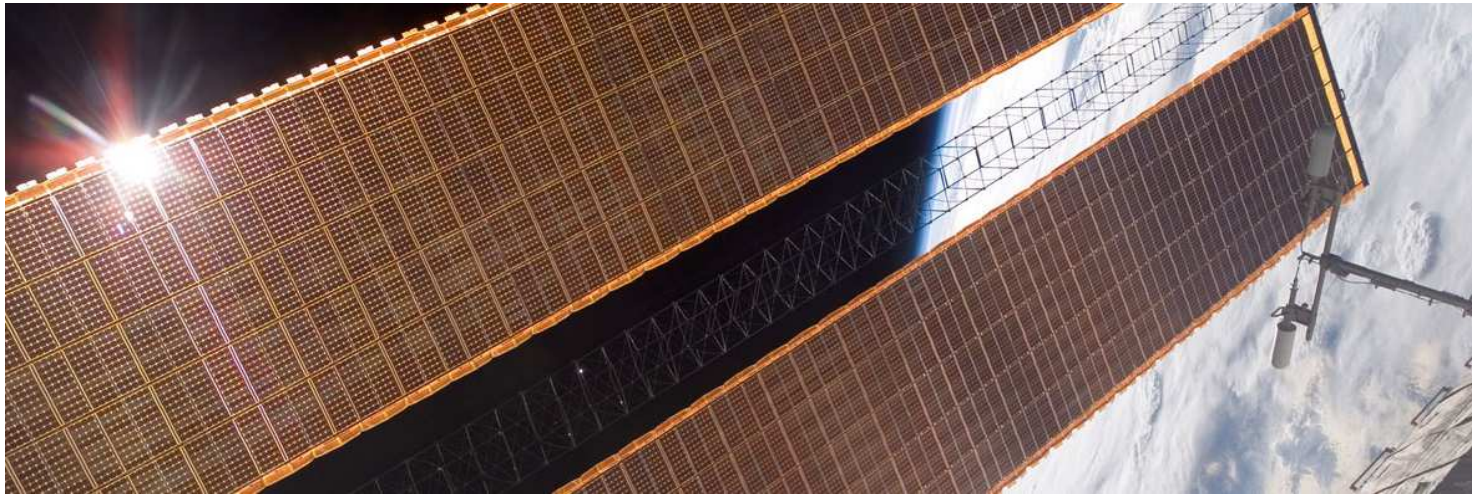
CESI
Shaping a Better Energy Future

Final Presentation
Qualification of the CTJ30-80 Solar Cell Assembly
Contract: **4000114125/15/NL/CBI CCN2**



Noordwijk 22/7/2022

Agenda

1. **About CESI**
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3. CCN2 activities
4. Qualification results at SCA level
5. Results of subgroup M
6. Conclusion and achievements
7. Acknowledgements & AOB

CESI is a Global Player Providing Technology Innovation Services for the Energy Transition

~2,000
Professionals

2,000+
Clients

70+
Countries Served

12
Global Sites

100%
Italian shareholders

CESI: High-end, Tailor Made Solutions for Global Clients

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Our Expertise in The Energy Industry at Your Disposal Through Ad-hoc Consultancies

ISMES

Renewable Engineering, Remediation, Compliance and Monitoring Services to Drive Circular Economy

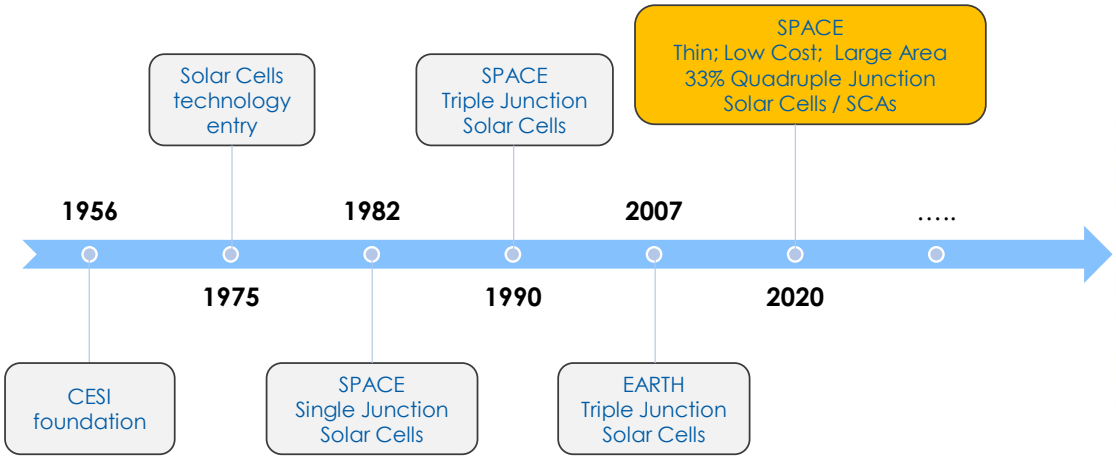
Space Solar Cells

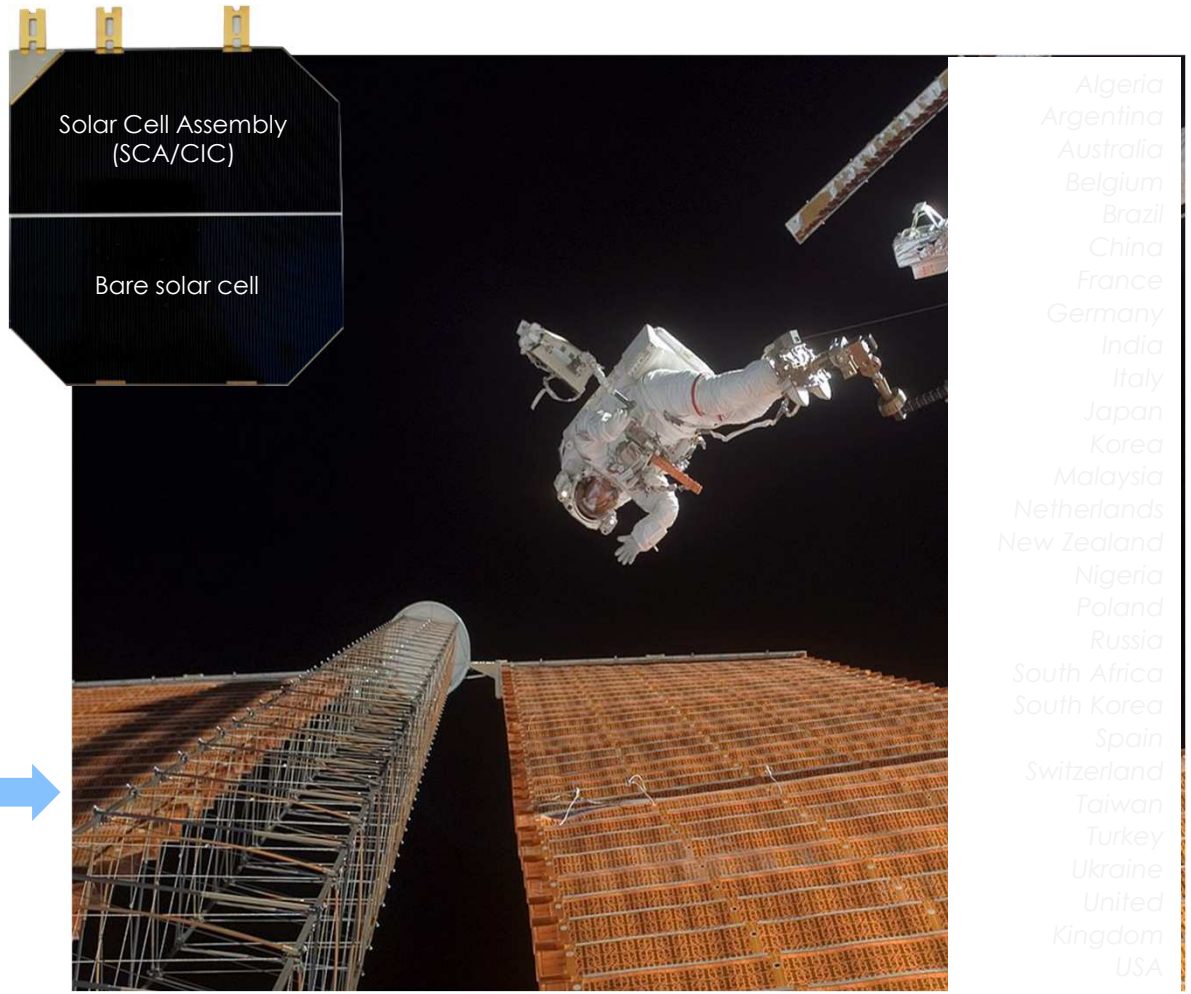
CESI

Production of Advanced Multi-junction Solar Cells for Space Applications

CESI has over 30-year legacy in high-performance GaAs multi junction space solar cells which achieved a remarkable flight heritage with global Clients from different continents

- **Fully proprietary & patented know-how** for the development and manufacturing of GaAs solar cells at bare & SCA level
- CESI Space team **published** more than 70 papers on Conference and **International Scientific Journals**
- **25+ clients** among the largest **Module Manufacturers & International Space Agencies**
- **Flight heritage of** more than **90 satellites** in Low, Medium, Geostationary, Earth Orbits





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CESI product portfolio can fulfill the requirements of any mission/client: from the high performance Institutional programs of space agencies (from low orbit to deep space)…

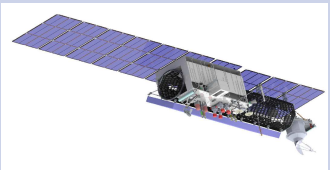
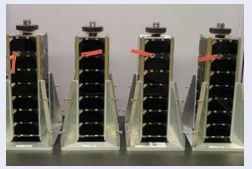
Name	Description	Application	Efficiency** (BOL* AM0, 25C)
CTJ30 (standard)	High Efficiency Solar cell for Space	high power demand Satellites LEO & GEO	30%
CTJ30-Thin	High Efficiency, Thin & Flexible Solar cell for Space	New Generation Solar Arrays (e.g. ROSA: Roll Out Solar Arrays) for GEO &LEO	29%
CTJ-LC (Low Cost)	Low Cost Solar cells for Space	New emerging "low budget" market Minisat/Cubesat/Large constellations LEO	28%
CTJ-LA (Large Area)	Large Area version for Space (c.a 70cm2 vs std 30cm2)	LA concept supports the simplification and efficiency of the assembly at panel level (less components, less welding, area saving)	29% → CTJ30-LA 28% → CTJ-LC-LA

"Low Cost", **"Thin"** and **"Large Area"** features can be **combined** as requested by clients to satisfy any specific mission requirements

NOTES:

(*) BOL: Beginning of Life; EOL: End of Life (**) *% of efficiency not directly comparable with terrestrial applications*

2. Many satellites are using CESI Solar Cells @June 2022

Cell type	Qualification status	First mission in orbit	Nr satellites in the last 5 years	Satellite class	Among others..	
CTJ30	Fully qualified according to ECSS E ST20-08C for LEO and GEO orbit at bare and SCA level (2013)	2014	28	Nano Medium Large	ABCS, Stecco Kanopus Meteor M	  Kanopus (top) and Meteor-M (bottom): courtesy of Kvant
CTJLC	Fully qualified according to ECSS E ST20-08C rev.1 for LEO and GEO orbit at bare and SCA level (2020)	2017	37	Nano/Small	αlpha, LabSat, SteamSat-2, Stork-1, Stork-2, Stork-3, Stork-4, Stork-5, SW1FT, Bio Nanosatellit A, Aurorasat-1 Commtrail, FSSCAT, Hibari, IHI SAT, NetSat Iperdrone, ELO Copia NeTSat	 Netsat constellation launched and deployed Sept. 2020- Courtesy of ZfT  Iperdrone: Courtesy of Tyvak International

