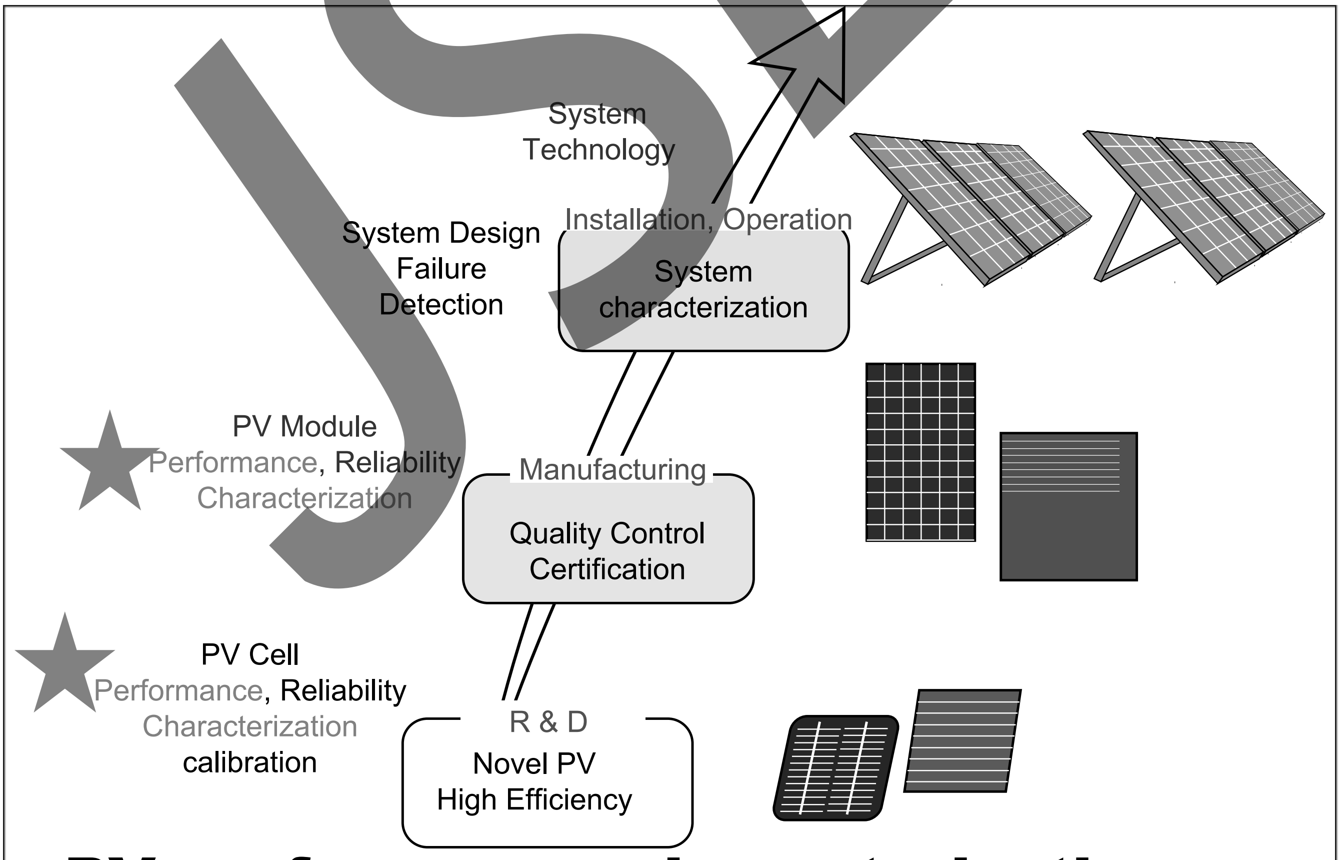
各種太陽電池の高精度性能評価技術

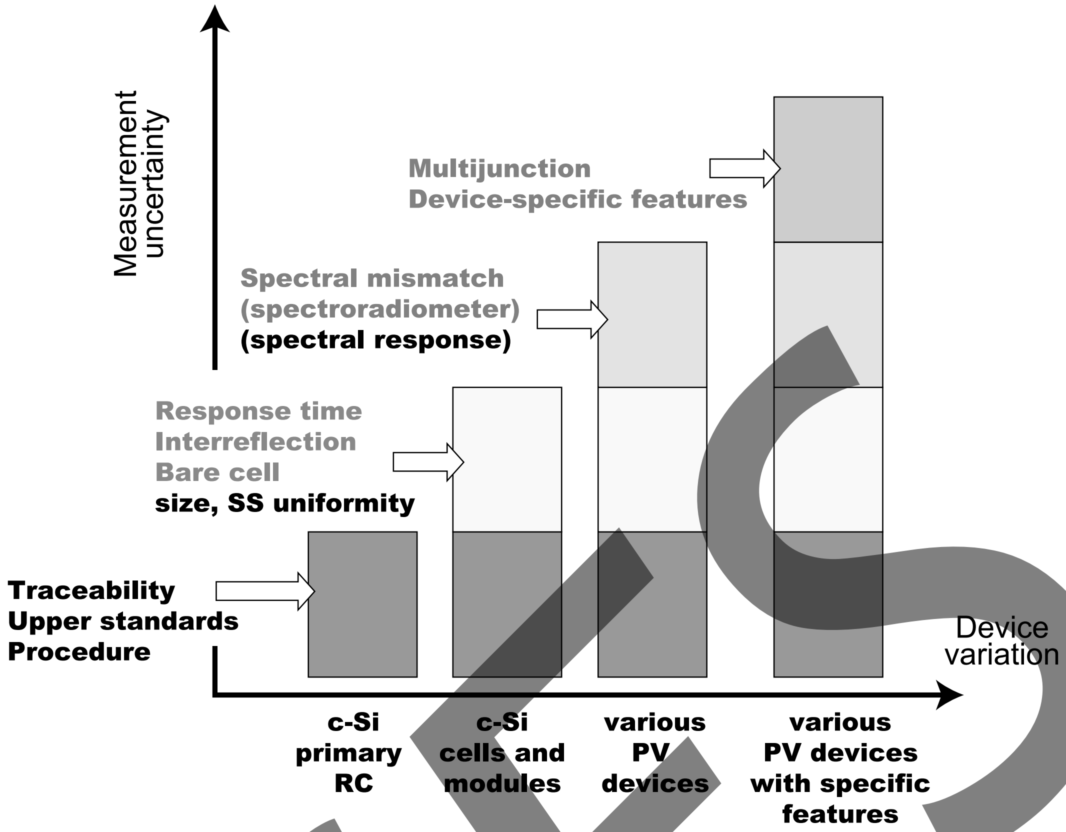
産業技術総合研究所　太陽光発電工学研究センター
菱川　善博

本太陽エネルギー学会 太陽光発電部会　第7回セミナー2011.12.19



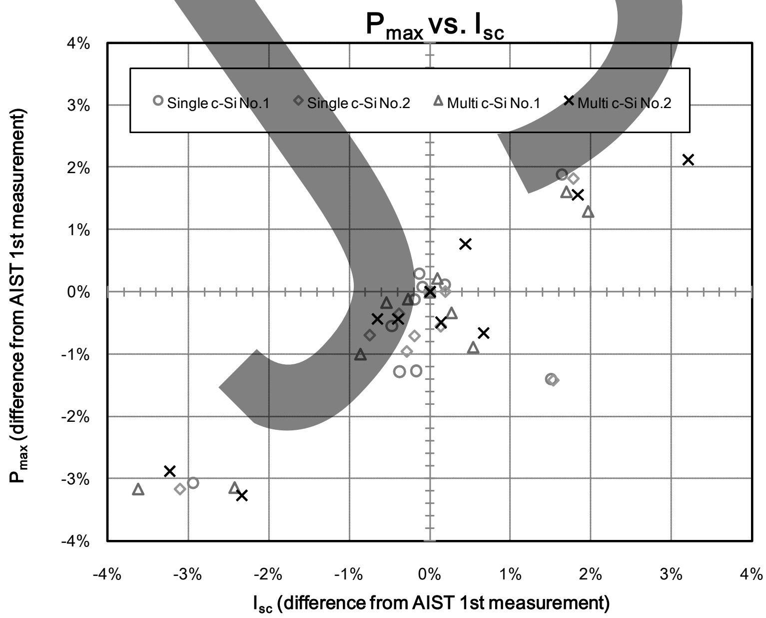
PV performance characterization

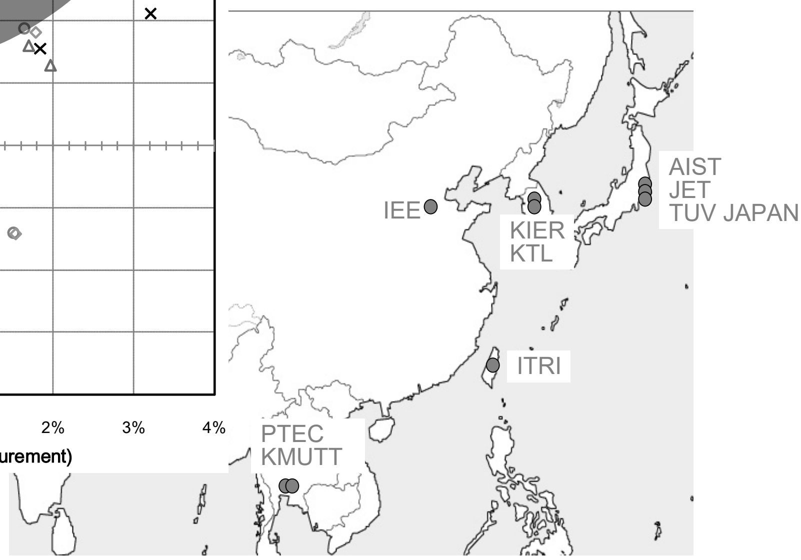
PV performance characterization



PV module measurement intercomparison

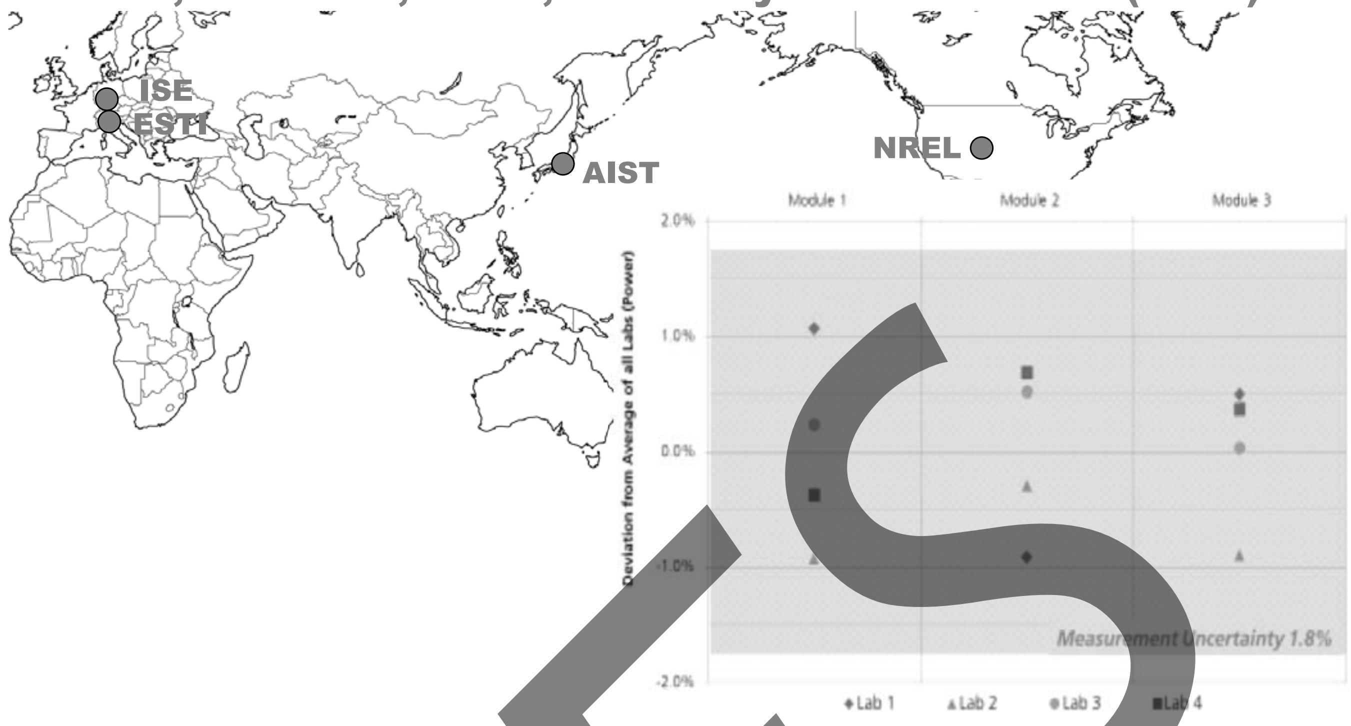
IEE, ITRI, JET, KIER, KMUTT, KTL, RTEC and TUV Rheinland Japan hosted by AIST (2009-2011)





PV module measurement intercomparison

AIST, JRC/ESTI, NREL, hosted by Fraunhofer ISE (2013)



Fraunhofer ISE press release "PV Modules Measured with Uniform Quality Worldwide", Freiburg, September 30, 2013, No. 25/13

Reference	Title
IEC 60891 ed2.0	Photovoltaic devices – Procedures for temperature and irradiance corrections to measured I-V characteristics
IEC 60904-1 ed2.0	Photovoltaic devices – Part 1: Measurement of photovoltaic current-voltage characteristics
IEC 60904-2 ed2.0	Photovoltaic devices – Part 2: Requirements for reference solar devices
IEC 60904-3 ed2.0	Photovoltaic devices – Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data
IEC 60904-4 ed1.0	Photovoltaic devices – Part 4: Reference solar devices – Procedures for establishing calibration traceability
IEC 60904-5 ed2.0	Photovoltaic devices – Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method
IEC 60904-7 ed3.0	Photovoltaic devices – Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices
IEC 60904-8 ed2.0	Photovoltaic devices – Part 8: Measurement of spectral response of a photovoltaic (PV) device
IEC 60904-9 ed2.0	Photovoltaic devices – Part 9: Solar simulator performance requirements
IEC 60904-10 ed2.0	Photovoltaic devices – Part 10: Methods of linearity measurement
