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ACCELERATED PUBLICATION

Solar cell efficiency tables (version 39)

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ABSTRACT

Consolidated tables showing an extensive listing of the highest independently confirmed efficiencies for solar cells and modules are presented. Guidelines for inclusion of results into these tables are outlined, and new entries since July 2011 are reviewed. Copyright © 2011 John Wiley & Sons, Ltd.

KEYWORDS
solar cell efficiency; photovoltaic efficiency; energy conversion efficiency

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1. INTRODUCTION

Since January 1993, '*Progress in Photovoltaics*' has published six monthly listings of the highest confirmed efficiencies for a range of photovoltaic cell and module technologies [1,2]. By providing guidelines for the inclusion of results into these tables, this not only provides an authoritative summary of the current state-of-the-art but also encourages researchers to seek independent confirmation of results and to report results on a standardised basis. In a recent version of these tables published in 2009 (Version 33) [2], results were updated to the new internationally accepted reference spectrum (IEC 60904–3, Ed. 2, 2008), where this was possible.

The most important criterion for inclusion of results into the tables is that they must have been independently measured by a recognised test centre listed in Appendix A. A distinction is made between three different eligible areas: total area, aperture area and designated illumination area as defined in Appendix B. 'Active area' efficiencies are not included. There are also certain minimum values of the area sought for the different device types (above 0.05 cm^2 for a concentrator cell, 1 cm^2 for a one-sun cell and 800 cm^2 for a module).

Results are reported for cells and modules made from different semiconductors and for sub-categories within each semiconductor grouping (e.g. crystalline, polycrystalline and thin film). From Version 36 onwards, spectral response information is included when available in the form of a plot of the external quantum efficiency (EQE) versus wavelength, either absolute values or normalised to the peak measured value. Current–voltage curves have also been included where possible from Version 38 onwards [1].

2. NEW RESULTS

Highest confirmed 'one sun' cell and module results are reported in Tables I and II. Any changes in the tables from those previously published [1] are set in bold type. In most cases, a literature reference is provided that describes either the result reported or a similar result. Table I summarises the best measurements for cells and submodules whereas Table II shows the best results for modules. Table III contains what might be described as 'notable exceptions'. While not conforming to the requirements to be recognised as a class record, the cells and modules in this table have notable characteristics that will be of interest to sections of the photovoltaic community, with entries based on their significance and timeliness.

Table I. Confirmed terrestrial cell and submodule efficiencies measured under the global AM1.5 spectrum (1000 W/m^2) at 25°C (IEC 60904–3: 2008, ASTM G-173-03 global).