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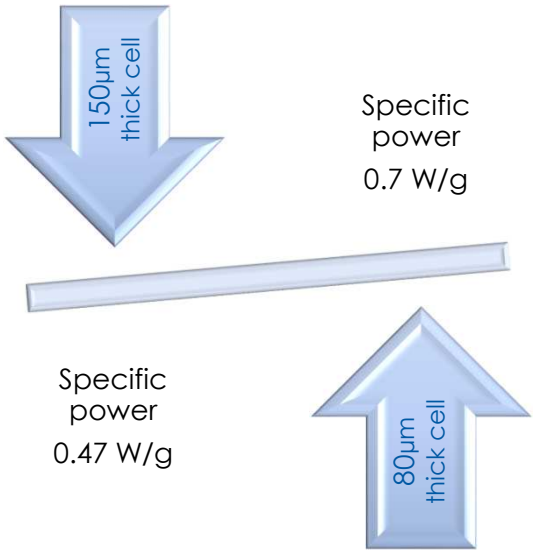
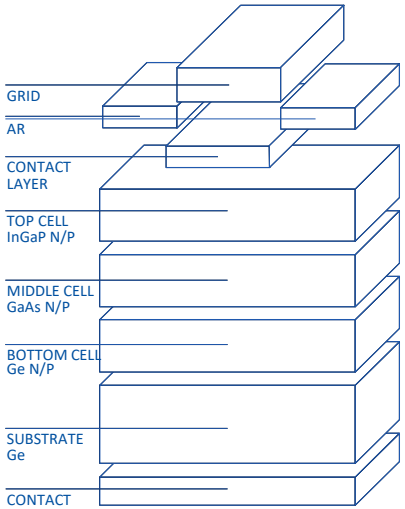
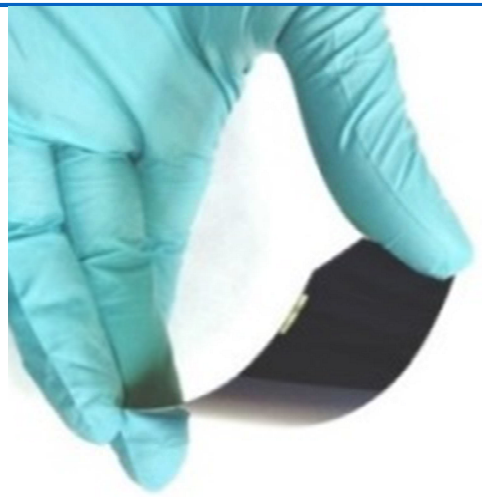
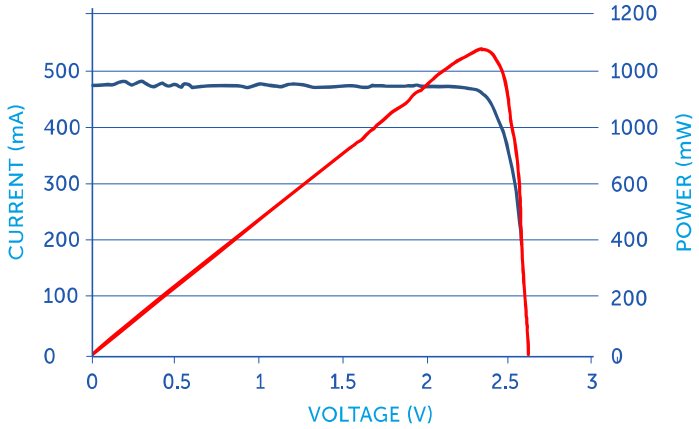
The CTJ30-Thin bare solar cells (ESA contract 4000114125/15/NL/CBi)







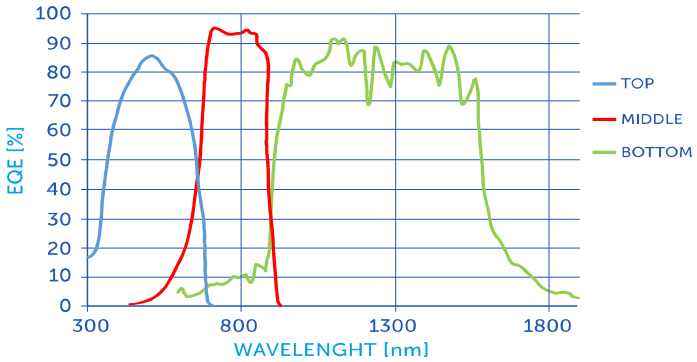
➢ High Efficiency (BOL) AM0, 25°C:	29.0%
➢ Standard Thickness	80 µm
➢ Standard Mass	50 mg/cm^2
➢ Bending radius	4-5 cm



Qualification completed in 2018

The CTJ30-Thin bare solar cells

External Quantum Efficency
(BOL AVERAGE EXTERNAL QUANTUM EFFICIENCY)



Radiation Degradation (Remaining Factors)

Proton Energy	Fluence (p/cm^2)	I_{SC}	V_{OC}	P_M
100 keV	1E10	0.99	0.98	0.96
100 keV	1E11	0.86	0.94	0.72
1MeV	1E10	1.00	0.98	0.98
1MeV	1E11	1.00	0.93	0.89
10MeV	1E11	1.00	0.99	0.98
10MeV	1E12	1.00	0.94	0.91

Electron Energy	Fluence (e/cm^2)	I_{SC}	V_{OC}	P_M
1MeV	1E14	0.99	0.98	0.97
1MeV	5E14	0.96	0.95	0.91
1MeV	1E15	0.91	0.93	0.84

Temperature Coefficients

Electron Energy	Fluence (e/cm^2)	$\Delta J_{SC}/\Delta T$ ($\mu A/cm^2/^\circ C$)	$\Delta V_{OC}/\Delta T$ ($mV/^\circ C$)	$\Delta J_{pmax}/\Delta T$ ($\mu A/cm2/^\circ C$)	$\Delta V_{pm}/\Delta T$ ($mV/^\circ C$)	$\Delta P_m/\Delta T$ ($\mu W/cm^2/^\circ C$)
0	BOL	15.3	-5.324	12.9	-6.026	-77.8
1MeV	1E14	16.7	-5.589	14.3	-5.964	-73.0
1MeV	5E14	17.2	-5.670	14.0	-6.050	-72.3
1MeV	1E15	16.4	-5.677	17.1	-6.092	-61.5

Qualification

- Metal Contact thickness 5-10µm
- Degradation after reverse bias < 1%
- Contact Pull Strength > 600gr (5.9 N)
- Humidity and Temperature < 1%

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Qualification of CESI thin solar cells at SCA level (CTJ30-80-SCA)

CCN2: Qualification of 80 µm CTJ30 solar cell assembly (CTJ30-80 SCA)

SCA manufacturing development

WP110

Manufacturing of CTJ30-80 SCAs and Test Plan

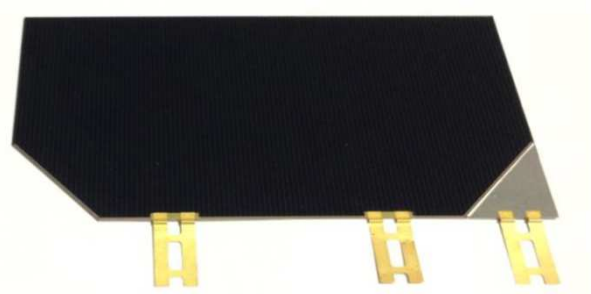
WP111

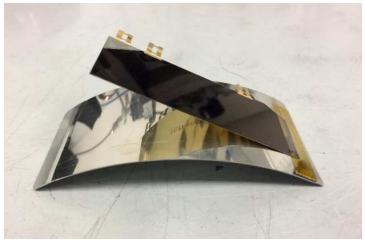
GEO and LEO Qualification of CTJ30-80 SCAs

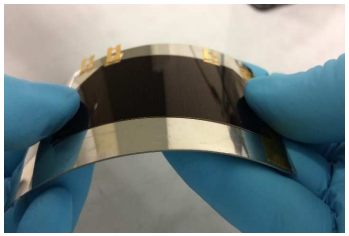
WP120

Specific tests for flexible array (Subgroup M)

WP130



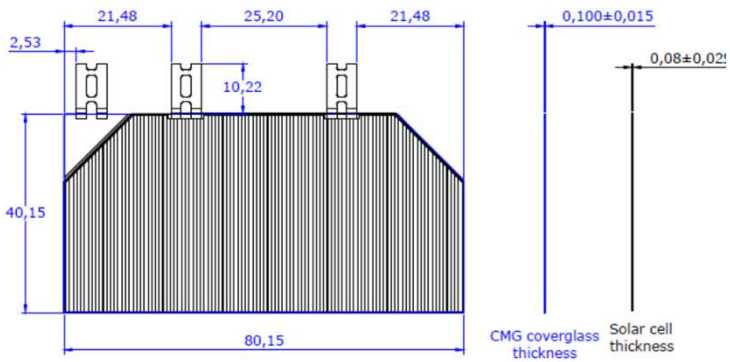




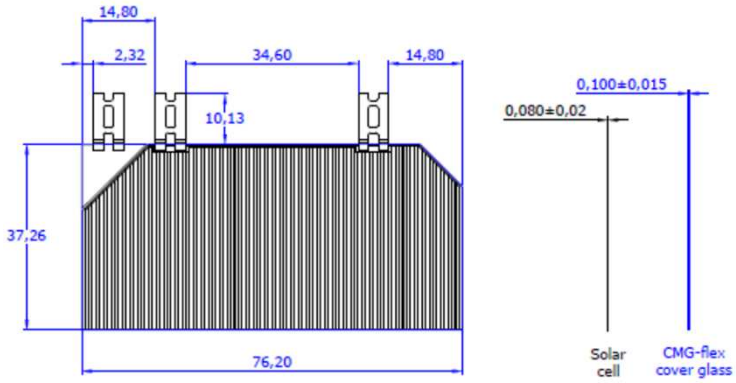
Materials for SCA manufacturing

- ✓ **Bare solar cells: CESI CTJ30-80, size 40.15 mm x 80.15mm and 76.2mm x 37.26mm**
- ✓ **Diodes: Azur Space part number: P/N 81751 (thin 100 µm)**
- ✓ **Coverglasses: Qioptiq CMG100:**
  - **for qualification: P/N 69076**
  - **for subgroup M : P/N 68088 (toughened/ flexible) (*)**
- ✓ **Interconnects: Ag/Au coated Invar P/N: N6x12 (Cell&diode front); Frog-B (Diode/Cell rear) for SCA size 40.15 mm x 80.15mm; S-Type for SCA size 76.2mm x 37.26mm**
- ✓ **Bonding resin: DC 93-500**

Standard SCA for Qualification



Flexible SCA for subgroup M



(*)Qioptiq Space Technology technical paper: D.A.Gray "FLEXIBLE COVER GLASS FOR NEXT-GENERATION SOLAR ARRAYS "10th European Space Power Conference, Conference Proceedings (2014)

Qualification Lot

- A batch of CTJ30_80 Triple Junction bare solar cells type InGaP/InGaAs/Ge was manufactured for the qualification at SCA level.

- 60 Solar Cell Assemblies, nominal dimension 80.15mm x 40.15mm x 0.25 mm active area 30.15 cm^2, were selected for the qualification test campaign.