IEC 61853-1 ed1.0	Photovoltaic (PV) module performance testing and energy rating – Part 1: Irradiance and temperature performance measurements and power rating
IEC 61215 ed2.0	Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval
IEC 61730-1 ed1.0	Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction
IEC 61730-2 ed1.0	Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing

規格番号	規格名称	制定年月日	最新改正年月日
JISC8904-2	太陽電池デバイスー第2部: 基準太陽電池デバイスに対する要求事項	2011/1/20	
JISC8904-3	太陽電池デバイスー第3部: 基準太陽光の分光放射照度分布による太陽電池測定原則	2011/1/20	
JISC8904-7	太陽電池デバイスー第7部: 太陽電池測定でのスペクトルミスマッチ補正の計算方法	2011/1/20	
JISC8910	一次基準太陽電池セル	2001/12/20	2005/9/20
JISC8912	結晶系太陽電池測定用ソーラシミュレータ	1989/11/1	2011/3/22
JISC8913	結晶系太陽電池セル出力測定方法	1989/11/1	2005/9/20
JISC8914	結晶系太陽電池モジュール出力測定方法	1989/11/1	2005/9/20
JISC8915	結晶系太陽電池分光感度特性測定方法	1989/11/1	2005/9/20
JISC8916	結晶系太陽電池セル・モジュールの出力電圧・出力電流の温度係数測定方法	1989/11/1	2005/9/20
JISC8917	結晶系太陽電池モジュールの環境試験方法及び耐久性試験方法	1989/11/1	2005/9/20
JISC8918	結晶系太陽電池モジュール	1989/11/1	2005/9/20
JISC8919	結晶系太陽電池セル・モジュール屋外出力測定方法	1995/9/1	2005/9/20
JISC8920	開放電圧による結晶系太陽電池の等価セル温度測定方法	2005/9/20	
JISC8933	アモルファス太陽電池測定用ソーラシミュレータ	1995/9/1	2011/3/22
JISC8934	アモルファス太陽電池セル出力測定方法	1995/9/1	2005/9/20
JISC8935	アモルファス太陽電池モジュール出力測定方法	1995/9/1	2005/9/20
JISC8936	アモルファス太陽電池分光感度特性測定方法	1995/9/1	2005/9/20
JISC8937	アモルファス太陽電池出力電圧・出力電流の温度係数測定方法	1995/9/1	2005/9/20
JISC8938	アモルファス太陽電池モジュールの環境試験方法及び耐久性試験方法	1995/11/1	2005/9/20
JISC8939	アモルファス太陽電池モジュール	1995/11/1	2005/9/20
JISC8940	アモルファス太陽電池セル・モジュール屋外出力測定方法	1995/11/1	2005/9/20
JISC8942	多接合太陽電池測定用ソーラシミュレータ	2009/3/20	
JISC8943	多接合太陽電池セル・モジュール屋内出力測定方法（基準要素セル法）	2009/3/20	
JISC8944	多接合太陽電池分光感度特性測定方法	2009/3/20	
JISC8945	多接合太陽電池出力電圧・出力電流の温度係数測定方法	2009/3/20	
JISC8946	多接合太陽電池セル・モジュール屋外出力測定方法	2009/3/20	

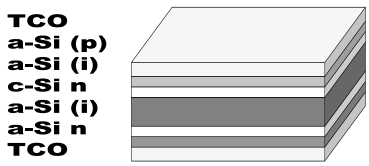
60904-2 reference devices
60904-3 STC
60904-8 SR
61853 Energy Rating
60904-1-1 MJ I-V
60904-8-1 MJ SR
, etc.