Classification[a]	Effic.[b] (%)	Area[c] (cm^2)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF[d] (%)	Test centre[e] (and date)	Description
Silicon							
Si (crystalline)	25.0 ± 0.5	4.00 (da)	0.706	42.7[f]	82.8	Sandia (3/99)[g]	UNSW PERL [18]
Si (multicrystalline)	20.4 ± 0.5	1.002 (ap)	0.664	38.0	80.9	NREL (5/04)[g]	FhG-ISE [19]
Si (thin film transfer)	19.1 ± 0.4	3.983 (ap)	0.650	37.8[h]	77.6	FhG-ISE (2/11)	ISFH (43-μm thick) [20]
Si (thin film submodule)	10.5 ± 0.3	94.0 (ap)	0.492[i]	29.7[i]	72.1	FhG-ISE (8/07)[g]	CSG Solar (1–2 μm on glass; 20 cells) [21]
III-V cells							
GaAs (thin film)	**28.3 ± 0.8**	**0.9944 (ap)**	**1.107**	**29.47[j]**	**86.7**	**NREL (8/11)**	**Alta devices** [3]
GaAs (multicrystalline)	18.4 ± 0.5	4.011 (t)	0.994	23.2	79.7	NREL (11/95)[g]	RTI, Ge substrate [22]
InP (crystalline)	22.1 ± 0.7	4.02 (t)	0.878	29.5	85.4	NREL (4/90)[g]	Spire, epitaxial [23]
Thin film chalcogenide							
CIGS (cell)	19.6 ± 0.6[k]	0.996 (ap)	0.713	34.8[l]	79.2	NREL (4/09)	NREL, CIGS on glass [24]
CIGS (submodule)	**17.4 ± 0.5**	**15.993 (da)**	**0.6815[i]**	**33.84[i]**	**75.5**	**FhG-ISE (10/11)**	**Solibro, four serial cells** [4]
CdTe (cell)	16.7 ± 0.5[k]	1.032 (ap)	0.845	26.1	75.5	NREL (9/01)[g]	NREL, mesa on glass [25]
Amorphous/nanocrystalline Si							
Si (amorphous)	10.1 ± 0.3[m]	1.036 (ap)	0.886	16.75[f]	67.0	NREL (7/09)	Oerlikon Solar Lab, Neuchatel [26]
Si (nanocrystalline)	10.1 ± 0.2[n]	1.199 (ap)	0.539	24.4	76.6	JQA (12/97)	Kaneka (2 μm on glass) [27]
Photochemical							
Dye sensitised	**11.0 ± 0.3[o]**	**1.007 (da)**	**0.714**	**21.93[h]**	**70.3**	**AIST (9/11)**	**Sharp** [5]
Dye sensitised (submodule)	9.9 ±0.4[o]	17.11 (ap)	0.719[i]	19.4[i,l]	71.4	AIST (8/10)	Sony, eight parallel cells [28]
Organic							
Organic thin film	**10.0 ± 0.3[o]**	**1.021 (ap)**	**0.899**	**16.75[j]**	**66.1**	**AIST (10/11)**	**Mitsubishi Chemical** [6]
Organic (submodule)	**4.2 ± 0.2[o]**	**294.5 (da)**	**0.714**	**12.26[j]**	**47.7**	**AIST (9/11)**	**Sumitomo Chemical (10 series cells)** [7]
Multijunction devices							
GaInP/GaInAs/Ge	**34.1 ± 1.2**	**30.17 (t)**	**2.691**	**14.7[j]**	**86.0**	**FhG-ISE (9/09)**	**AZUR (monolithic)** [8]
a-Si/nc-Si/nc-Si (thin film)	12.4 ± 0.7[p]	1.050 (ap)	1.936	8.96[h]	71.5	NREL (3/11)	United Solar [29]
a-Si/nc-Si (thin film cell)	**12.3 ± 0.3[q]**	**0.962(ap)**	**1.365**	**12.93[j]**	**69.4**	**AIST (7/11)**	**Kaneka** [9]
a-Si/nc-Si (thin film submodule)[j]	11.7 ± 0.4[n,r]	14.23 (ap)	5.462	2.99	71.3	AIST (9/04)	Kaneka [30]

[a]CIGS, $CuInGaSe_2$; a-Si, amorphous silicon/hydrogen alloy.
[b]Effic., efficiency.
[c](ap), aperture area; (t), total area; (da), designated illumination area.
[d]FF, fill factor.
[e]FhG-ISE, Fraunhofer Institut für Solare Energiesysteme; JQA, Japan Quality Assurance; AIST, Japanese National Institute of Advanced Industrial Science and Technology.
[f]Spectral response reported in Version 36 of these Tables.
[g]Recalibrated from original measurement.
[h]Spectral response and current–voltage curve reported in Version 38 of these Tables.
[i]Reported on a "per cell" basis.
[j]Spectral response and current–voltage curve reported in present version of these Tables.
[k]Not measured at an external laboratory.
[l]Spectral response reported in Version 37 of these Tables.
[m]Light soaked at Oerlikon prior to testing at NREL (1000 h, one sun, 50°C).
[n]Measured under IEC 60904–3 Ed. 1: 1989 reference spectrum.
[o]Stability not investigated. References 31 and 32 review the stability of similar devices.
[p]Light soaked under 100 mW/cm2 white light at 50°C for over 1000 h.
[q]Stabilised by manufacturer.
[r]Stabilised by 174 h, one sun illumination after 20 h, five sun illumination at a sample temperature of 50°C.

To encourage discrimination, Table III is limited to approximately 10 entries with the present authors having voted for their preferences for inclusion. Readers who have suggestions of results for inclusion into this table are welcome to contact any of the authors with full details. Suggestions conforming to the guidelines will be included on the voting list for a future issue.