Isc [A]	Voc [V]	Pmax [W]	Ipmax [A]	Vpmax [V]	$P_{L@2.26V}$ [W]	$I_{L@2.26V}$ [A]	F.F.	Eff. [%]	Ird+ [µA]	Vdd [V]
0.525	2.594	1.152	0.503	2.289	1.15	0.508	0.85	28.0	<0.5	0.74

Acceptance Test	Results	Sample size
Visual inspection, including ELM	Passed	100%
Dimensions	Passed	100%
Mass	Mass 0.095 g/cm2	3%
Rear SCA interconnect adherence	>800g per leg (0°)	1%
Electrical performances (cell + diode)	See table above	100%
Solar Cell Reverse Bias test	No degradation	100%
Humidity and temperature (90°C, 95%RH, 1 day)	No degradation	2% lot

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Qualification Test campaign at SCA level

Group	Description	Qualifying tests
A	**Front interconnect adherence**	Thermal cycling GEO+LEO: 1650 cycles, -170°C/ +130°C for GEO conditions, followed by 6000 cycles, -140°C / +140°C for LEO conditions.
E	**Rear Interconnect adherence**	
B	**BOL performance data and UV test**	UV exposure test: 1000 equivalent sun-hours in vacuum at 90°C
C	**EOL performance data**	Electron irradiation at 1MeV, 1 10^{15} e^- /cm^2 dose
F	**Ageing test**	3,000 hours standard LEO missions, 150°C under AM0 illumination in vacuum and samples biased at Vop=2.26V

		A (20+2)	E (20+2)	B (20+3)	C (10+2)	F (20)
Front Interconnect Welding	FIW	3	4			
Coverglass Bonding	CB		5			
Rear Interconnect Welding	RIW	3a	6			
Visual inspection	VI	1,4,7, 10	1,7,11,15	1,14,17	1,11	1,5
Dimension and weight	DW			2	2	2
Electrical performance	EP	2,5,8	2,8,12	4,7,11,15	3,6,12,16	3,6
Temperature coefficients & Diode Temperature Behaviour	TC TB			9	8,14	
Spectral response	SR				7,17	
Thermo-optical data	TO			12,16	18	
Thermal cycling	CY	6	10			
Interconnector adherence	IA	9	14			
Electron irradiation	EI				9	
Photon irradiation and temperature annealing	PH			6	10	
Diode characterization	DC		3,9,13	5,8,18	4,13	
Cell reverse bias test	RB			10	5,15	
Ultraviolet exposure	UV			13[4]		
Flatness	FT			3		
Life Test	LT					4

Qualification Test campaign at diode level

Group	Description	Qualifying tests
BI	**Burn in test and ESD**	Welded diode infant mortality test: 216 h with the diodes at 140°C at -5V reverse bias for 92% of the time and to 510mA forward bias for 8% of the time
OD	**Diode front/rear interconnector adherence**	Thermal cycling GEO+LEO as per SCA
OB	**Extended storage simulation**	Humidity and Thermal cycling GEO+LEO as per SCA
C	**EOL performance data**	Electron irradiation at 1 MeV, 10^{15} e^-/cm^2 dose (performed together with the SCAs)
V	**Welded diode ageing test and switching behavior**	Ageing test: 1000 hours GEO and 3000 hours LEO at 140°C. Switch behavior: -ground testing mode: 100 cycles at 90°C between -5V reverse bias and 510mA forward bias -primary discharge: 100 cycles at 90°C between -5.3 reverse bias and +4.5A forward bias

Test	Symbol	Bare external protection diodes (92+27) spares samples)				
		OD (32+8 spares)	OB (10+2 spares)	BI (20+10 spares)	C (10+2 spares)	V (20+4 spares)
Welding of Interconnectors	WI			5	1	1
Visual inspection	VI	1, 5,8,11	1,5,8,11	1,6,9,12,15	2,5,9,12	2,6,14
Dimensions & Weight	DW	2	2	2	3	3
Diode Characterisation	DC	3, 6,9	3,6,9	7,10,13	4,6,10,13	4,7,9,11 ,13
Thermal Cycling	CY	4	7			
Welded diode infant mortality (Burn in)	BI	7		8		5
Humidity & Temperature	HT		4			
Contact uniformity	CU			3		
Surface Finish	SF			4		
Contact adherence	CA		10			
Pull	PT	10		14		
Electron Irradiation	EI				8	
Temperature annealing	TA				11	
Temperature behaviour	TB				7,14	
Human body ESD test (ESD)	DE			11		
Welded diode behaviour in switching mode (Switching)	DS					8,12
Welded diode long term stability (Life)	DL					10

Overview of subgroups A and E

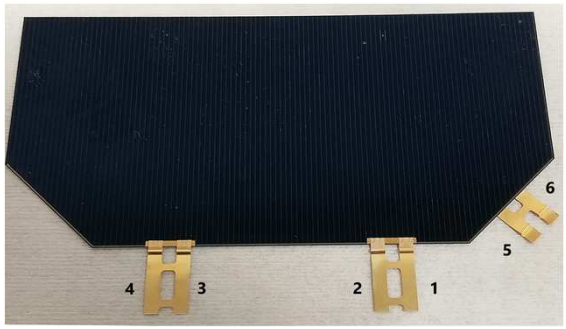
SUBGROUP A (GEO and LEO CY) (20+2 samples)			
TEST		Requirement	Results
Visual Inspection bare	1	In SCD	✓
Electrical Performance bare	3	I_{L_min}≥ 488 mA; I_{L_Ave}≥ 509 mA	Average IL= 515 mA
Front interconnect weld	4	Pull on sacrificial samples: >600g each leg	✓
Rear Interconnect weld	5	Pull on sacrificial samples: >600g	✓
VI after FIW+RIW	6	In SCD	No shunt at interconnects welds
EP after FIW+RIW	7	I_{L_min}≥ 488 mA; I_{L_Ave}≥509 mA	Average IL= 512mA (ΔIL=-0.4% wrt BSC)
Thermal cycling GEO	8	ΔI_L<3% wrt BOL	✓
Visual Inspection	9	In SCD	No degradation observed
EP after GEO CY	10	ΔI_L<3% wrt BOL	ΔIL=-0.5% wrt BOL ΔI_L values in the range 1.1% to +0.0%
Interconnect Adherence	11	Ultimate Pull strength >600g at 0° or cell breakage value	Carried out after LEO CY

SUBGROUP E (GEO and LEO CY) (20+3 samples)			
TEST		Requirement	Results
Visual Inspection bare	1	In SCD	✓
EP+DC bare	3	I_{L_min}≥ 488 mA; I_{L_Ave}≥ 509 mA Ird <1µA; Vdd <.8V @620mA	Average IL= 516 mA Average Vdd= 0.714
Front interconnect weld	4	Pull on sacrificial samples: >600g each leg	✓
Coverglass bonding	5	--	✓
Rear Interconnect weld	6	Pull on sacrificial samples: >600g	✓
VI after FIW+CB+RIW	7	In SCD	No occurrences
EP+DC SCA	8	I_{L_min}≥ 488 mA; I_{L_Ave}≥504 mA Ird <1µA; Vdd <.8V @620mA	Average Vdd= 0.724 Average IL= 507 mA (ΔIL=-2% wrt BSC)
Thermal cycling GEO	9	None, environmental test only	✓
Visual Inspection	10	In SCD	No degradation observed
EP+DC after GEO CY	11	ΔI_L<3% wrt BOL	Average Vdd= 0.726 ΔI_L=-0. 7% wrt BOL
Interconnect Adherence on P contact	12	Ultimate Pull strength >600g at 0° or cell breakage value	Carried out after LEO CY

Subgroups A and E

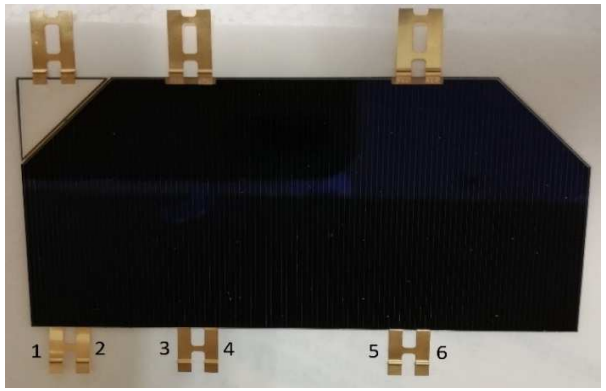
Thermal cycling GEO: 1650 cycles between -175°C (-10;0) / +130°C (0;+10), 30°C/min (except around 0°C), no dwell, N2 atmosphere

Thermal cycling LEO: 6000 cycles between -140°C (-10;0) / +140°C (0;+10), 30°C/min (except around 0°C) , no dwell, N2 atmosphere



	Pull strength Front Legs N6x12 (kg)	Pull strength Rear Legs N6x12 (kg)
Average	1.48	1.5
Maximum	2.58	2.04
Minimum	0.82	0.95

Requirement pull strength >600 g per leg

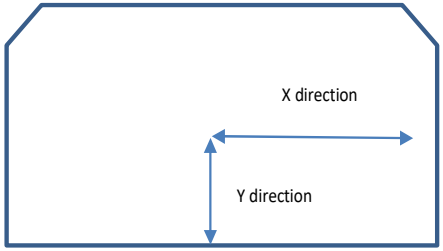


	Pull strength(kg)
Average	1.58
Maximum	2.85
Minimum	0.68(*)

(*) due to a weld break

Overview of subgroup B

SUBGROUP B (20+3 samples)			
TEST		**Requirement**	**Results**
Visual Inspection SCA	1	In SCD	✓
Dimensions, Mass and Flatness	2	Mass <3g;	**Average mass: 2.92g** **Average deflection : 131µm x direction** **61µm y direction**
EP+DC SCA BOL	3	I_{L_min}≥ 488 mA; I_{L_Ave}≥504 mA Ird <1µA; Vdd <.8V @620mA	**Average IL= 509 mA** **Average Vdd= 0.717V**
Photon Irradiation	4	48h illumination, 60°C annealing 24h	✓
EP+DC SCA after PH	5	Degradation <3% on I_L Vdd <0.8V @620mA	✓
Temperature coefficients (TC+TB)	6	For characterization	✓
SCA reverse bias	7	Degradation <3%	✓
Thermo optical properties BOL	8	For characterization	**$\alpha_{s,avg}$ = 0.906 ± 0.018** **$\varepsilon_{N\text{-}Avg}$=0.858± 0.03**
UV Test	9	ΔIsc ≤ 3% variation <3% in TO wrt BOL	**Average ΔIsc =-0.3%** **(measure accuracy 1%)**
TO after UV	12	TO within measurement accuracy wrt BOL	**$\alpha_{s,avg}$ = 0.905 ± 0.018** **$\varepsilon_{N\text{-}Avg}$=0.857 ± 0.03**



Subgroup B Temperature Coefficients

Average Temperature coefficients for all SCA solar cells in sub B in the range 15°/80 °C

	ΔIsc/ΔT	ΔVoc/ΔT	$\Delta P_{max}/\Delta T$	$\Delta I_{max}/\Delta T$	$\Delta V_{max}/\Delta$
	mA/cm²/°C	mV/°C	mW/cm²/°C	mA/cm²/°C	mV/°C
average	0.0155±0.0021	-6.1 ±0.1	-0.0855±0.0074	0.0110±0.0029	-6.4 ±0.2

Average temperature coefficients for two cells of subgroup B calculated -150°/+150 °C

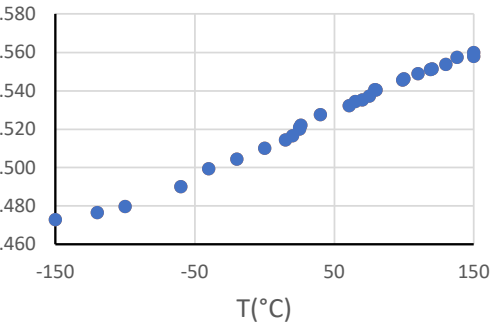
	ΔIsc/ΔT	ΔVoc/ΔT	$\Delta P_{max}/\Delta T$	$\Delta I_{max}/\Delta T$	$\Delta V_{max}/\Delta$
	mA/cm²/°C	mV/°C	mW/cm²/°C	mA/cm²/°C	mV/°C
average	0.0095±0.005	-5.7 ±0.02	-0.0793±0.049	0.0069±0.004	-5.8 ±0.03

Diode Temperature coefficients (Vdd)

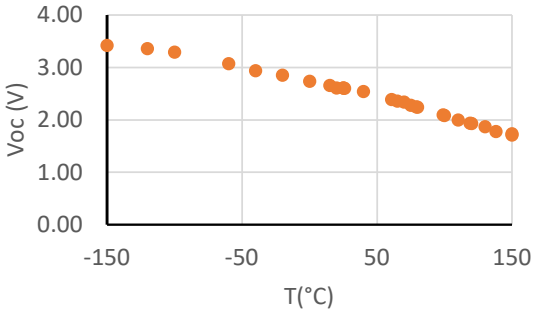
$Tc_{(Vdd)}$=-1.46±0.06 mV/°C +15°/+80°C