JIS C8913
JIS C8919
JIS C8934
JIS C8940
JIS C8943
JIS C8946
TS C0051
, etc.

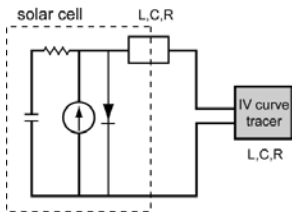
各種新型太陽電池の性能評価技術

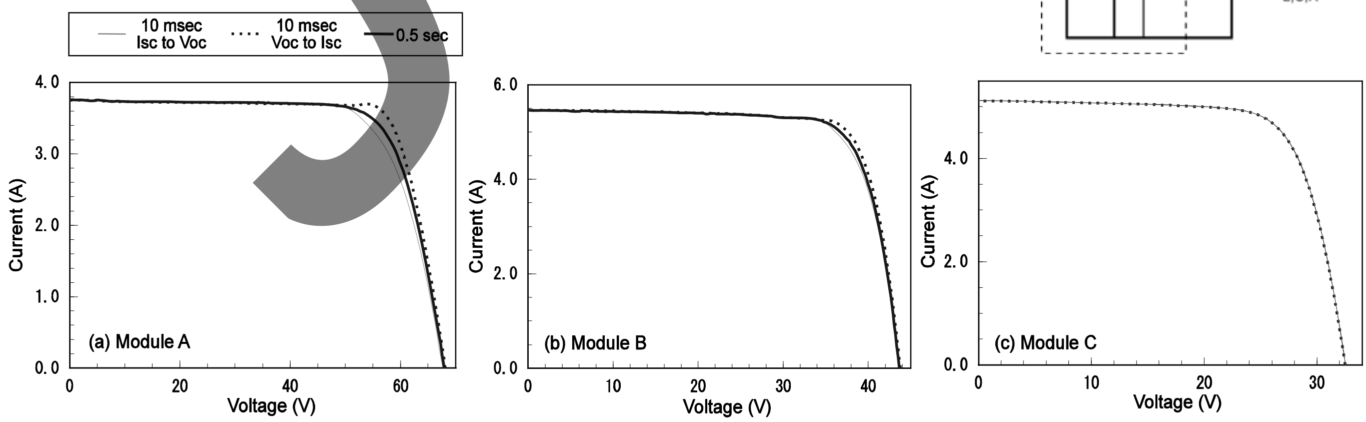
High-efficiency c-Si solar cells:

I-V sweep speed and direction



Conventional c-Si cells < 100 msec.
Recent high efficiency devices >100 msec.
dependent on device/module structures.





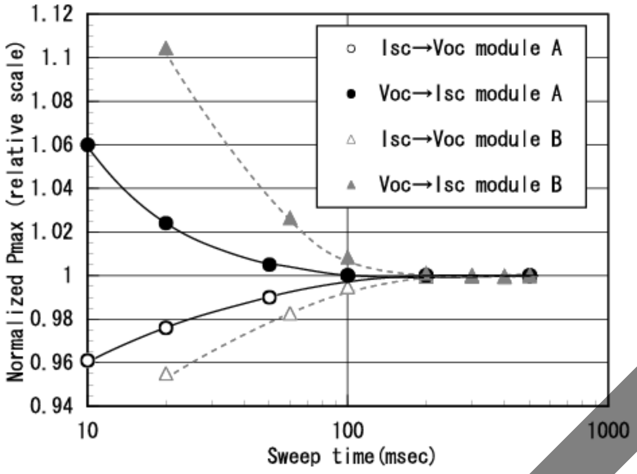
Effect of sweep speed and direction on the I-V characteristics of high-efficiency c-Si PV modules (HIT, BC, conventional).

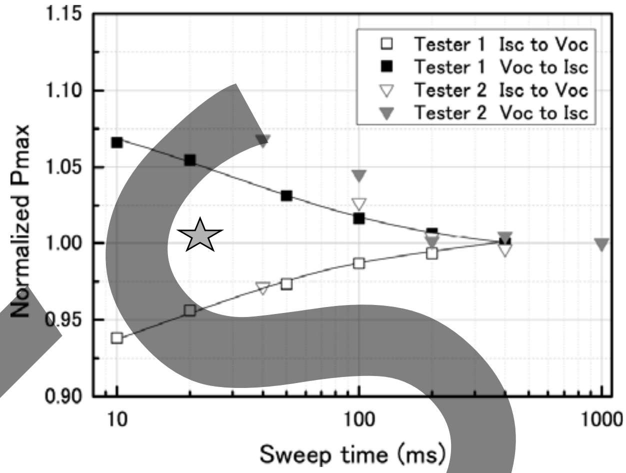
High-efficiency c-Si solar cells:

I-V sweep speed and direction

under discussion
JIS C8913
JIS C8919
JIS C8934
JIS C8940
JIS C8943
JIS C8946
TS C0051

Response time is dependent on both the **PV device and measurement equipment.**





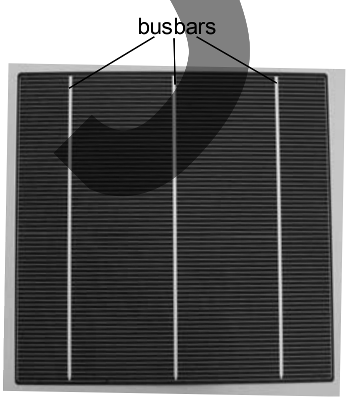
Effect of sweep speed and direction on the I-V characteristics of high-efficiency c-Si solar cell (HIT structure).

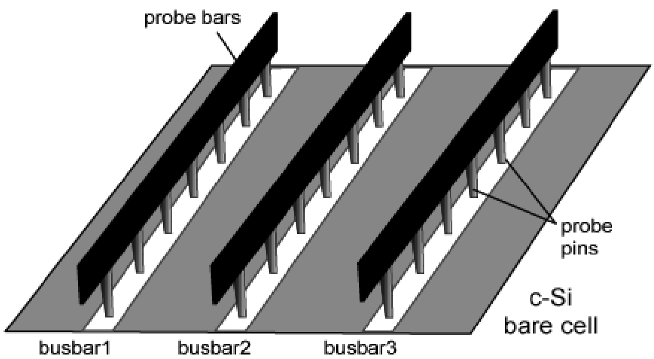
c-Si bare cells:

distribution of electric field in the cell surface

Sometimes leads to inappropriate 4 terminal connection

"good" 4 terminal connection



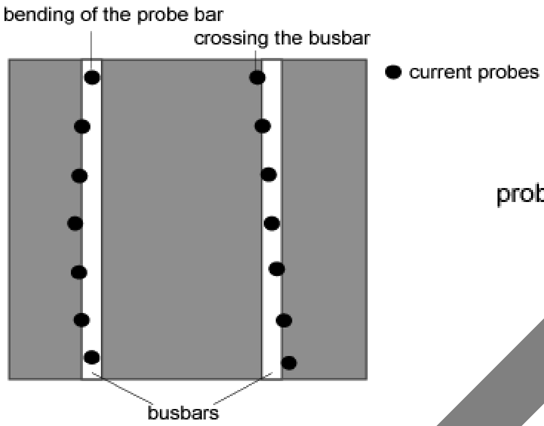


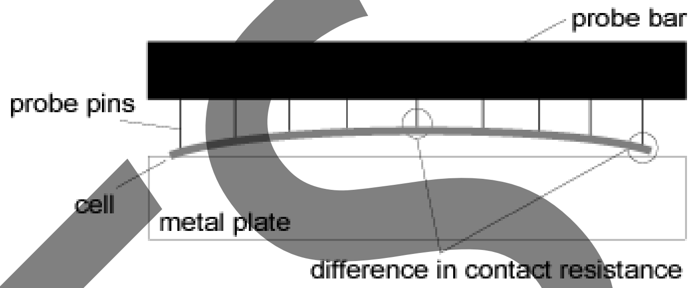
Sample stage with multiple contact probes for measuring the I-V curve of c-Si bare cells.

c-Si bare cells:
distribution of electric field in the cell surface

Cells with thinner electrodes and thinner (bending) wafers are increasing
(typ. 数mV~数十mV)