Table II. Confirmed terrestrial module efficiencies measured under the global AM1.5 spectrum (1000 W/m^2) at a cell temperature of 25°C (IEC 60904–3: 2008, ASTM G-173-03 global).

Classification[a]	Effic.[b] (%)	Area[c] (cm^2)	V_{oc} (V)	I_{sc} (A)	FF[d] (%)	Test centre (and date)	Description
Si (crystalline)	22.9 ± 0.6	778 (da)	5.60	3.97	80.3	Sandia (9/96)[e]	UNSW/Gochermann [33]
Si (large crystalline)	21.4 ± 0.6	15 780 (ap)	68.6	6.293	78.4	NREL (10/09)	SunPower [34]
Si (multicrystalline)	**18.2 ± 0.4**	**14 709 (ap)**	**38.29**	**9.11[f]**	**76.7**	**ESTI (8/11)**	**Schott Solar (60 serial cells)** [10]
Si (thin-film polycrystalline)	8.2 ± 0.2	661(ap)	25.0	0.320	68.0	Sandia (7/02)[e]	Pacific Solar (1–2 μm on glass) [35]
GaAs (thin film)	**23.5 ± 0.7**	**856.8 (ap)**	**10.77**	**2.222[f]**	**84.0**	**NREL (12/11)**	**Alta Devices** [3]
CIGS	15.7 ± 0.5	9703 (ap)	28.24	7.254[g]	72.5	NREL (11/10)	Miasole [36]
CIGSS (Cd free)	13.5 ± 0.7	3459 (ap)	31.2	2.18	68.9	NREL (8/02)[e]	Showa Shell [37]
CdTe	12.8 ± 0.4	6687 (ap)	94.1	1.27	71.4	NREL (1/11)	PrimeStar [1]
a-Si/a-SiGe/a-SiGe (tandem)	10.4 ± 0.5[h,i]	905 (ap)	4.353	3.285	66.0	NREL (10/98)[e]	USSC [38]

[a]CIGSS, CuInGaSSe; a-Si, amorphous silicon/hydrogen alloy; a-SiGe, amorphous silicon/germanium/hydrogen alloy.
[b]Effic., efficiency.
[c](ap), aperture area; (da), designated illumination area.
[d]FF, fill factor.
[e]Recalibrated from original measurement.
[f]Spectral response and current–voltage curve reported in present version of these Tables.
[g]Spectral response reported in Version 37 of these Tables.
[h]Light soaked at NREL for 1000 h at 50°C, nominally one-sun illumination.
[i]Measured under IEC 60904–3 Ed. 1: 1989 reference spectrum.

Table III. 'Notable exceptions': 'Top ten' confirmed cell and module results, not class records measured under the global AM1.5 spectrum (1000 Wm^{-2}) at 25°C (IEC 60904–3: 2008, ASTM G-173-03 global).

Classification[a]	Effic.[b] (%)	Area[c] (cm^2)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF (%)	Test centre (and date)	Description
Cells (silicon)							
Si (MCZ crystalline)	24.7 ± 0.5	4.0 (da)	0.704	42.0	83.5	Sandia (7/99)[d]	UNSW PERL, SEH MCZ substrate [39]
Si (large crystalline)	24.2 ± 0.7	155.1(t)	0.721	40.5[e]	82.9	NREL (5/10)	Sunpower n-type CZ substrate [40]
Si (large crystalline)	**23.7 ± 0.6**	**100.7(t)**	**0.745**	**39.38[f]**	**80.9**	**AIST (5/11)**	**Sanyo HIT, n-type substrate** [11]
Si (large multicrystalline)	19.5 ± 0.4	242.7(t)	0.652	39.0[e]	76.7	FhG ISE (3/11)	Q-Cells, laser-fired contacts [41]
Cells (other)							
GaInP/GaAs/GaInAs (tandem)	**36.9 ± 1.5**	**0.891 (ap)**	**3.006**	**14.05[g]**	**87.5**	**AIST (9/11)**	**Sharp, monolithic** [12]
CIGS (thin film)	20.3 ± 0.6	0.5015 (ap)	0.740	35.4[e]	77.5	FhG-ISE (6/10)	ZSW Stuttgart, CIGS on glass [42]
CZTSSe (thin film)	**10.1 ± 0.2**	**0.448 (ap)**	**0.517**	**30.8[f]**	**63.5**	**Newport (12/10)**	**IBM solution grown** [13]
a-Si/nc-Si/nc-Si (tandem)	12.5 ± 0.7[h]	0.27 (da)	2.010	9.11	68.4	NREL (3/09)	United Solar stabilised [43]
Dye-sensitised	**11.4 ± 0.3[i]**	**0.231 (ap)**	**0.743**	**21.34**	**72.2**	**AIST (6/11)[d]**	**NIMS** [14]
Luminescent submodule	7.1± 0.2[i]	25 (ap)	1.008	8.84[e]	79.5	ESTI (9/08)	ECN Petten, GaAs cells [44]