$Tc_{(Vdd)}$ =-1.63±0.01 mV/°C -150°/ +150°C

Isc



Voc



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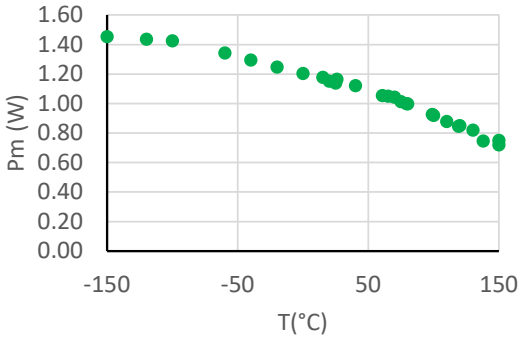

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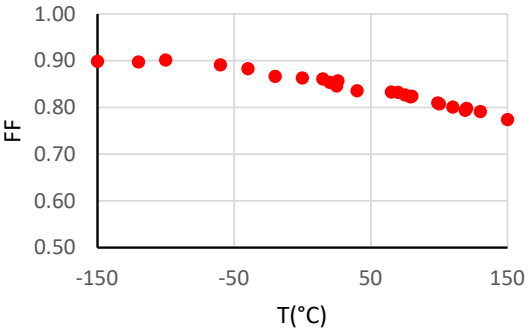
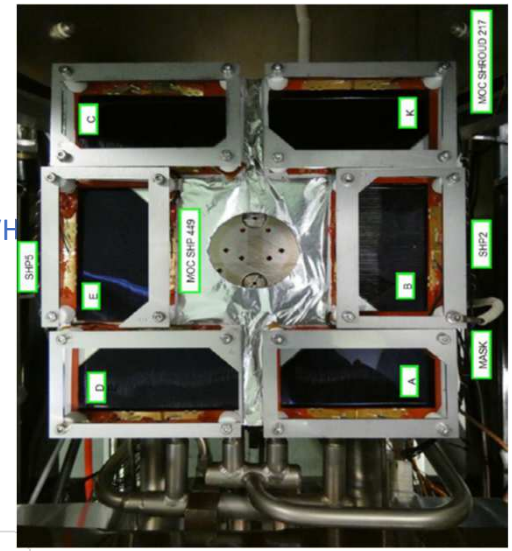
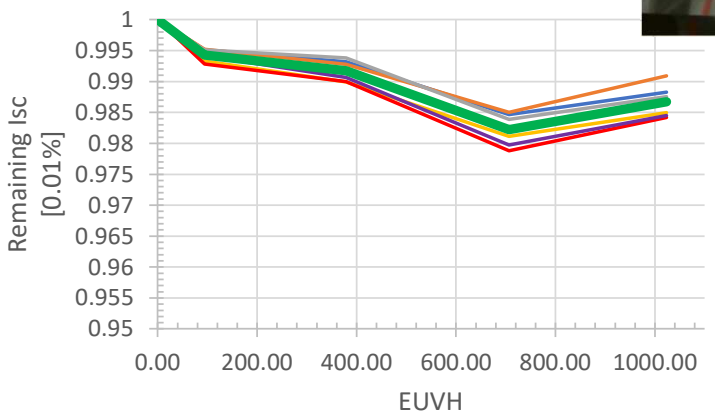


Subgroup B UV Test

TEST CONDITIONS

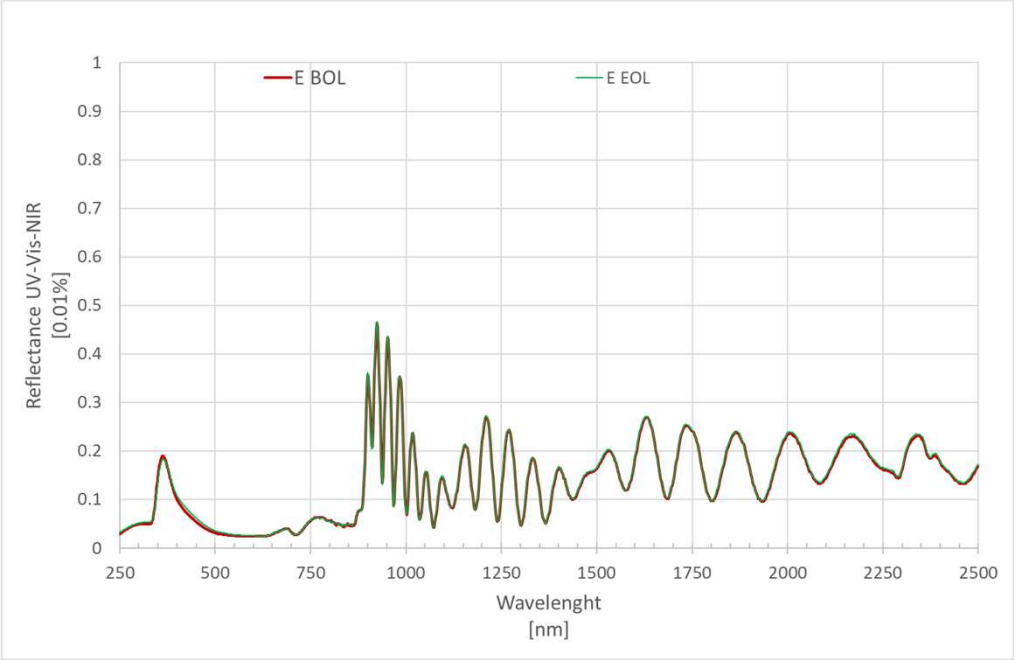
- ✓ UV Illumination: <10 SC in the UV range [200-400nm] (average actual: 6.37x)
- ✓ UV Exposure Duration: nominal 1000 EUVH in four stints (actual 1095.8 EUVH)
- ✓ Samples Temperature: 90ºC ± 10ºC
- ✓ Pressure: not higher than 10^{-5} mbar





TEST RESULTS

- Isc is stable under UV (no darkening)
- Average ΔIsc =-0.3% (measure accuracy 1%) in EP outside the chamber



Overview of subgroup C

Sub group C (12 samples)			
Test		**Requirements**	**Results**
Visual inspection (VI)	1	VI criteria in SCD	✓
Dimensions and weight (DW)	2	samples shall fit a calibrated jig and their mass shall be ≤ 3g	**Largest mass: 2.98g**
Electrical performance (EP)	3	I_{LMIN} = 488 mA (16.2 mA/cm^2) (for single SCA) I_{LMIN_AVG} = 504 mA (16.7 mA/cm^2) (for each qualification lot	**Average IL= 508 mA**
Diode Characterisation (DC)	4	V_{dd} (max): <800mV @620mA I_{rd} max: <1µA@ -5V	**Average Vdd= 0.727V**
Solar Cell reverse bias test (RB)	5	$\Delta I_L \leq 3\%$ for all samples in EP Test Sequence 6	**Average Il=508 mA** **Δ Il=-0.11%**
Electrical performance (EP)	6	$\Delta I_L \leq 3\%$ for all samples with respect to Test Item 3	
Spectral response BOL	7	Characterization step	✓
Temperature coefficients and diode temperature behavior	8	Characterisation step (BOL and EOL on same samples)	✓
Electron irradiation (EI)	9	Process step	✓

Subgroup C Overview

Sub group C (12 samples)			
Test		**Requirements**	**Results**
Photon soak and temperature Annealing (PH)	10	Characterization step	✓
Visual inspection (VI)	11	VI criteria in SCD	✓
Electrical performance (EP)	12	Same Remaining power factor within 3% after annealing with respect to bare cell values	✓
Diode Characterisation (DC)	13	Diode performances shall be in line within 3% with respect to the value declared by supplier	✓
Temperature coefficients and diode temperature behavior	14	Characterization step	✓
Solar Cell reverse bias test (RB)	15	No degradation for all samples in EP Test Item 16	✓
Electrical performance (EP)	16	$\Delta I_L \leq 3\%$ for all samples with respect to Test item 12	
Spectral response EOL	17	None, characterization step	
Thermo optical properties EOL	18	Characterization step	**$a_{s',avg} = 0.904 \pm 0.018$** **$\varepsilon_{N\text{-}Avg} = 0.84 \pm 0.03$**

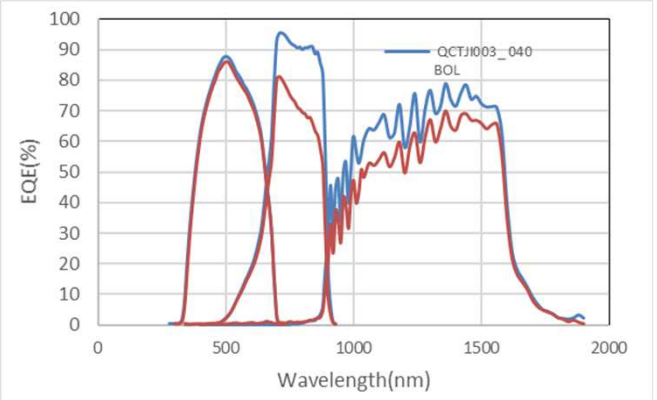
BOL (Sub B)
$a_{s',avg} = 0.906 \pm 0.018$
$\varepsilon_{N\text{-}Avg} = 0.858 \pm 0.03$

Subgroup C: irradiation electron 1MeV energy, 1. 10^{15} e-/cm^2 dose

The RPF are in line with BSC findings

	Energy	dose	RF (Isc)	RF (Voc)	RF (Pm)	RF (Im)	RF (Vm)
CTJ30_80_SCA	1 MeV	1.00E+15	**0.90**±0.009	**0.94**±0.002	**0.84**±0.007	**0.89**±0.006	**0.94**±0.005
CTJ30_80_Bare cells irradiated together with the SCAs	1 MeV	1.00E+15	**0.90**±0.0.9	**0.94**±0.005	**0.84**±0.009	**0.90**±0.01	**0.94**±0.011
CTJ30_80_ bare cells From quaification report	1 MeV	1.00E+15	**0.93**±0.02	**0.93**±0.003	**0.84±0.01**	**0.89**±0.02	**0.94**±0.01

Comparison spectral response BOL and EOL



Average temperature coefficients for all EOL CTJ30_80_SCA in the range 15°-80 °C

Energy	dose	ΔIsc/ΔT	ΔVoc/ΔT	$\Delta P_{max}/\Delta T$
MeV	**e-/cm^2**	**mA/cm^2/°C**	**mV/°C**	**mW/cm2/°C**
-	**BOL**	0.0143±0.003	-6.1 ±0.003	-0.0873±0.006
1	**1.00E+15**	0.0133 ±0.003	-6.5 ±0.003	-0.0799±0.006

EOL Temperature coefficients calculated in the range -150°C /+ 150°C for 2 cells.