"good" 4 terminal connection

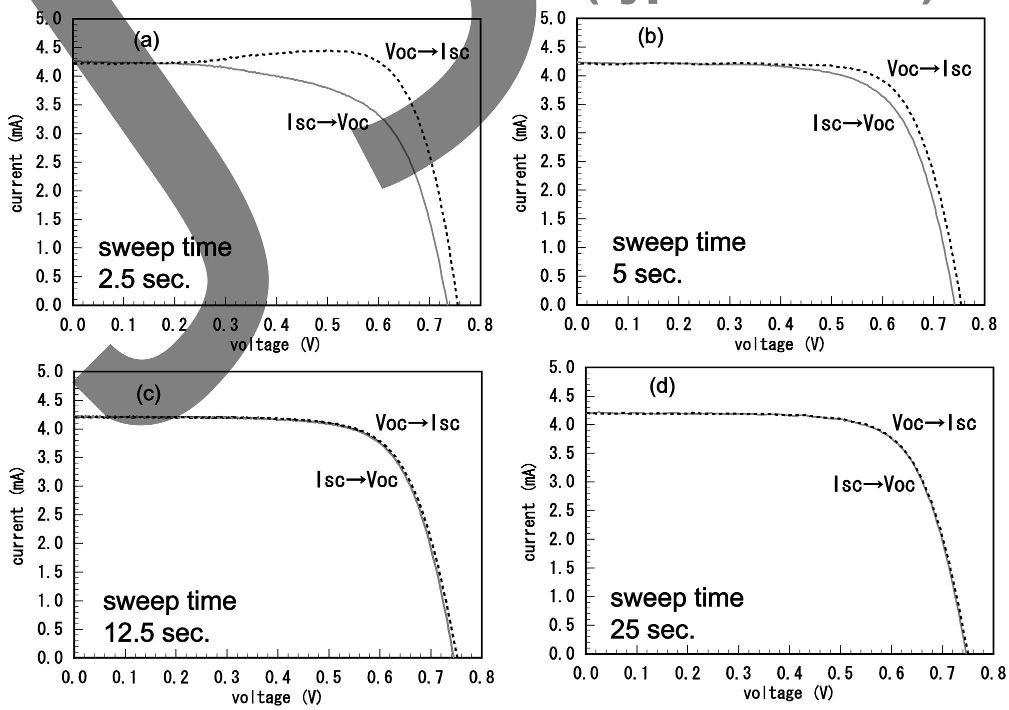




Sample stage with multiple contact probes for measuring the I-V curve of c-Si bare cells.

DSC: I-V Curve

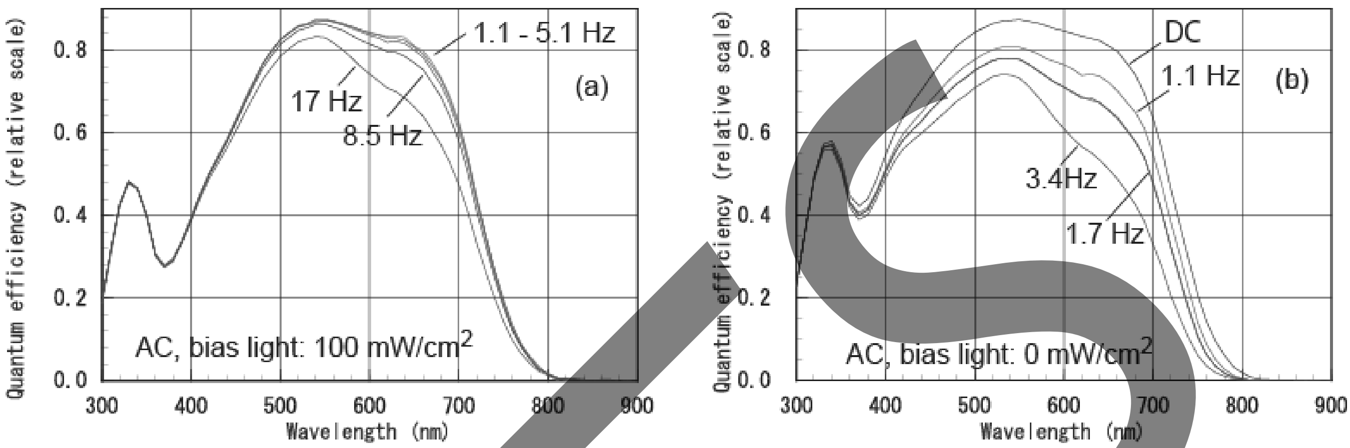
Dependent on the voltage sweep direction at sweep time of **~seconds and minutes**
(typ. 1 - 5 min.)



I-V curves of DSC as functions of the sweep time and sweep direction.

DSC: Spectral response

- Very slow response time than other PV devices
- Response time is dependent on the wavelength
- Bias light is necessary for accurate characterization
- Chopper frequency of **1 - 5 Hz or slower (typ. ~1 Hz)**

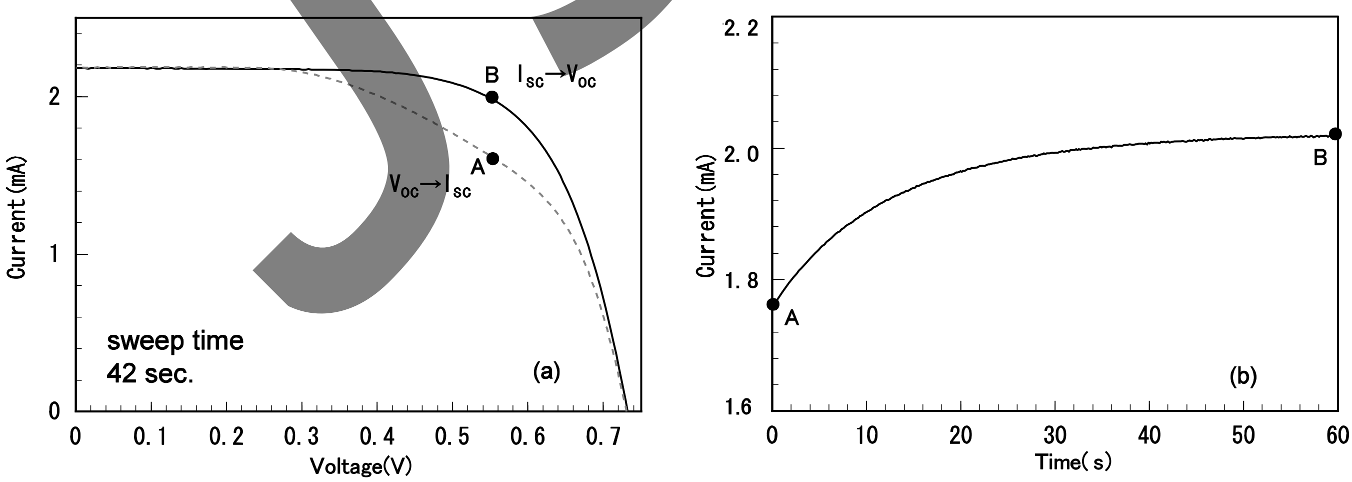


Spectral response measurement of DSC.

DSC: I-V Curve (slow devices)

Measurement from both directions (I_{sc} to V_{oc}, V_{oc} to I_{sc})

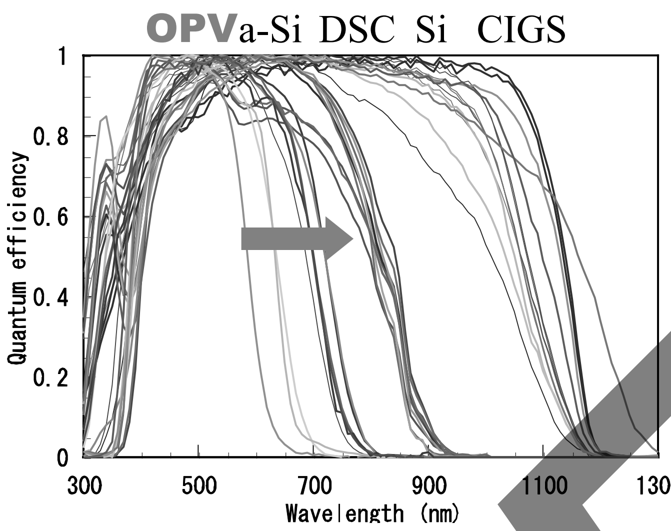
Confirmation of **P_{max} at a fixed bias voltage**

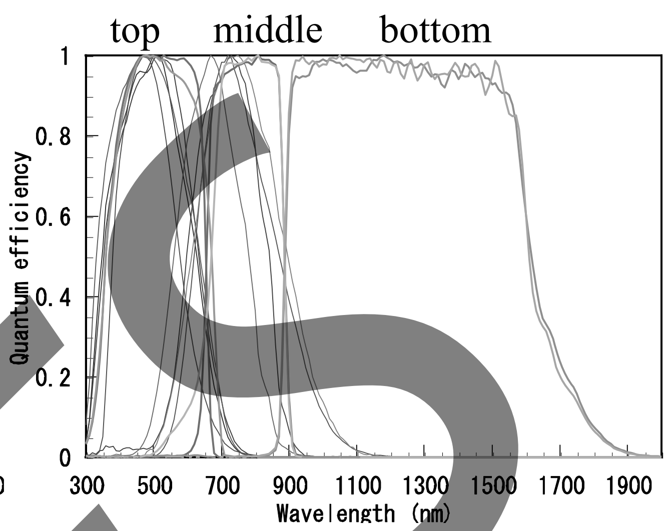


Example of the I-V parameters of DSC as functions of the sweep time and sweep direction.