[a]CIGS, $CuInGaSe_2$; CZTSS, $Cu_2ZnSnS_{4-y}Se_y$
[b]Effic., efficiency
[c](ap), aperture area; (t), total area; (da), designated illumination area
[d]Recalibrated from original measurement
[e]Spectral response reported in Version 37 of these Tables
[f]Spectral response and current–voltage curve reported in the present version of these Tables
[g]Spectral response and current–voltage curves reported in Version 38 of these Tables
[h]Light soaked under 100 mW/cm2 white light at 50°C for 1000 h
[i]Stability not investigated

Table IV. Terrestrial concentrator cell and module efficiencies measured under the ASTM G-173-03 direct beam AM1.5 spectrum at a cell temperature of 25°C.

Classification	Effic.[a] (%)	Area[b] (cm^2)	Intensity[c] (suns)	Test centre (and date)	Description
Single cells					
GaAs	29.1 ± 1.3[d]	0.0505 (da)	117	FhG-ISE (3/10)	Fraunhofer ISE
Si	27.6 ± 1.0[f]	1.00 (da)	92	FhG-ISE (11/04)	Amonix back-contact [45]
Multijunction cells					
GaInP/GaAs/GaInNAs (two-terminal)	43.5 ± 2.6	0.3124 (ap)	418	NREL (3/11)	Solar Junction, Triple Cell [46]
GaInP/GaInAs/Ge (2-terminal)	41.6 ± 2.5[e]	0.3174(da)	364	NREL (8/09)	Spectrolab, lattice-matched [47]
Submodules					
GaInP/GaAs; GaInAsP/GaInAs	38.5 ± 1.9[g]	0.202 (ap)	20	NREL (8/08)	DuPont *et al.*, split spectrum [48]
GaInP/GaAs/Ge	27.0 ± 1.5[h]	34 (ap)	10	NREL (5/00)	ENTECH [49]
Modules					
Si	20.5 ± 0.8[d]	1875 (ap)	79	Sandia (4/89)[i]	Sandia/UNSW/ENTECH (12 cells) [50]
'*Notable Exceptions*'					
Si (large area)	21.7 ± 0.7	20.0 (da)	11	Sandia (9/90)[i]	UNSW laser grooved [51]

[a]Effic., efficiency
[b](da), designated illumination area; (ap), aperture area
[c]One sun corresponds to direct irradiance of 1000 Wm^{-2}
[d]Not measured at an external laboratory
[e]Spectral response reported in Version 36 of these Tables
[f]Measured under a low aerosol optical depth spectrum similar to ASTM G-173-03 direct [52]
[g]Spectral response reported in Version 37 of these Tables
[h]Measured under old ASTM E891-87 reference spectrum
[i]Recalibrated from original measurement

Table IV shows the best results for concentrator cells and concentrator modules (a smaller number of 'notable exceptions' for concentrator cells and modules additionally is included in Table IV).

Thirteen new results are reported in the present version of these tables, including two landmark 10% milestone results and outright records for the highest efficiency solar cell and module under non-concentrated sunlight.