Energy	dose	ΔIsc/ΔT	ΔVoc/ΔT	$\Delta P_{max}/\Delta T$
MeV	**e-/cm^2**	**mA/cm^2/°C**	**mV/°C**	**mW/cm2/°C**
-	**BOL**	0.0104±0.006	-5.6 ±0.03	-0.0711±0.01
1	**1.0E+15**	0.0135±0.004	-5.8±0.003	-0.055±0.001

Diode Temperature coefficients EOL (Vdd)

$Tc_{(Vdd)}$=-1.83±0.6 mV/°C +15°/ +80°C

$Tc_{(Vdd)}$ =-1.74±0.01 mV/°C -150° /+150°C

Overview of subgroup F

Subgroup F			
Test		**Requirements**	**Results**
Visual inspection (VI)	1	VI criteria in SCD	
Dimensions and weight (DW)	2	samples shall fit a calibrated jig and their weight shall be < 3 g	**Average mass 2.85g**
Electrical performance (EP)	3	I_{LMIN} = 488 mA (16.2 mA/cm^2) (for single SCA) I_{LMIN_AVG} = 504mA (16.7 mA/cm^2) (for each qualification lot	**Average IL= 508 mA** **Average Vdd= 0.733V**
LIFE TEST	4	$\Delta I_L \leq 3\%$ for all samples in EP Test item 6	
Visual inspection (VI)	5	VI criteria in SCD	
Electrical performance (EP)	6	$\Delta I_L \leq 3\%$ for all samples	

Subgroup F: UV test was carried out at ESTEC

Long Term Test sequence and condition:

- ✓ Sample characterization before test, including visual inspection (VI), electrical performance (EP), electroluminescence (EM) and dark IV (DIV)
- ✓ Facility bake-out and cleanliness verification
- ✓ Long Term Test 1000 hrs (GEO requirement) at 150°C -0°C/+5°C, 80% in forward mode (VL=2.26V) and 20% in reverse mode (VR=-0.35V) under AM0, 1 solar constant illumination.
- ✓ Intermediate characterization (VI, EP, EM and IV)
- ✓ Long Term Test additional 2000 hrs (to reach LEO requirement) at 150°C -0°C/+5°C, 80% in forward mode and 20% in reverse mode
- ✓ Final sample characterization after the test (VI, EP, EM and DIV)

Test passed: all samples meet the requirement

$\Delta IL_{average}$= -1.73%

Qualification Test campaign at diode level

Group	Description	Qualifying tests
BI	**Burn in test and ESD**	Welded diode infant mortality test: 216 h with the diodes at 140°C at -5V reverse bias for 92% of the time and to 510mA forward bias for 8% of the time
OD	**Diode front/rear interconnector adherence**	Thermal cycling GEO+LEO as per SCA
OB	**Extended storage simulation (Bare diode level)**	Humidity and Thermal cycling GEO+LEO as per SCA
C	**EOL performance data**	Electron irradiation at 1 MeV, 10^{15} e^-/cm^2 dose (performed together with the SCAs)
V	**Welded diode ageing test and switching behavior**	Ageing test: 1000 hours GEO and 3000 hours LEO at 140°C. Switch behavior: -ground testing mode: 100 cycles at 90°C between -5V reverse bias and 510mA forward bias -primary discharge: 100 cycles at 90°C between -5.3 reverse bias and +4.5A forward bias

Qualification Test campaign at Diode level: Subgroup BI

Test	Symbol	Bare external protection diodes (92+27 spares samples)				
		OD (32+8 spares)	OB (10+2 spares)	**BI (20+10 spares)**	C (10+2 spares)	V (20+4 spares)
Welding of Interconnectors	WI			**5**	1	1
Visual inspection	VI	1, 5,8,11	1,5,8,11	**1,6,9,12,15**	2,5,9,12	2,6,14
Dimensions & Weight	DW	2	2	**2**	3	3
Diode Characterisation	DC	3, 6,9	3,6,9	**7,10,13**	4,6,10,13	4,7,9,11,13
Thermal Cycling	CY	4	7			
Welded diode infant mortality (Burn in)	BI	7		**8**		5
Humidity & Temperature	HT		4			
Contact uniformity	CU			**3**		
Surface Finish	SF			**4**		
Contact adherence	CA		10			
Pull test	PT	10		**14**		
Electron Irradiation	EI				8	
Temperature annealing	TA				11	
Temperature behaviour	TB				7,14	
Human body ESD test (ESD)	DE			**11**		
Welded diode behaviour in switching mode (Switching)	DS					8,12
Welded diode long term stability (Life)	DL					10

Diode assembly qualification campaign - Subgroup BI

Average Welded diode characteristics

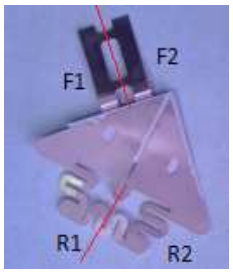
	Ird @-5V	Vdd @620 mA
	(µA)	(V)
Average	<0.5	0.720

The burn-in sequence was organized in three phases

Test sequence	Time (h)	Temperature (°C)	Bias conditions
Phase 1	192	140(-0/+10°C)	$V_{reverse\_diode}$= -5±0.02 V
Phase 2	16	140(-0/+10°C)	$I_{forward\_diode}$=620±3 mA
Phase 3	8	140(-0/+10°C)	$V_{reverse\_diode}$=--5±0.02 V

The average welded diode characteristics after BI are in line with BOL data

	Ird @-5V	Vdd @620 mA
	(µA)	(V)
Average	<0.5	0.718



Pull test

	F1	F2	R1	R2
	Pull strength (kg)	Pull strength (kg)	Pull strength (kg)	Pull strength (kg)
Average	1.75	1.89	1.71	1.58
Min	1.22	1.59	0.95	0.72
Max	2.72	2.08	2.17	2.29

**Requirement: minimum pull strength per leg: 0.6kg or value at cell/IC breakage*

ESD test

	Solar cell		Diode	
TEST Phase	Averge Il (A)	ΔIl(%)(*)	Average Ird @-5V (nA)	Average Vdd@620 mA (V)
Electrical Performance BOL	0.517		<500	**0.719**
ESD 12 kV pulse cathode	--	--	--	**--**
Electrical Performance	0.517	-0.05%	<500	**0.721**
ESD 12 kV pulse anode	--	--	--	**--**
Electrical Performance	0.517	0.0%	<500	**0.721**
ESD 12 kV multi pulse cathode	--	--	--	**--**
Electrical Performances	0.517	-0.01%	<500	**0.720**
ESD 12 kVmulti- pulse anode	--	--	--	**--**
Electrical Performance	0.516	-0.06%	<500	**0.721**

HB-ESD does not evidence failures/ degradation of the diode and of the associated solar cell assembly

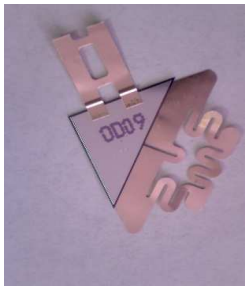
Qualification Test campaign at Diode level: Subgroup OD

Test	Symbol	Bare external protection diodes (92+27 spares samples)				
		OD (32+8 spares)	OB (10+2 spares)	BI (20+10 spares)	C (10+2 spares)	V (20+4 spares)
Welding of Interconnectors	WI			5	1	1
Visual inspection	VI	**1, 5,8,11**	1,5,8,11	1,6,9,12,15	2,5,9,12	2,6,14
Dimensions & Weight	DW	**2**	2	2	3	3
Diode Characterisation	DC	**3, 6,9**	3,6,9	7,10,13	4,6,10,13	4,7,9,11,13
Thermal Cycling	CY	**4**	7			
Welded diode infant mortality (Burn in)	BI	**7**		8		5
Humidity & Temperature	HT		4			
Contact uniformity	CU			3		
Surface Finish	SF			4		
Contact adherence	CA		10			
Pull test	PT	**10**		14		
Electron Irradiation	EI				8	
Temperature annealing	TA				11	
Temperature behaviour	TB				7,14	
Human body ESD test (ESD)	DE			11		
Welded diode behaviour in switching mode (Switching)	DS					8,12
Welded diode long term stability (Life)	DL					10

Diode assembly qualification campaign - Subgroup OD (Thermal cycling+ Pull test)

Configuration 1: front IC only (P-contact): 20 samples

Configuration 2: front IC +rear IC: 20 samples



Thermal cycling test conditions

CY	Number of cycles	Temp. Range [°C]	Cycle Duration (*) [min]	Environment
GEO	1650	-175 (-10;0) / +130 (0;+10)	30 °C/min. max temperature grade, no dwell	Inert atmosphere (Nitrogen)
LEO	6000	-140 (-10;0) / +140 (0;+10)	30 °C/min. max temperature grade, no dwell	Inert atmosphere (Nitrogen)

Diodes after IC welding	Ird @-5V (µA)	Vdd @620 mA (V)
Diode (only Front interconnect)	<0.5	**0.719**
Diodes (both Front and Rear interconnects)	<0.5	**0.716**

After GEO CY	Ird @-5V (µA)	Vdd @620 mA (V)
Diode (only Front interconnect)	<0.5	**0.742**
Diodes (both Front and Rear interconnects)	<0.5	**0.734**

After LEO CY	Ird @-5V (µA)	Vdd @620 mA (V)
Diodes (only Front interconnect)	<0.5	**0.742**
Diodes (both Front and Rear interconnects)	<0.5	**0.728**

After burn in	Ird @-5V (µA)	Vdd @620 mA (V)
Diodes (only Front interconnect)	<0.5	**0.733**
Diodes (both Front and Rear interconnects)	<0.5	**0.727**

Pull test

OD diode type		Interconnect N6x12 Pull strength(kg)	Interconnect FROG B Pull strength(kg)
Diodes (only Front interconnect)	**Average**	2.44	-
	Maximum	3.31	-
	Minimum	1.22	-
Diodes (both Front and Rear interconnects)	**Average**	2.58	1.7
	Maximum	3.17	2.54
	Minimum	1.68	0.91

Requirement: minimum pull strength per leg: 0.6kg or value at cell/IC breakage

Qualification Test campaign at Diode level: Subgroup OB

Test	Symbol	Bare external protection diodes (92+27 spares samples)				
		OD (32+8 spares)	OB (10+2 spares)	BI (20+10 spares)	C (10+2 spares)	V (20+4 spares)
Welding of Interconnectors	WI			5	1	1
Visual inspection	VI	1, 5,8,11	1,5,8,11	1,6,9,12,15	2,5,9,12	2,6,14
Dimensions & Weight	DW	2	2	2	3	3
Diode Characterisation	DC	3, 6,9	3,6,9	7,10,13	4,6,10,13	4,7,9,11,13
Thermal Cycling	CY	4	7			
Welded diode infant mortality (Burn in)	BI	7		8		5
Humidity & Temperature	HT		4			
Contact uniformity	CU			3		
Surface Finish	SF			4		
Contact adherence	CA		10			
Pull test	PT	10		14		
Electron Irradiation	EI				8	
Temperature annealing	TA				11	
Temperature behaviour	TB				7,14	
Human body ESD test (ESD)	DE			11		
Welded diode behaviour in switching mode (Switching)	DS					8,12
Welded diode long term stability (Life)	DL					10

Diode assembly qualification campaign - Subgroup OB

Average bare diode characteristics

Bare diode (12 samples)	Ird @-5V	Vdd @620 mA
	(µA)	(V)
Average	<0.5	0.722

Humidity test conditions

30 days at 60 °C under relative humidity ≥ 90%.

After HT1	Ird @-5V	Vdd @620 mA
	(µA)	(V)
Average	<0.5	0.721

Thermal cycling test conditions

CY	Number of cycles	Temp. Range [°C]	Cycle Duration [min]	Environment
GEO	1650	-175 (-10;0) / +130 (0;+10)	30 °C/min. max temperature grade, no dwell	Inert atmosphere (Nitrogen)
LEO	6000	-140 (-10;0) / +140 (0;+10)	30 °C/min. max temperature grade, no dwell	Inert atmosphere (Nitrogen)

After GEO CY	Ird @-5V	Vdd @620 mA
	(µA)	(V)
Average	<0.5	0.739

After LEO CY	Ird @-5V	Vdd @620 mA
	(µA)	(V)
Average	<0.5	0.746

Peel test (Scotch 600 tape)

No residues of diode material was observed on tape, no delaminated metal area was present on the diode.