OPV: very wide variation of SR

- The basic features are similar to other thin film PV devices.
- The spectral response (SR) of OPV sometimes shows different features than other PV devices, due to its **very wide variation**

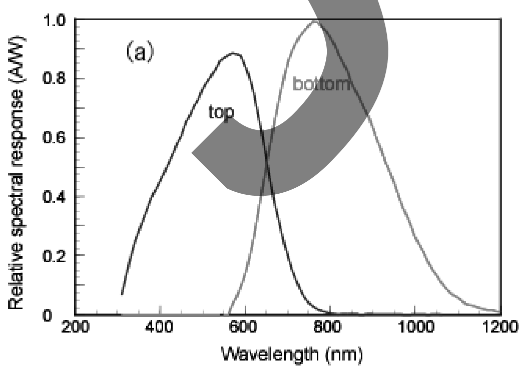


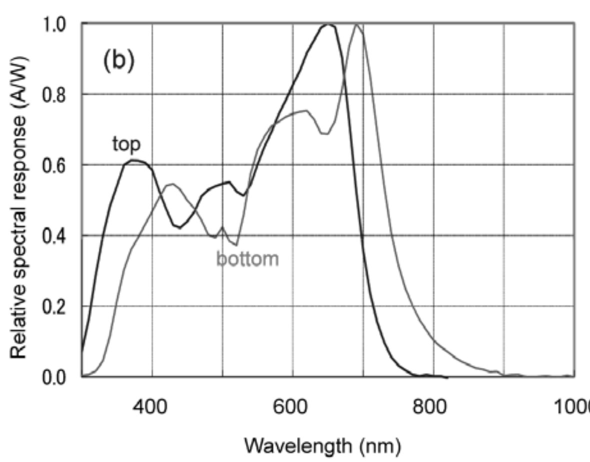


Quantum efficiency of various PV cells

OPV: very wide variation of SR

- The basic features are similar to other thin film PV devices.
- The spectral response (SR) of OPV, with optical interference patterns, sometimes shows **different appearance to other PV devices**





Example of the relative spectral responses (A/W) of an a-Si tandem and an OPV tandem devices.

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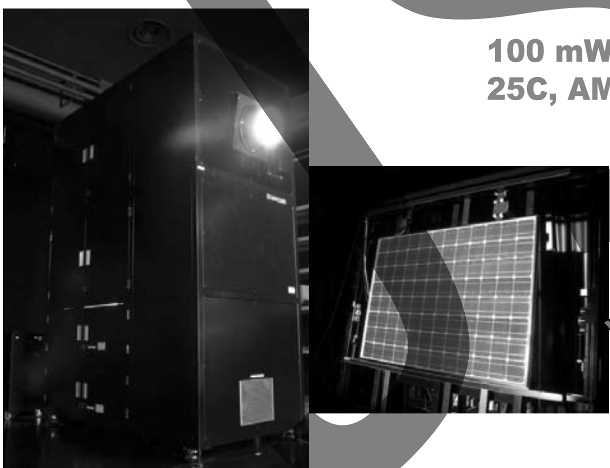
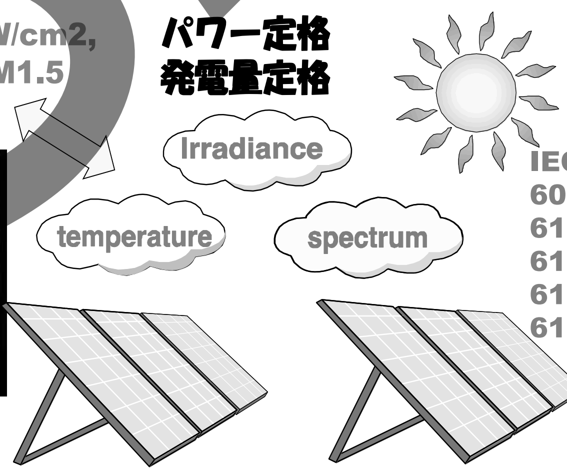
RCPVT 太陽光発電工学研究センター

太陽電池のパワー定格，エネルギー定格

Power rating and Energy rating



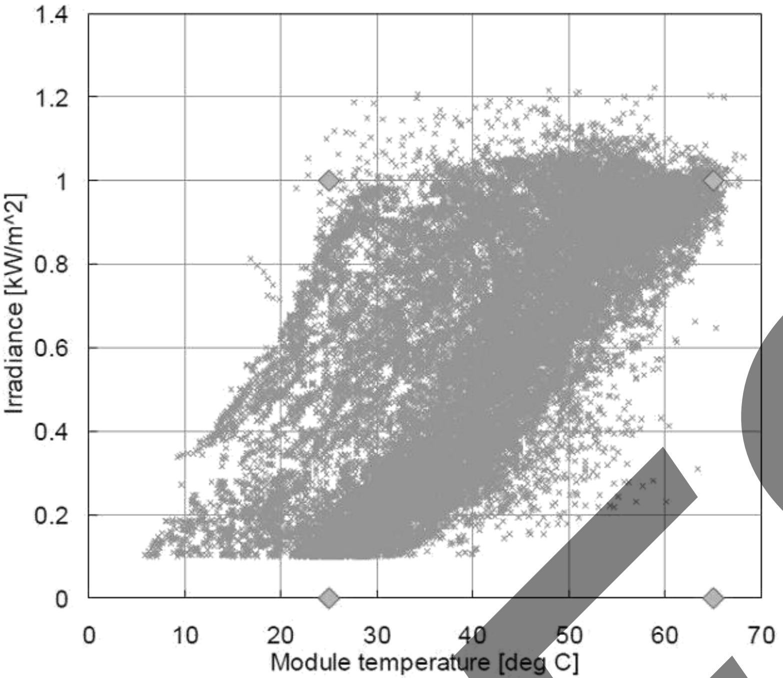


IEC
60891 published
61853-1 published
61853-2
61853-3
61853-4

IRRADIANCE	Spectrum		Module temperature		
W-m^{-2}		15 °C	25 °C	50 °C	75 °C
1 100	AM1,5	NA			
1 000	AM1,5				
800	AM1,5				
600	AM1,5				
400	AM1,5				NA
200	AM1,5			NA	NA
100	AM1,5			NA	NA

STC +irradiance + temperature

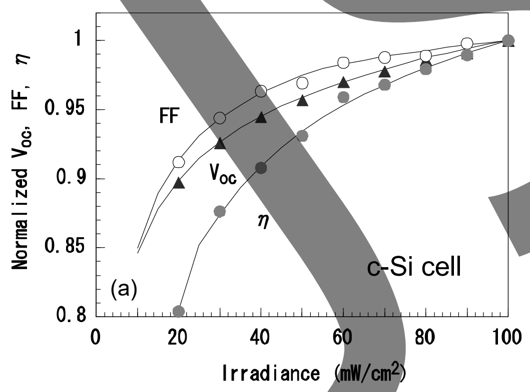
Irradiance and temperature dependence

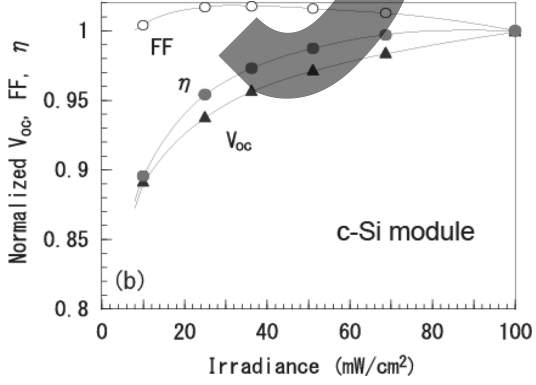


approximate range:
$0 < E < 1.1$ (kW/m^2)
$10 < T < 65$ (ºC)
Open rack, Tokyo, Japan