The first new result in Table I is an outright record for solar conversion by any single-junction photovoltaic device, following on from the 28.1% result reported in the previous version of these tables [1]. An efficiency of 28.3% has been measured at the National Renewable Energy Laboratory (NREL) for a 1-cm^2 thin-film GaAs device fabricated by Alta Devices, Inc.. Alta Devices is a Santa Clara based 'start-up' seeking to develop low-cost, 30% efficient solar modules [3].

The second new result is for a $CuIn_xGa_{1-x}Se_2$ submodule with 17.4% efficiency reported for a 16-cm^2 device consisting of four serially connected cells, fabricated by Solibro [4] and measured by the Fraunhofer Institute for Solar Energy Systems.

Another new result in Table I is for a dye-sensitised cell with efficiency of 11.0% reported for a 1-cm^2 cell fabricated by Sharp [5] and measured by the Japanese National Institute of Advanced Industrial Science and Technology (AIST), marginally improving over the 10.9% results reported by the same company in the previous version of these tables [1].

Two new results are reported in the organic cell area, where progress continues unabated. The first is the achievement of a landmark milestone for an organic cell, with 10.0% efficiency (unstabilised) reported for a 1-cm^2 device fabricated by Mitsubishi Chemical [6] and measured by AIST. Also reported is an improvement in efficiency to 4.2% for a 295-cm^2 submodule fabricated by Sumitomo Chemical [7] and again measured by AIST. The stability of this device was also not investigated.

Another major new result is a new record for energy conversion efficiency for any moderate area photovoltaic converter, not using sunlight concentration. An efficiency of 34.1% is reported for a 30-cm^2 $Ga_{0.5}In_{0.5}P/Ga_{0.99}In_{0.01}As/Ge$ multijunction cell fabricated by AZUR Space Solar Power [8] and measured by Fraunhofer Institute for Solar Energy Systems. This device was measured some time ago in 2009, but unfortunately was missed in previous versions of these tables.

The final new result in Table I is for a 1-cm^2 double junction amorphous/nanocrystalline silicon solar cell (a-Si/nc-Si) fabricated by Kaneka [9] where an efficiency of 12.3% has been measured by AIST. The cell was stabilised by the manufacturer prior to measurement.

Following a vigorous burst of activity in the multicrystalline silicon module area reported in the four previous versions of these tables, where five groups exceeded the previous record for module efficiency six times over a 2-year period, one of these groups has done even better. In Table II, a new

efficiency record of 18.2% is reported for a large (1.5-m^2 aperture area) module fabricated by Schott Solar [10] and measured by the European Solar Test Installation, Ispra.

Also reported in Table II is a record result for a thin-film GaAs module, with an efficiency of 23.5% reported for an 857-cm^2 module fabricated by Alta Devices [3] and measured by NREL. With the ongoing improvement in GaAs cell performance reported in Table I, this efficiency might also be expected to further improve in the future.

The first new result in Table III relates to an efficiency increase to 23.7% for a large 100-cm^2 crystalline silicon cell fabricated by Sanyo [11] and measured by AIST. The cell uses Sanyo's HIT cell structure (Heterojunction with intrinsic thin layer).

A second new result in Table III relates to a cell that demonstrates the highest efficiency yet for the conversion of non-concentrated sunlight into electricity. An efficiency of 36.9% is reported for a small area (0.89 cm^2) GaInP/GaAs/GaInAs multijunction cell fabricated by Sharp [12] and measured by AIST. This cell is only slightly smaller than that required to be considered as an outright record.

Another new result in Table III is the further improvement of a small area (0.45 cm^2) $Cu_2ZnSnS_{4-y}Se_y$ (CZTSS) cell fabricated by IBM T.J. Watson Research Center [13] to 10.1% efficiency as measured by the Newport Technology and Applications Center's Photovoltaic Laboratory. This cell is smaller than the 1-cm^2 size required for classification as an outright record.

The final new result in Table III is the demonstration of 11.4% efficiency for a small area (0.23 cm^2) dye-sensitised solar cell fabricated by the Photovoltaic Unit of the Japanese National Institute for Materials Science [14] and measured by AIST. The cell area is too small to qualify as an outright record. Although higher values for dye-sensitised cells have been recently reported in the journal *Science* [15], these higher values appear to be based solely on 'in-house' measurements [16], with such measurements known to be notably unreliable (Editors of, and reviewers for, reputable journals are encouraged to ensure that any published solar cell result claiming to be the best in its field has been independently certified by an appropriately qualified laboratory).