Qualification Test campaign at Diode level: Subgroup V

Test	Symbol	Bare external protection diodes (92+27 spares samples)				
		OD (32+8 spares)	OB (10+2 spares)	BI (20+10 spares)	C (10+2 spares)	V (20+4 spares)
Welding of Interconnectors	WI			5	1	**1**
Visual inspection	VI	1, 5,8,11	1,5,8,11	1,6,9,12,15	2,5,9,12	**2,6,14**
Dimensions & Weight	DW	2	2	2	3	**3**
Diode Characterisation	DC	3, 6,9	3,6,9	7,10,13	4,6,10,13	**4,7,9,11,13**
Thermal Cycling	CY	4	7			
Welded diode infant mortality (Burn in)	BI	7		8		**5**
Humidity & Temperature	HT		4			
Contact uniformity	CU			3		
Surface Finish	SF			4		
Contact adherence	CA		10			
Pull test	PT	10		14		
Electron Irradiation	EI				8	
Temperature annealing	TA				11	
Temperature behaviour	TB				7,14	
Human body ESD test (ESD)	DE			11		
Welded diode behaviour in switching mode (Switching)	DS					**8,12**
Welded diode long term stability (Life)	DL					**10**

Diode assembly qualification campaign - Subgroup V (Diode switching test on 24 samples)

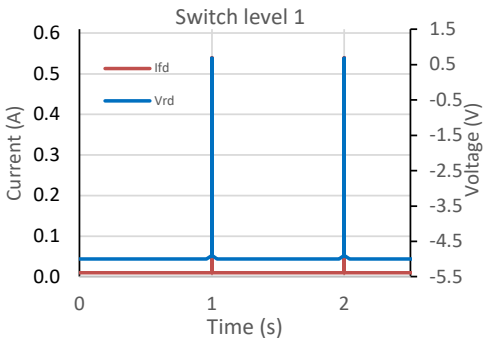
Diodes after welding	Ird @-5V (µA)	Vdd @620 mA (V)
Average	<0.5	0.722

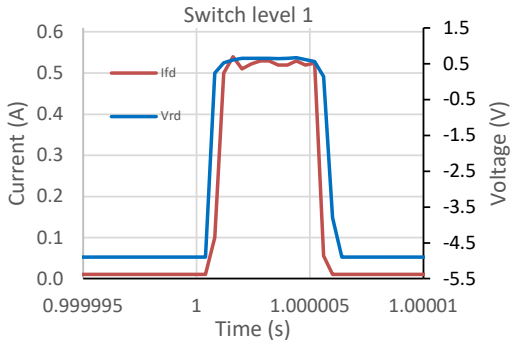
Diodes after burn in	Ird @-5V (µA)	Vdd @620 mA (V)
Average	<0.5	0.728

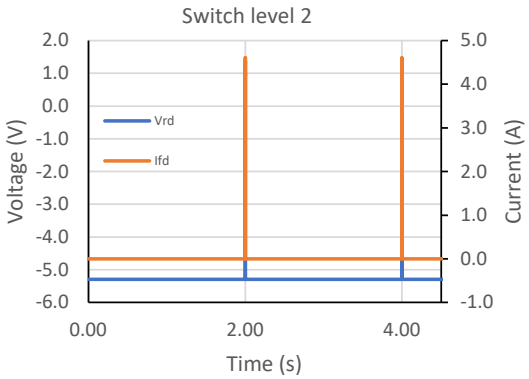
Diodes after switching test (BOL)	Ird @-5V (µA)	Vdd @620 mA (V)
Average	<0.5	0.730

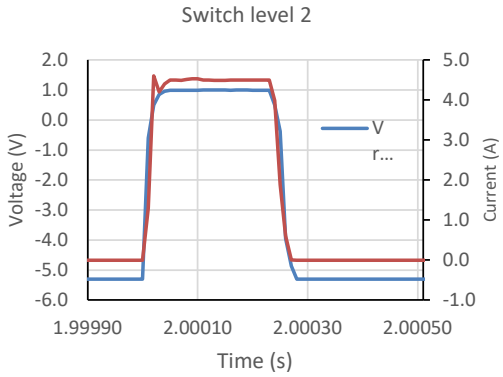
Diode switching sequence

Test sequence	No. of cycles	Temperature (°C)	Cycle conditions
Switch level 1 (ground testing and bus commutations)	100	90	$V_{reverse\_diode}$= -5V; $I_{forward\_diode}$= 510mA; T_1 and T_4= 1µs T_2= 50µs T_3= 1s
Switch level 2 (primary discharges)	100	90	$V_{reverse\_diode}$= -5.3V; $I_{forward\_diode}$= 4.5A; T_1 and T_4= 50µs T_2= 180µs T_3= 2s





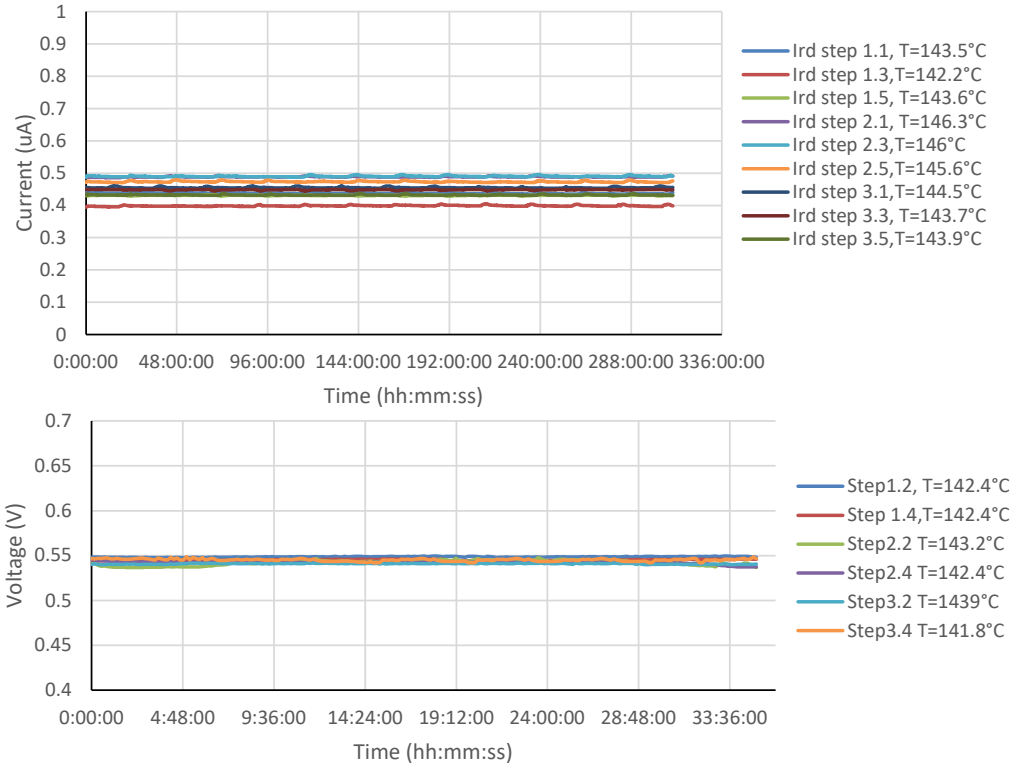




Diode assembly qualification campaign - Subgroup V (Diode long term stability test on 24 samples)

Diode long term stability sequence and conditions

Test sequence	duration	Temperature (°C)	Test conditions*
Step 1 (reverse bias)	310 h	140(-0/+9)	Keep constant $V_{reverse\_diode}$= -3.4V; and monitor $I_{reverse\_diode}$
Step 2 (forward bias)	35 h	140(-0/+9)	Keep constant $I_{forward\_diode}$= 510mA; and monitor $V_{forward\_diode}$
Step 3 (reverse bias)	310 h	140(-0/+9)	Keep constant $V_{reverse\_diode}$= -3.4V; and monitor $I_{reverse\_diode}$
Step 4 (forward bias)	35 h	140(-0/+9)	Keep constant $I_{forward\_diode}$= 510mA; and monitor $V_{forward\_diode}$
Step 5 (reverse bias)	310 h	140(-0/+9)	Keep constant $V_{reverse\_diode}$= -3.4V; and monitor $I_{reverse\_diode}$



Diodes after long term stability	Ird @-5V (µA)	Vdd @620 mA (V)
Average	<0.5	0.731

Diodes after switching test	Ird @-5V (µA)	Vdd @620 mA (V)
Average	<0.5	0.730

Agenda

1. About CESI
2. Qualified CTJ30_80 bare solar cells
3. CCN2 activities
4. Qualification results at SCA level
5. Results from Subgroup M
6. Main benefits and achievements
7. Acknowledgements & AOB

Group M: definition of subgroups for BSC and SCA thin flexible solar cells

Subgroup M aimed at verifying the flexibility and the reliability of thin (80 µm) solar cells / solar cell assemblies mounted on curved surfaces or on flexible supports and identifying methods to test the cell behavior in bending configuration.

BSC level

- Subgroup M1/BSC – **Long term Bending** properties at Bare cell level
- Subgroup M2/BSC – Interaction with a flexible substrate at Bare cell level (shrinking test)
- Subgroup M3/BSC – **Ultimate Bending** properties at Bare cell level

SCA Level

- Subgroup B – UV test
- Subgroup C – Electron irradiation 1MeV, 1 10^{15} e^-/cm^2 fluence
- Subgroup E –Thermal cycling (only LEO CY)
- Subgroup M1/SCA – **Long term Bending** properties at SCA level
- Subgroup M2/SCA – Interaction with a flexible substrate at SCA level (**shrinking test**):
- Subgroup M3/SCA – **Ultimate Bending** properties at SCA level

Subgroup M: four test methods have been implemented

METHOD

Standard bending (*)

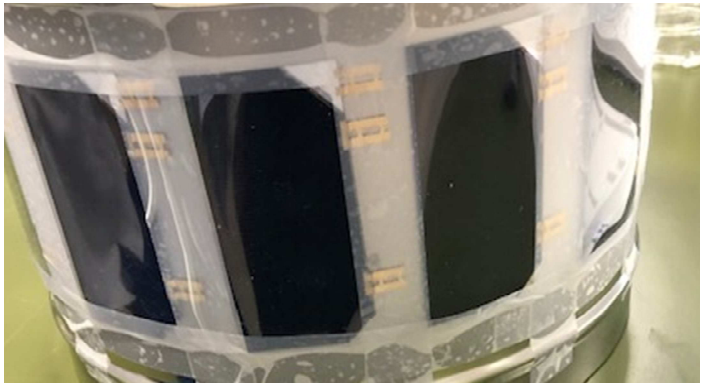
The solar cells are bent to a cylinder 11.5 cm radius in the four modes :

- Face-front, long side
- Face front, short side
- Face- rear, long side
- Face-Rear, short side

(*)these test conditions are also applied for the **multiple bending sequence**

Long duration bending

Flexible BSC and SCA are wrapped around an aluminium cylinder (11.5 cm radius) for **8 months**.
After this period samples are gently unwrapped and BSC and SCA removed from the cylinder to allow further analysis.



Methods

METHOD

Shrinking test

BSC, SCA, and SCA on flexible blanket are submitted to a thermal shock test, consisting of :

20 cycles between -197°C/+130°C (2 minutes per cycle).