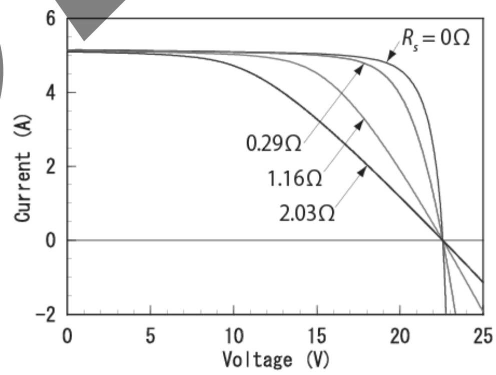
Example of the ranges of the E and T in Japan

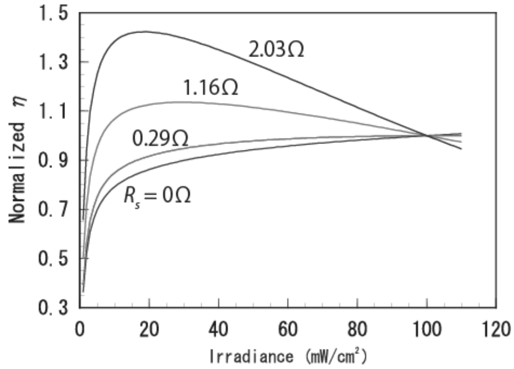
・照度特性：直列抵抗Rsの影響が支配的である





結晶Si太陽電池セル、モジュールの照度特性の一例（実験結果）

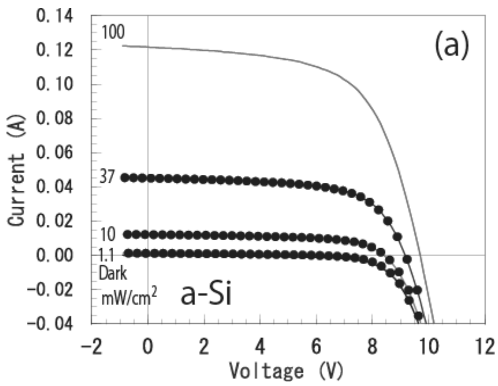


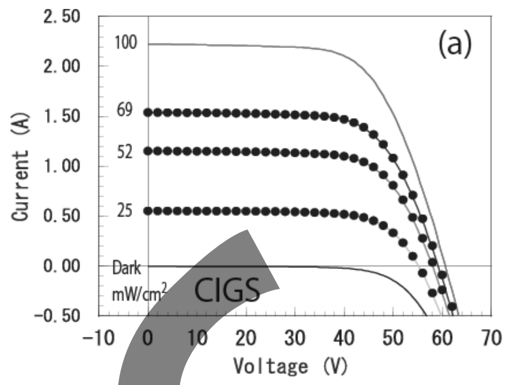


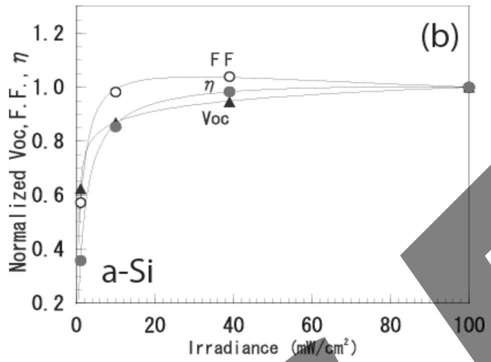
太陽電池モジュールの照度特性における直列抵抗の影響のシミュレーション

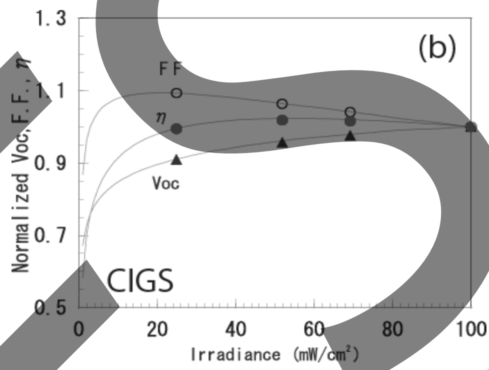
照度特性

- 新型太陽電池を含め、線形補間法で正確に補正可能であることを確認。
- 照度特性：直列抵抗Rsの影響が支配的である



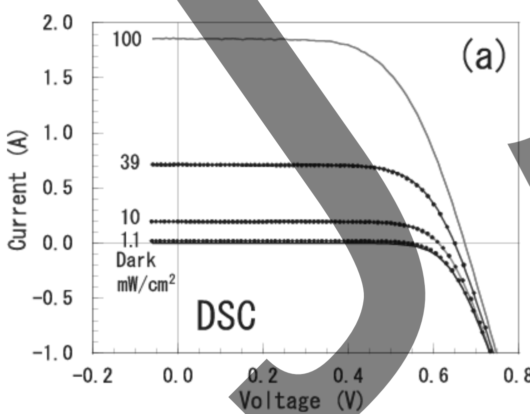


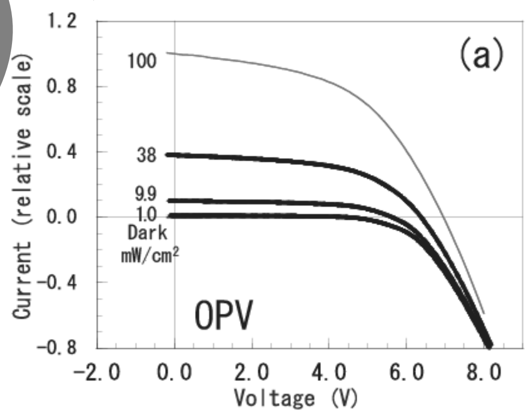


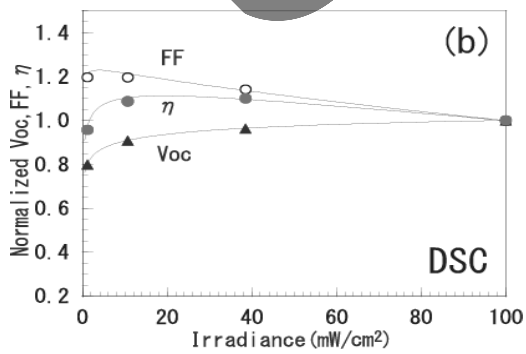


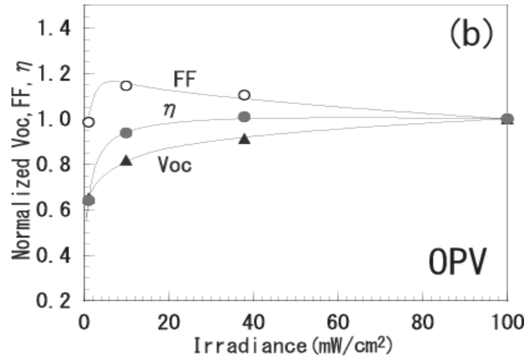
AIST

- 新型太陽電池を含め、線形補間法で正確に補正可能であることを確認。
- 照度特性：直列抵抗Rsの影響が支配的である（＋構造，材料）









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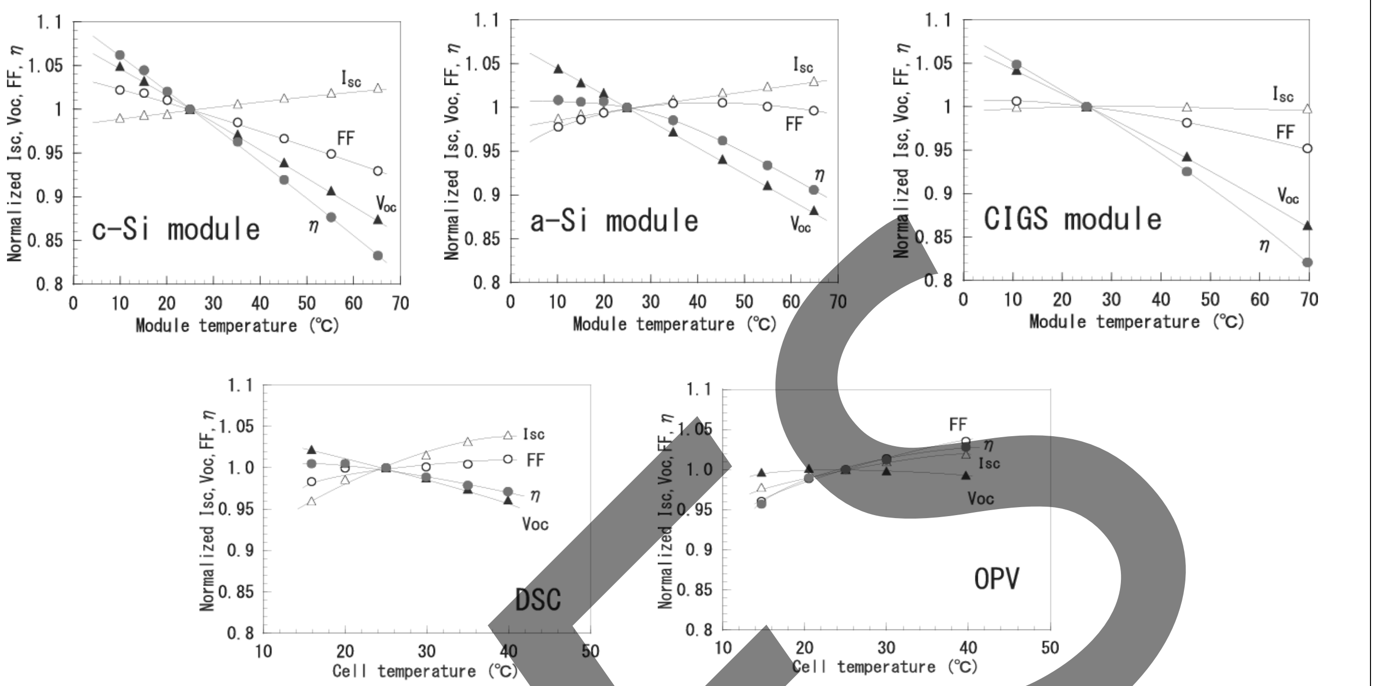
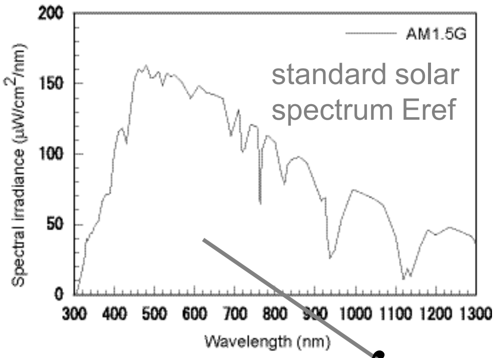
太陽光発電工学研究センター

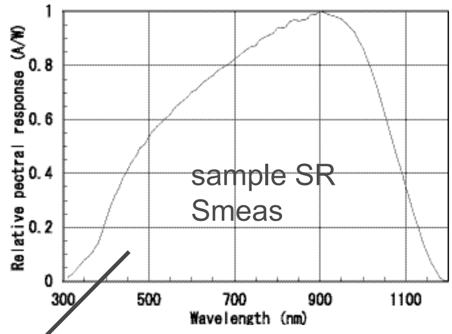
温度特性

- 新型太陽電池を含め、線形補間法で正確に補正可能であることを確認。
- 温度特性：太陽電池の材料・構造が強く影響

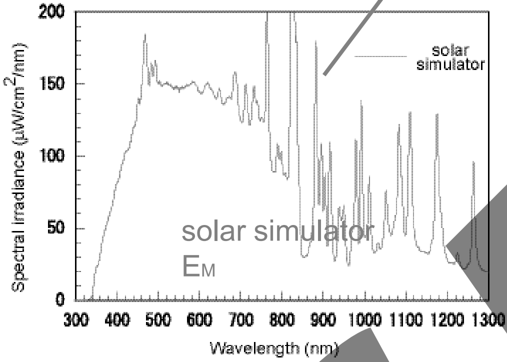


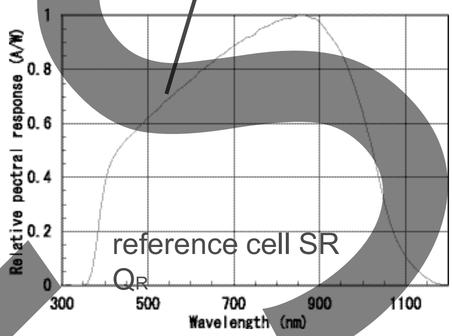
性能評価高精度化の課題





$$I_{SC,ref} = I_{SC,meas} \times \frac{\int E_{ref}(\lambda)S_{meas}(\lambda)d\lambda}{\int E_{meas}(\lambda)S_{meas}(\lambda)d\lambda}\frac{\int E_{meas}(\lambda)S_{ref}(\lambda)d\lambda}{\int E_{ref}(\lambda)S_{ref}(\lambda)d\lambda}$$