The external quantum efficiencies, in some cases normalised to the peak EQE values, for the new GaAs cell and module results of Tables I and II are shown in Figure 1 (a) as well as the response for the dye-sensitised and organic cells and submodule of Table I. Figure 1(b) shows the EQE of the new silicon cell and modules results in the present issue of these tables together with the new CZTSSe result (normalised) of Table III. The wavelength at which the EQE drops to 50% of its peak value at long wavelength provides a reasonable estimate of the cell bandgap, estimated in this way as 1.23 eV for the CZTSSe cell. The bandgaps of CZTSSe and CZTS are commonly quoted as circa 1.0 and 1.5 eV, respectively [17], suggesting a mid-range composition for the record cell. Figure 1(c) shows the EQE of the constituent cells for the two new multijunction cell results.

Figure 2 shows the current density–voltage curves for the corresponding devices. For the case of modules and the a-Si/nc-Si tandem cell, the measured current–voltage data have been reported on a 'per cell' basis (voltage has been divided by the number of cells in series per series string, whereas current has been multiplied by this

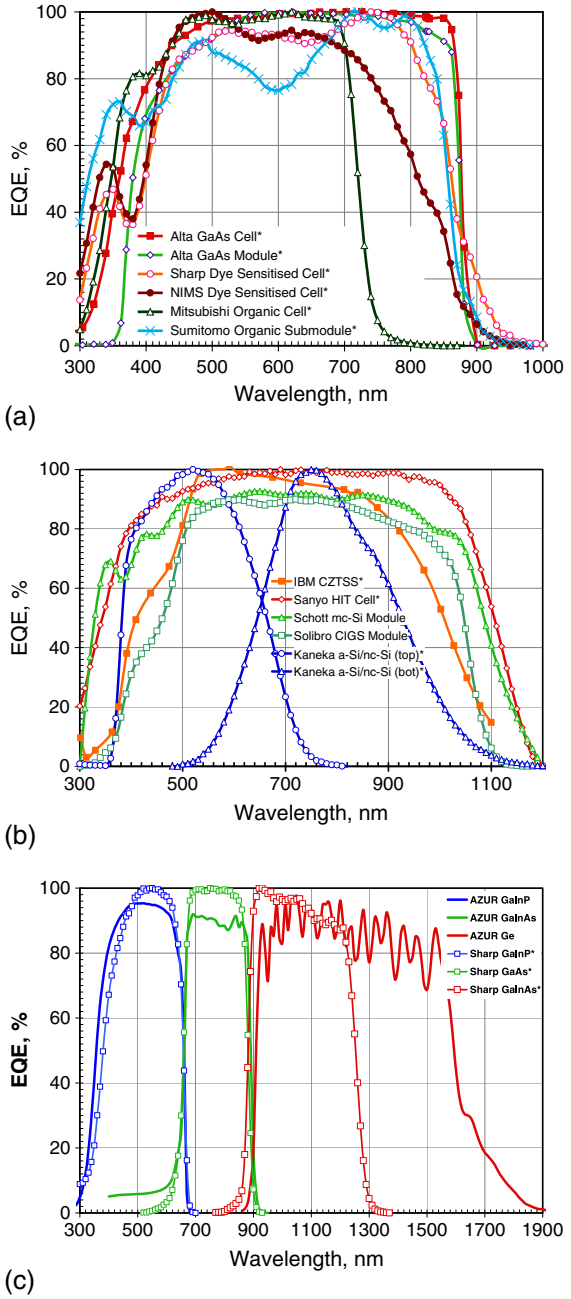

Figure 1. (a) External Quantum Efficiency (EQE) for the new GaAs cell and module results in this issue, as well as for the new dye-sensitised cell results and the new organic cell and module results; (b) EQE for the new silicon cell and module entries in this issue plus for the new CZTSS cell result; (c) EQE for the new triple junction multijunction cells in this issue (* Normalised data).

quantity and divided by the cell or module area). In some cases, the number of cells per series string has been estimated.