The objective is to evaluate how the cells at bare and SCAs level (or the SCAs on blanket) adapt to the abrupt temperature changes in connection with the presence of resin and coverglasses (SCA level) or blanket and resin

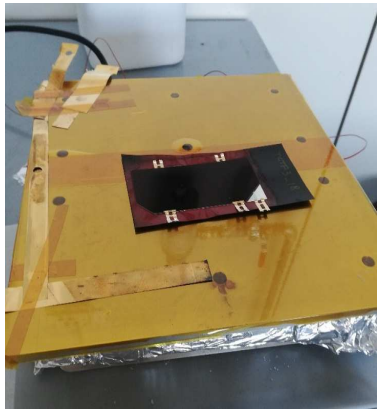
Ultimate bending

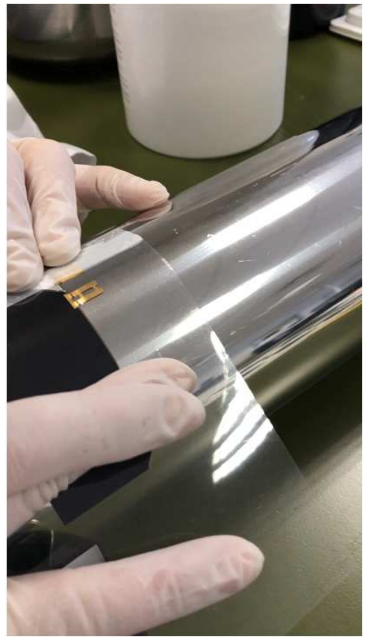
The solar cells are bent to cylinders with decreasing radius in the four modes. The radius of breakage and mode are recorded

Requirement:

no breakage above 7 cm radius for bare cells

no breakage above 9 cm radius for SCAs





SCA
5 cm radius

Bare solar cells: test matrix

Test	Test Code	M1 (10 samples)	M2 (10 samples)	M3 (10 samples)
Front Interconnect Welding	FIW		4	
Rear Interconnect Welding	RIW		5	
Visual inspection	VI	1, 6,9, 15,21	1,8,11,14,17	1
Dimension and weight	DW	2	2	2
Electrical performance	EP	4,7,10,13,16,19,22,25	3,6,9,12,15,18	3,5
Flatness	FT	3,11,17, 23		
Bending standard	BS	5,12,18, 24	10,16	
Shrinking test	ST	8,20	13	
Long bending	LB	14		
Multiple bending	MB			4
Ultimate bending	UB	26		6
Blanket Bonding	BB		7	

Bare cells: electrical performance and flatness

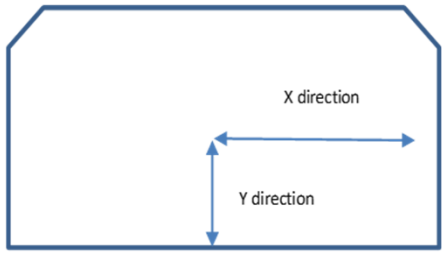
No relevant variation in the electrical performance after standard bending, long bending and multiple bending test and after shrinking test at bare level

Average electrical performance		Isc [A]	Voc [V]	Pmax [W]	Ipmax [A]	Vpmax [V]	PL [W]	IL [A]	F.F.	ΔIl [%]
BOL	Step 4	0.479	2.554	1.042	0.464	2.246	1.030	0.454	0.85	
After standard bending	Step 7	0.476	2.553	1.032	0.461	2.238	1.013	0.448	0.85	-1.32%
After Shrinking test	step 10	0.479	2.549	1.042	0.462	2.256	1.026	0.454	0.85	1.34%
After bending standard	Step 13	0.476	2.550	1.039	0.460	2.257	1.021	0.452	0.85	-0.44%
After long bending	Step 16	0.476	2.552	1.030	0.461	2.234	1.016	0.451	0.85	-0.22%
After standard bending	Step 19	0.476	2.558	1.027	0.460	2.233	1.016	0.450	0.84	-0.22%
After Shrinking test	Step 22	0.476	2.555	1.028	0.460	2.234	1.016	0.450	0.85	0.00%
After standard bending	Step 25	0.474	2.557	1.028	0.458	2.242	1.021	0.452	0.84	0.44%

Sub group M1

Variation of the flatness after shrinking test, this do not affect the mechanical properties

Flatness- Average values		Bowing X direction (mm)	Bowing Y direction (mm)
BOL	Step 3	***0.102***	***0.333***
After Shrinking test	Step 11	***0.095***	***0.042***
After long bending	Step 17	**0.108**	**0.043**



Bare cells –Shrinking test Subgroup M2

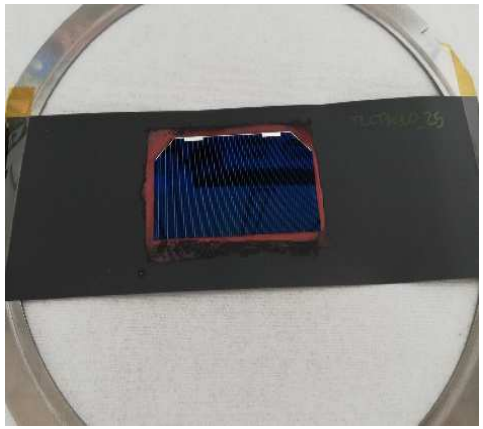
- Ok on bare solar cells

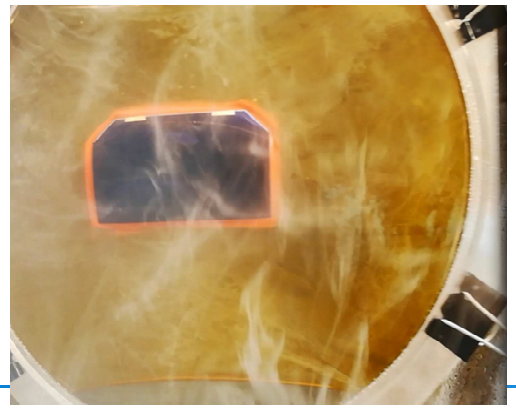
- Not applicable if bare cells are glued on flexible blanket
  - Peek 100 µm thick
  - Kapton 70 µm thick
  - Carbon reinforced polymide 50 µm thick

Resin Wacker RTV-S691

Test conditions:

- blanket free-to-move
- blanket on frame



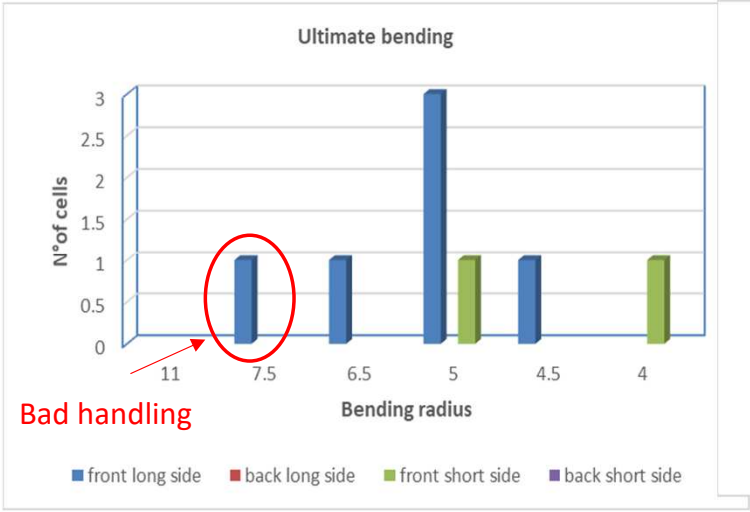


Cells rolled and twisted on the long size and broke

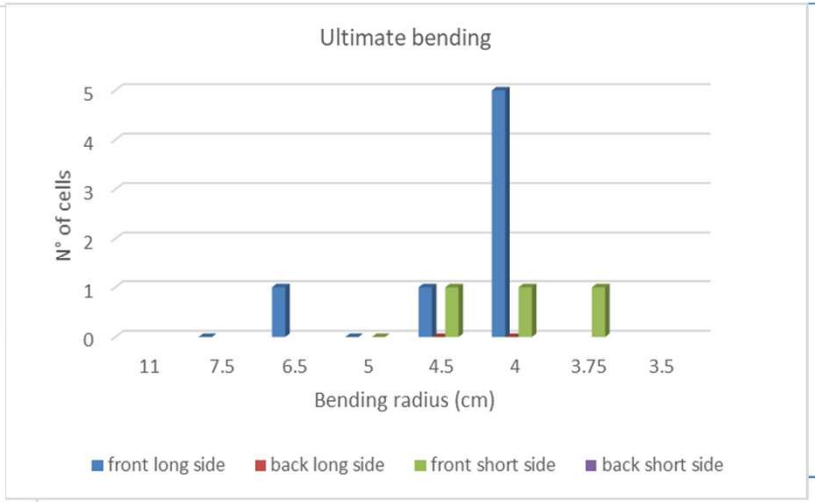
Bare cells –ultimate bending results

Requirement: no breakage at 7 cm radius

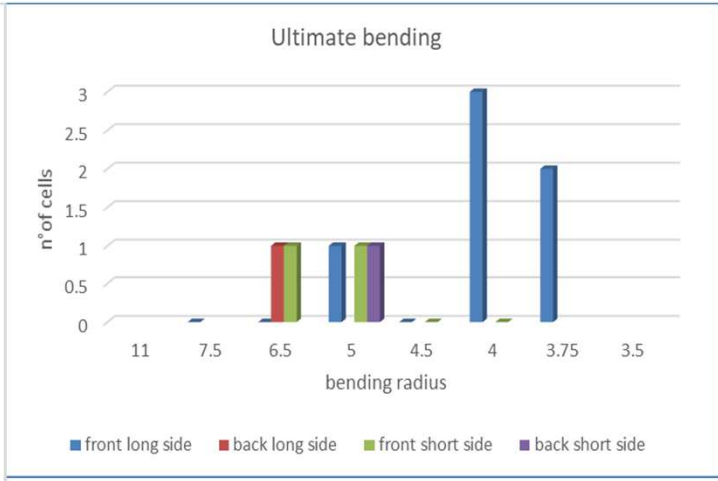
Subgroup M 1 (long bending)



Subgroup M 2 (BOL- interconnect welding)



Subgroup M 3 (Multiple bending)



The ultimate average bending radius at bare level is in the range 4-5 cm in all subgroup tested BOL and EOL

Flexible solar cell assembly: test matrix

Test	Test Code	B (3)	C (4)	E (6)	M1 (10)	M2 (6)	M3 (8)
Front Interconnect Welding	FIW			4			
Coverglass Bonding	CB			5			
Rear Interconnect Welding	RIW			6		4	
Visual inspection	VI	1,11	1,7,13	1,7,11,18	1,7,11,17,22	1,6,10,14, 18	1
Dimension and weight	DW	2	2		2,8	2	2
Electrical performance	EP	3,6,12	3,,8,14	2,8,12,15	4,12a,15a,18,23	3,7,11,15, 19	3a,5a
Thermal cycling	CY			10 (only LEO CY)			
Pull test	PT			17			
Spectral response	SR		11				
Thermo-optical data	TO	8,10	10				
Electron irradiation	EI		5				
Photon irradiation and temperature annealing	PH	5,	6				
Diode characterization	DC	4,7,13	4,9,15	3,9,13, 16	5,9,12b,15b,19, 24	4,8,12,16, 20	3b,5b
Ultraviolet exposure[4]	UV	9					
Flatness	FT				3,13,20		
Bending standard	BS		12	14	6,14,	9,17	
Shrinking test	ST				10;21	13	
Long bending	LB				16		
Multiple bending	MB						4
Ultimate bending	UB				25		6
Blanket Bonding	BB					5	

Flexible SCAs–electrical performance and flatness

No relevant variation in the electrical performance after standard bending, long bending and multiple bending test and after shrinking test at bare level

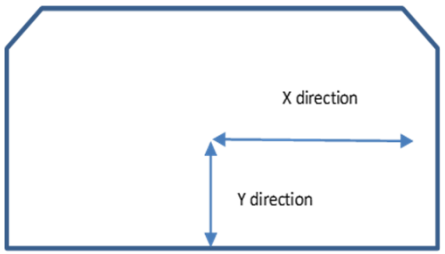
Sub group M1/SCA

Average electrical performance		Isc [A]	Voc [V]	Pmax [W]	Ipmax [A]	Vpmax [V]	PL [W]	IL [A]	F.F.	Δil [%]
BOL	Step 4	0.48	2.54	1.033	0.461	2.223	1.024	0.448	0.84	
After standard bending	Step 8	0.479	2.54	1.027	0.462	2.223	1.012	0.448	0.85	**0.00%**
After Shrinking test	step 12	0.478	2.542	1.021	0.462	2.21	1.001	0.443	0.84	**-1.12%**
After bending standard	Step 15	0.479	2.544	1.021	0.462	2.21	1.006	0.445	0.84	**0.45%**
After long bending	Step 18	0.478	2.548	1.022	0.46	2.222	1.008	0.446	0.84	**0.22%**
After Shrinking test	Step 24	0.478	2.55	1.025	0.461	2.222	1.005	0.445	0.84	**-0.22%**

Average diode performance		Ird @-5V (μA)	Vdd @620 mA (V)
BOL	Step 5	<0.5	0.738
After standard bending	Step 9	<0.5	0.743
After Shrinking test	Step 12	<0.5	0.739
After bending standard	Step 16	<0.5	0.739
After long bending	Step 19	<0.5	0.745
After Shrinking test	Step 24	<0.5	0.753