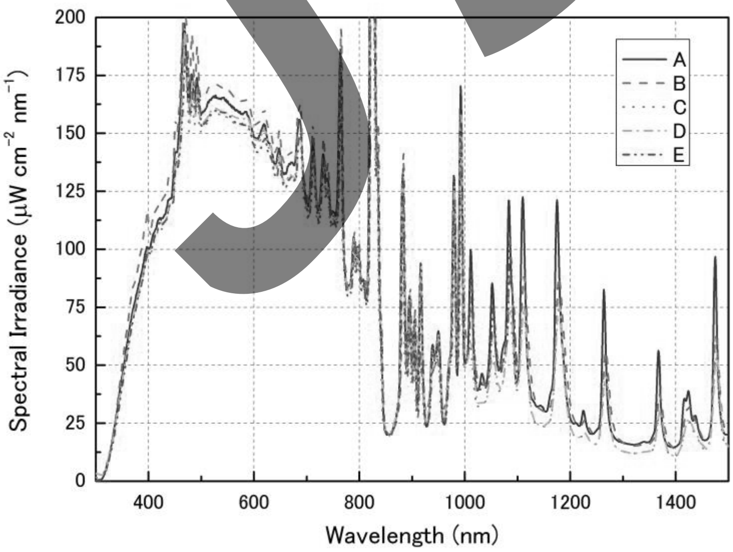




Spectral irradiance measurement

Measurements of the spectral irradiance usually includes larger uncertainty than the SR and I_{SC}.

$$I_{SC,ref} = I_{SC,meas} \times \frac{\int E_{ref}(\lambda)S_{meas}(\lambda)d\lambda}{\int E_{meas}(\lambda)S_{meas}(\lambda)d\lambda}\frac{\int E_{meas}(\lambda)S_{ref}(\lambda)d\lambda}{\int E_{ref}(\lambda)S_{ref}(\lambda)d\lambda}$$



- The same standard lamp
- The same SS

Difference in the measurement result is ~10%

Spectral irradiance of a SS measured by various spectroradiometers.

Spectral irradiance measurement

The possible technical issues for the **spectroradiometers** are;

- Linearity according to the irradiance and exposure time
(The irradiance of SS is 10 - 100 times higher than the standard lamps)
- Angular dependence of the input optics
- Stability of the optics

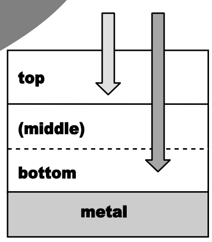
Spectrally adjustable solar simulators

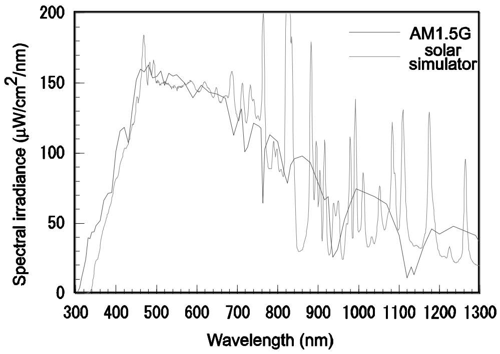
Muti-junction PV devices

Different component cells are connected in series

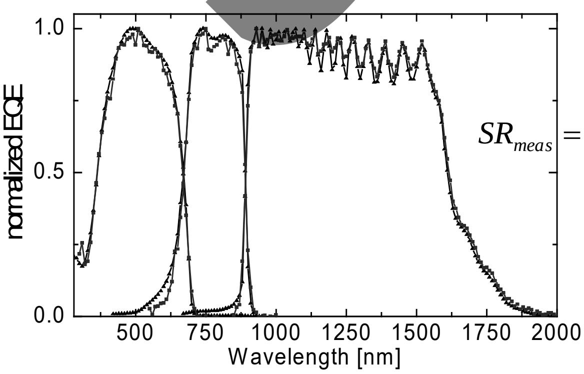
Requirement of current continuity

Accurate measurement needs more careful attention (simulator spectrum, SR, reference cells, etc.)