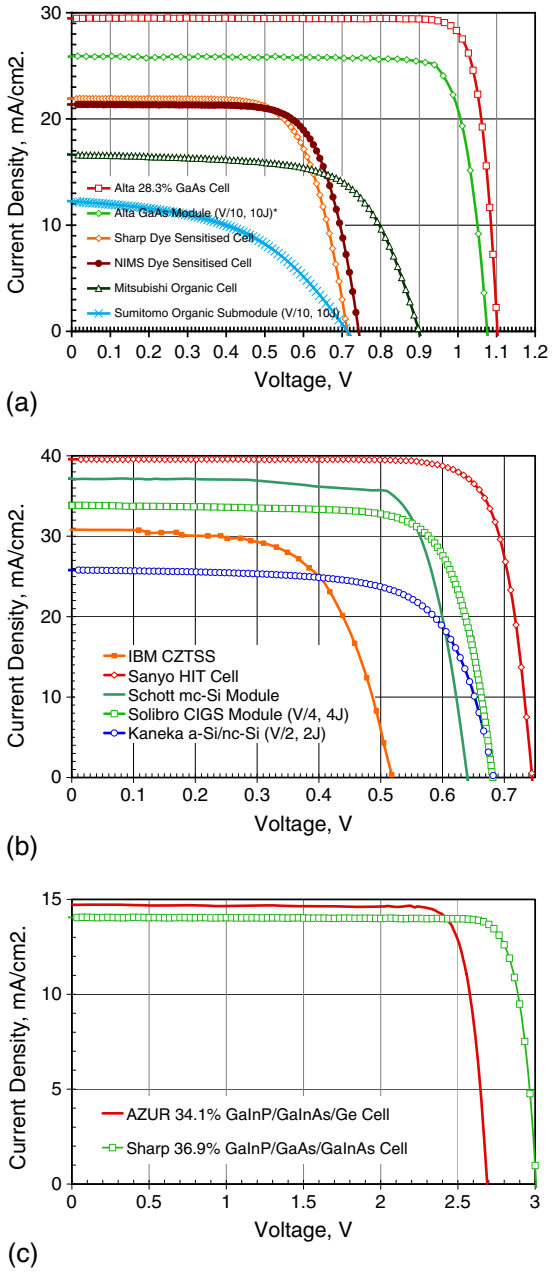

Figure 2. (a) Current density–voltage (JV) curve for the new GaAs cell and module results in this issue, as well as for the new dye-sensitised cell results and the new organic cell and module results; (b) JV curves for the new silicon cell and module entries in this issue plus for the new CZTSS cell result; (c) JV curves for the new triple junction multijunction cells in this issue (* Cells per series string estimated).

3. DISCLAIMER

Whereas the information provided in the tables is provided in good faith, the authors, editors and publishers cannot accept direct responsibility for any errors or omissions.

APPENDIX A

APPENDIX: LIST OF DESIGNATED TEST CENTRES

A list of designated test centres follows. Results from additional ISO/IEC 17025 certified centres participating in international round-robins involving cells of a similar type to those being reported will also be considered on a case-by-case basis.

European Solar Test Installation (ESTI),
CEC Joint Research Centre,
Via E. Fermi 2749, 21020 Ispra (Varese), Italy.
Contact: Dr Ewan Dunlop
Telephone: (39) 332–789090
Facsimile: (39) 332-789-268
E-mail: esti.services@jrc.ec.europa.eu
(Cells and modules)

Fraunhofer-Institut für Solare Energiesysteme ISE,
Heidenhofstr. 2, D-79110 Freiburg,
Germany.
Contact: Dr Wilhelm Warta/Jochen Hohl-Ebinger,
CalLab PV Cells; Frank Neuberger, CalLab PV Modules
Telephone: (49) 761- 4588–5192
Facsimile: (49) 761-4588-9100
E-mail: Wilhelm.Warta@ise.fraunhofer.de
(Terrestrial, space and concentrator cells and modules)

