinement to main method

Technology	Technology-specific part
c-Si	IEC 61215-1-1
CdTe	IEC 61215-1-2
α-Si	IEC 61215-1-3
CIGS	IEC 61215-1-4



Qualification (performance)

IEC 61215 series including technology-specific parts

- No technology-specific parts cover silicon-perovskite tandems
  - Or perovskite single junctions
- Work to define this would usually require that we have field failures to characterise
  - Otherwise we don't know what the laboratory tests are aiming to simulate
- Perhaps an interim TS (technical specification, not quite a full standard) to give guidance would be useful?
  - Our work suggests a perovskite-specific part would look like the CdTe part, IEC 61215-1-2

Testing – spectrum

IEC 60904-1-1 and IEC 60904-9

- Spectral specification is much more strict for multijunctions. Why?
- For single junctions, we can apply a *mismatch factor* to the device measurements
  - Corrects for deviations in spectrum c.f. AM1.5, and
  - Reference cell spectral response c.f. DUT response
- Can *calculate* mismatch factors for each junction in a tandem, but
  - Can only apply one to the whole device
- So the approach taken is to get the spectrum right to begin with
  - Requires a multi-zone, tuneable simulator
- Standard here is fine, but familiarity and/or equipment is often lacking

	For single junction IEC 60904-9 class A+	**For multi-junction** IEC 60904-1-1
Spectrum assessed over:	Six bands each containing roughly equal power	Each junction
Allowed deviation from AM1.5	±12.5%	±1%

Testing – stabilisation

IEC 60904-1

- Already a requirement that:
  - "*Care shall be taken in measuring PV devices that are metastable*",
  - "*…stabilisation should be performed before any characterisation*" and,
  - "*…the device under test shall be measured such that it reflects, as closely as possible, the performance of the device under steady-state conditions*"
- The technology-specific IEC 61215-1-x give feasible stabilisation procedures
  - But this doesn't include perovskites…
- For perovskites, maximum-power-point tracking is often used
  - To establish the performance under steady-state illumination
  - And simultaneously stabilise
- But the method isn't really *defined* anywhere

Bifaciality assessment

IEC TS 60904-1-2

- Short-circuit current bifiaciality coefficient defined as:

$$\varphi_{Isc} = \frac{I_{SCr}}{I_{SCf}}$$

I_{SCr}: I_{sc} under rear-only illumination

I_{SCf}: I_{sc} under front-only illumination

(and similar quantities for V_{oc} and P_{max})

- Requires *separate* front and rear illumination to determine the bifaciality coefficients
  - Yields roughly zero in the case of a tandem
- Rear-side illumination alone cannot generate in the top cell
  - Zero total current because device is top cell limited
- Propose an option to measure bifaciality coefficients using:
  - Front-only illumination, and
  - *Both-sides* illumination

Energy rating outline

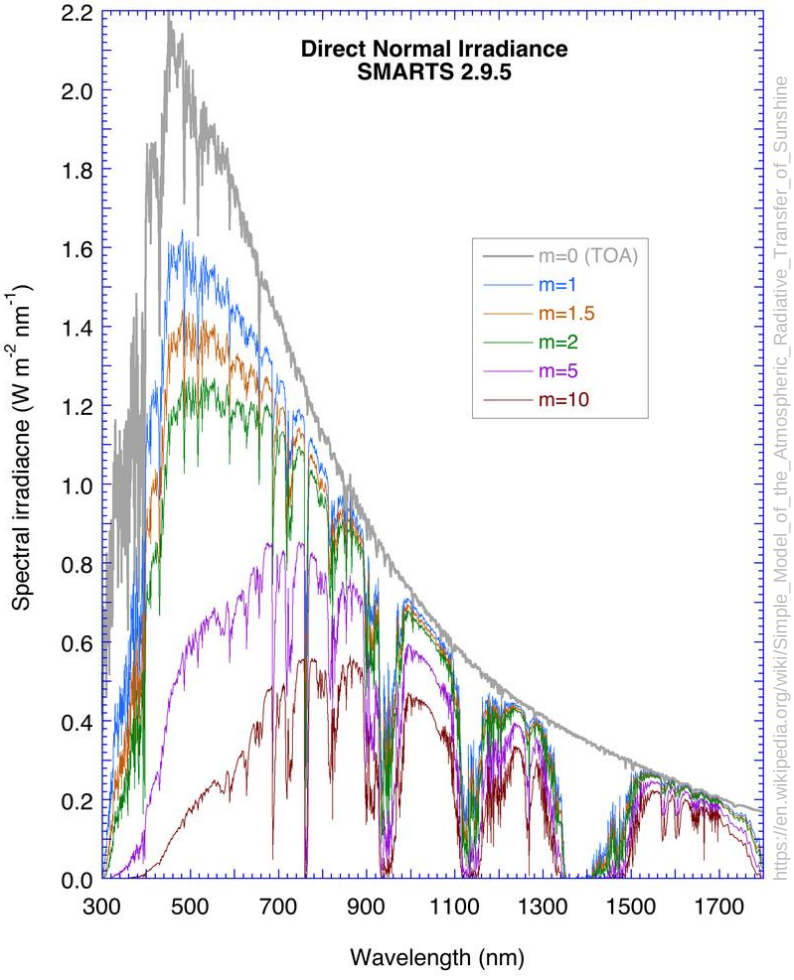
IEC 61853 series

- Designed to provide an estimate of kWh produced per year in various climates
- Spectral and weather data provided throughout a typical year
- Choice of four climates
- You measure your module:
  - Under AM1.5
  - At various irradiance levels, and
  - At various temperatures
- The method interpolates between these measurements to estimate energy generated:
  - Every hour
  - Throughout the year
- Then sums over the whole year

Energy rating

IEC 61853 series

- But this may not be sophisticated enough for multi-junctions
- The spectrum you measure under isn't required to vary with irradiance as it would in real life
  - i.e. dimmer spectra appearing more red
- If the limiting junction changes, then the interpolation assumption is definitely invalid
  - But fill factor, short-circuit current will start to change before this point
- Could be addressed by the measurements having to take place under different spectra at the various irradiances
  - Significantly more complicated
  - Need to know how well irradiance is correlated with spectral changes



Conclusions

- Mostly the standards could be applied as-is for a *perovskite single junction*
  - IEC 61215 being the main exception
  - MPP tracking definition could be included in a technology-specific IEC 61215-1-x
- But *tandems* (whether perovskite or not) have issues in:
  - Bifaciality measurements
  - Energy rating calculation
- On a practical note, qualification labs are not always set up to apply IEC 60904-1-1
  - So the standards might be available…
  - But there may still be barriers to using them