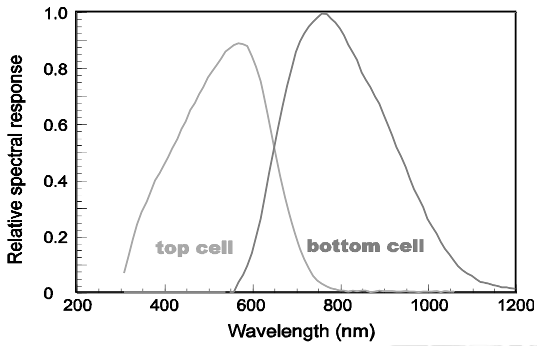




Under discussion IEC60904-1-1, 60904-8, 60904-8-1

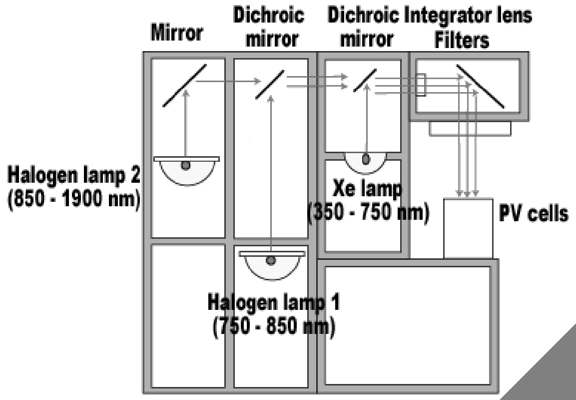


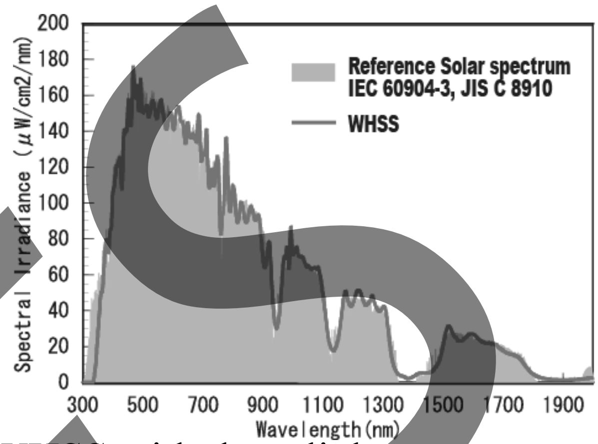
$$SR_{meas} = \frac{\sum_{i=1}^{n} SR_i \frac{dV_i}{dI_i}}{\sum_{i=1}^{n} \frac{dV_i}{dI_i}}$$



Spectrally adjustable solar simulators

- Both the high fidelity to the reference solar spectrum and spectral adjustability is necessary for the performance characterization of **multi-junction PV devices**
- Several PV testing labs. and institutes are developing and installing spectrally adjustable SS's

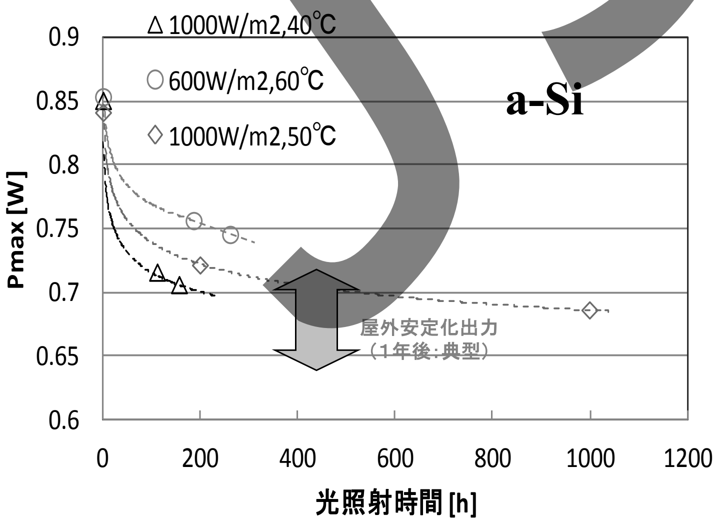




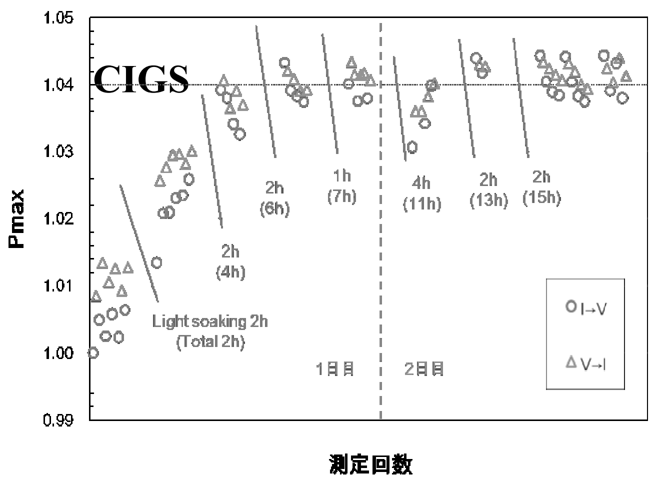
Schematic optics and spectrum of WHSS with three light sources

太陽電池実効性能評価技術の研究開発

光照射効果:最も大きな誤差要因(特に薄膜太陽電池)
光照射効果(1年以上)と光照度の関係、アニール効果の温度依存性、その相乗効果等の基本的特性をサブモジュールサイズで検証(アモルファスSi,CIGS)。
IEC61646に規定の光照射条件の範囲の影響を定量化→各種薄膜、結晶にも適用できる標準化を念頭



a-Si太陽電池サブモジュールの屋内光照射効果の一例(IEC61646, etc.)条件範囲内で5%以上差

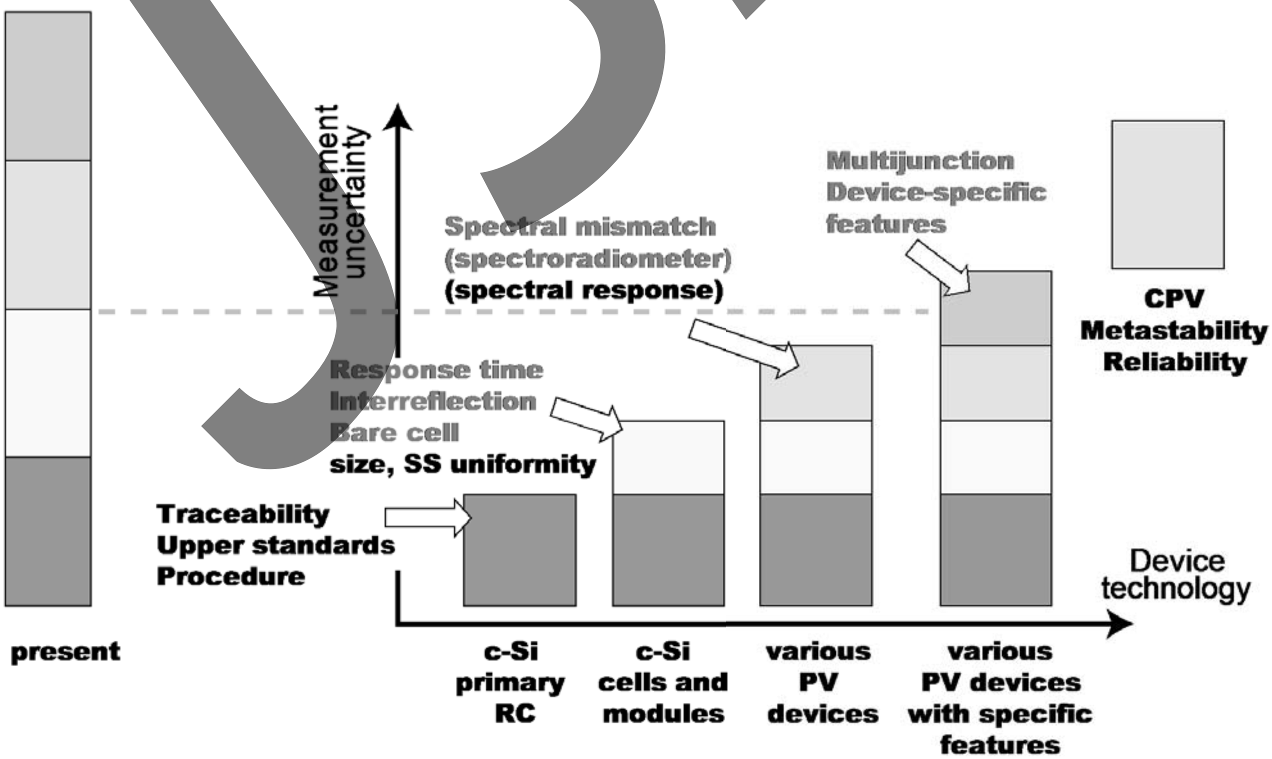


CIGS太陽電池サブモジュールの光照射効果の一例

まとめ

AIST

SUMMARY: Near-future improvements



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