National Institute of Advanced Industrial Science and Technology (AIST)
Central 2, Umezono 1-1-1, Tsukuba,
Ibaraki, 305–8568 Japan
Contact: Dr Yoshihiro Hishikawa
Telephone: (81) 29-861-5780 (direct)
Facsimile: (81) 29-861-5829
E-mail: y-hishikawa@aist.go.jp
(Terrestrial cells and modules)

National Renewable Energy Laboratory,
1617 Cole Blvd., Golden, CO 80401, USA.
Contact: Mr Keith Emery
Telephone: (1) 303-384-6632
Facsimile: (1) 303-384-6604
E-mail: keith.emery@nrel.gov
(Concentrator cells and modules)

Physikalisch-Technische Bundesanstalt,
Bundesallee 100, D-38116 Braunschweig,
Germany.

Contact: Dr Stefan Winter
Telephone: (49) 531-592-4140
Facsimile: (49) 531-592-694140
E-mail: Stefan.Winter@ptb.de
(Cells mounted on a base plate)

APPENDIX B

AREA DEFINITIONS

The area of the cell or module is an important parameter in determining efficiency. The areas used in the tables conform to one of the three following classifications illustrated in Figure 3:

(i) *Total area*: The total projected area of the cell or module.

This is the preferred area for reporting of results. For the case of a cell attached to glass, the total area would be the area of the glass sheet. For a module, it would include the area of frames.

(ii) *Aperture area*: The portion of the total cell or module area that includes all essential components, including active material, busbars, fingers and interconnects.

In principle, during testing, illumination is restricted to this portion such as by masking. Such restriction is not essential if the test centre is satisfied that there is no response from light incident outside the assigned aperture area.

(iii) *Designated illumination area*: A portion of the cell or module area from which some cell or module contacting components are excluded.

In principle, during testing, illumination is restricted to this portion such as by masking. Such restriction is not essential if the test centre is satisfied that there is no response from light incident outside the assigned designated illumination area. For concentrator cells, cell busbars would lie outside of the area designed for illumination and this area classification would be the most appropriate. For a cell on insulating substrates, cell contacts may lie outside the designated illumination area. For modules, cell string interconnects may lie outside the masked area.

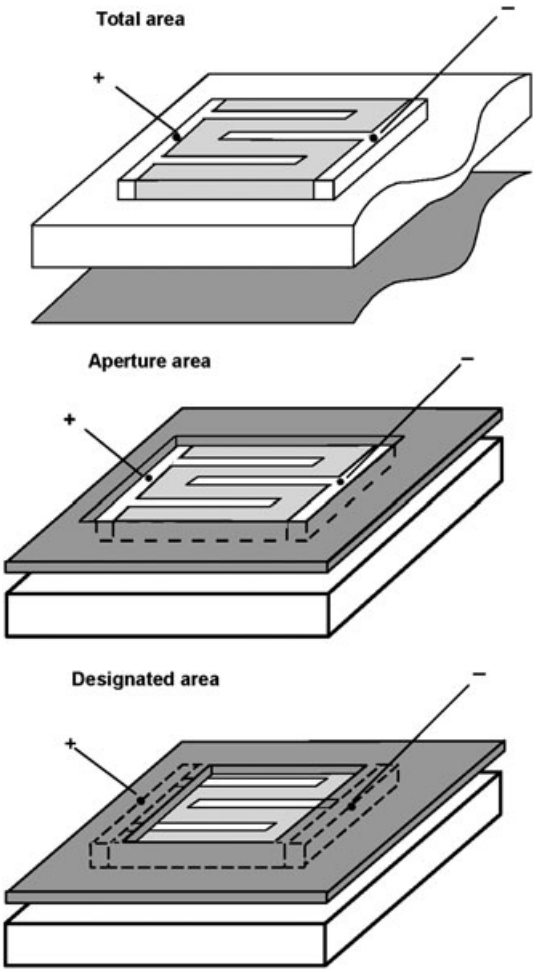

Figure 3. Area classifications: Total area (shown grey), Aperture area and Designated illumination area (the latter two areas are the areas not covered by the mask; masking is not required if the test centre is satisfied, there is no response from the areas shown masked).

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