Variation of the flatness after shrinking test, the test do not affect the mechanical properties

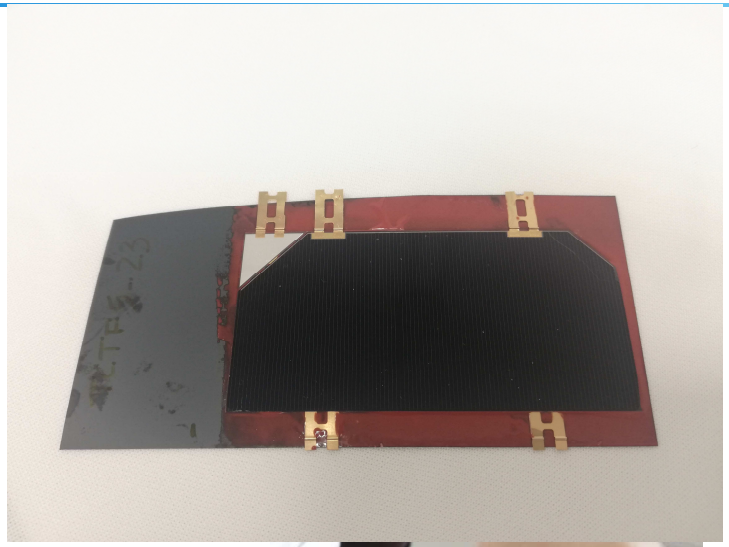
Flateness Average values		Bowing X direction (mm)	Bowing Y direction (mm)
BOL	Step 3	***0.083***	***0.041***
After Shrinking test	Step 11	**0.149**	**0.051**
After long bending	Step 17	**0.137**	**0.050**



Flexible SCAs–Shrinking test

- Ok on thin solar cell assembly
- Test applicable but critical for SCAs glued on flexible blanket (carbon reinforced polymide 50 um thick)

20 cycles between -197°C/+130°C (2 minutes per cycle)



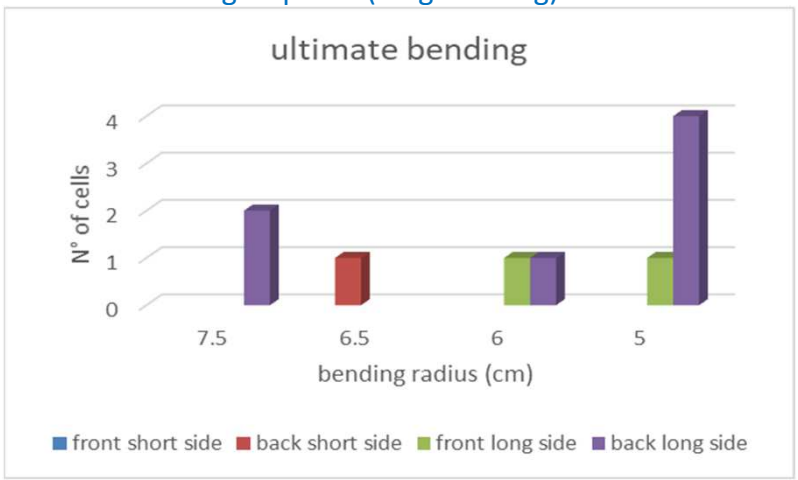
Cracks were observed on two SCA coverglass after dipping in LN_2.

- In the first case the cracks originated during the first cycle in LN_2.
- In the second case the defect appeared after 7 cycles.

The cracks did not get worse in the subsequent cycles and no breakages at cell level were evidenced.

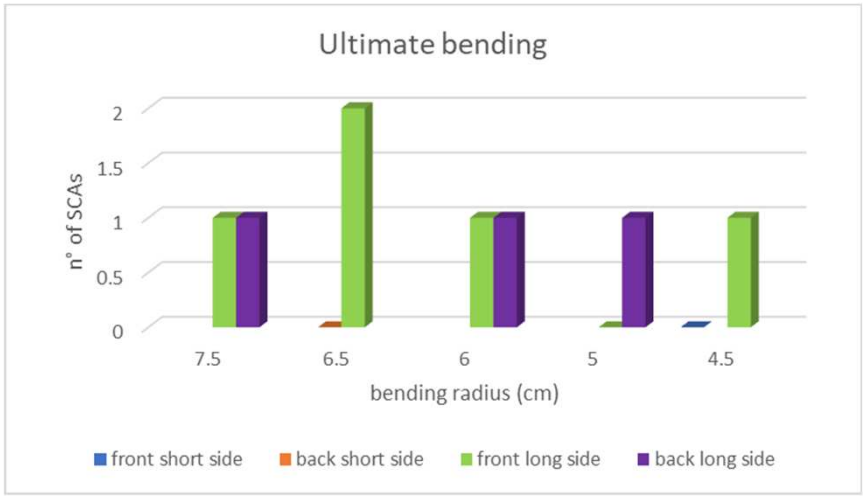
Flexible SCAs – ultimate bending results

Subgroup M 1 (long bending)



Requirement: no breakage at 9 cm radius

Subgroup M 3 (Multiple bending)



CELL ID	Bending radius (cm)	Mode	Type of breakage
TCTF002 009	5	back long side	cell breakage
TCTF002 010	5	back long side	cell breakage
TCTF002 020	6	back long side	cell breakage
TCTF003 015	6.5	front long side	cell and coverglass breakage
TCTF003 016	7.5	back long side	cell and coverglass breakage
TCTF003 019	5	back long side	cell breakage
TCTF003 020	5	front long side	coverglass breakage
TCTF003 022	5	back long side	cell breakage
TCTF005 006	7.5	back long side	cell and coverglass breakage
TCTF005 012	6.5	back short side	cell and coverglass breakage

CELL ID	**Bending radius (cm)**	**Bending mode**	**Type of breakage**
TCTF002_008	7.5	back long side	cell breakage
TCTF002_026	7.5	front long side	coverglass breakage
TCTF003_013	6.5	front long side	coverglass breakage
TCTF003_018	6	front long side	coverglass breakage
TCTF002_023	6.5	front long side	coverglass breakage
TCTF004_020	4.5	front long side	coverglass breakage
TCTF005_008	6	back long side	cell breakage
TCTF005_019	5	back long side	cell breakage

The ultimate average bending radius at SCAs level is about 6.5 cm: in most cases the break occurs during the bending in the “long side” mode and only the coverglass or only the solar cells crack.

Subgroup M/B and M/E

UV test and thermal cycling condition satisfied

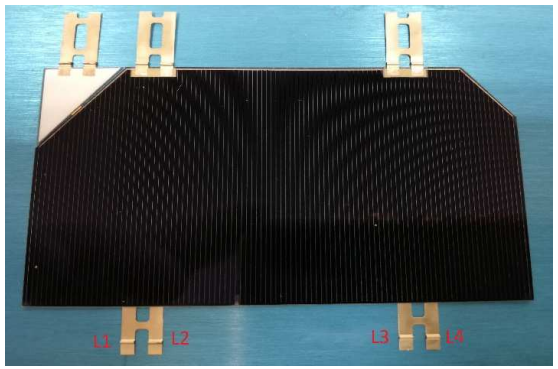
	NUV-Vis-NIR SOLAR ABSORPTANCE		MIR EMITTANCE	
SAMPLE ID	BOL	EOL	BOL	EOL
A-TCTF001_019	0.90	0.90	0.85	0.85
B TCTF002_002	0.90	0.90	0.85	0.85
C TCTF002_004	0.90	0.90	0.85	0.85

CY	Number of cycles	Temp. Range [°C]	Cycle Duration (*) [min]	Environment
LEO	6000	-140 (-10;0) / +140 (0;+10)	30 °C/min. max temperature grade, no dwell	Inert atmosphere (Nitrogen)

- ✓ The ΔI_L values of the solar cells range between -1.29% to -0.11%
- ✓ Bending standard after CY succesfully passed

Isc remaining factor as a function of the EUHV illumination measured in the UV chamber

EUVH	TCTF001_019 (A)	TCTF002_002 (B)	TCTF002_004 (C)
0	1	1	1
198.92	0.9925	0.9929	0.9953
464.47	0.9944	0.9963	0.9938
809.17	0.9956	0.9948	0.9936
1044.46	0.9933	0.9933	0.9911



Cell ID	Leg 1 (L1)	Leg 2 (L2)	Leg 3 (L3)	Leg 4 (L4)
	Pull strength (kg)	Pull strength (kg)	Pull strength (kg)	Pull strength (kg)
Average	1.82	1.46	1.88	1.90
min	1.74	1.41	1.74	1.78
Max	1.85	1.45	1.80	1.93

Subgroup M/C

Flexible CTJ30_80 SCAs with the 68088/CMG coverglass have similar EOL properties of the qualified CTJ30_80 SCAs after electron irradiation.

Remaining factor after electron irradiation (1 MeV fluences 1 10^{15} e-/cm^2)

	Energy	dose	RF (Isc)	RF (Voc)	RF (Pm)	RF (Im)	RF (Vm)
Subgroup M/C	1 MeV	1.00E+15	**0.90**±0.01	**0.94**±0.001	**0.84**±0.01	**0.89**±0.01	**0.94**±0.01
CTJ30_80_SCA from qualification	1 MeV	1.00E+15	**0.90**±0.009	**0.94**±0.002	**0.84**±0.007	**0.89**±0.006	**0.94**±0.005
CTJ30_80_ bare cells	1 MeV	1.00E+15	**0.93**±0.02	**0.93**±0.003	**0.84±0.01**	**0.89**±0.02	**0.94±**0.01

Bending standard after electron irradiation successfully passed

Agenda

1. About CESI
2. Qualified CTJ30_80 bare solar cells
3. Description of the activities
4. Qualification results at SCA level
5. Results of subgroup M
6. Conclusion and achievements
7. Acknowledgements & AOB

Conclusion on the qualification

All performed qualification tests have been passed successfully and all requirements have been met for Thin GaInP/GaAs/Ge triple junction Solar Cell Assemblies CTJ30_80 manufactured by CESI using the qualified CTJ30-80 thin.

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WP	Item	Target Requirement	Minimum Requirement	Results on qualification lot
WP111	Manufacturing CTJ30-80 SCA (size 30 cm^2 and 27 cm^2)	• eff. 28.5% (AM0, 25°C) • Mass <0.1 g/cm^2 • SCA thickness <230µm	minimum eff. 28.0% (AM0, 25°C)	Eff 28% Mass <0.1 g/cm^2
WP120	EOL (Electron 1 MeV energy, 1E15 e^-/cm^2)	Remaining Power Factor 0.85	minimum RPF 0.82	Remaining Power Factor 0.84
WP130	Flexibility	No degradation after 8 months in bent configuration	Maximum I_{Load} degradation 2%	Average Degradation ΔIl=-0.2% Maximum degradation -1%

The qualification of thin and flexible triple junction solar cells at bare and SCA level demonstrated that the thinning of such devices from 150 µm down to 80 µm does not affect the suitability and reliability in space environment.

Conclusions on the Subgroup M

The specific engineering tests described in this report allowed collecting information on the reliability of the thin (80 µm) solar cells CTJ30_80 SCAs with flexible coverglass.

- flexible CTJ30_80 SCAs with the 68088/CMG coverglass have similar EOL properties of the qualified CTJ30_80 SCAs after electron irradiation, UV test and thermal cycling.
- the electrical properties of CTJ30_80 (both bare cells and SCAs) are in line with standard BSC/SCA, after long and multiple bending
- The ultimate average bending radius at bare level is in the range 4-5 cm in all tested subgroups
- The ultimate average bending radius at SCA level is in the range 6-7 cm in all tested subgroups

The test methods and procedures implemented and verified in this activity may offer a base for discussion in view of future implementation of specific tests to characterize the mechanical properties (bendability) of thin solar cells in the ECSS standard.

Perspective (Further Technical And Commercial Evolution) for thin CTJ30_80 cells

The evolution in the field of thin space solar cells based on III-V compounds can be summarized in following steps

Scale-up the thinning technology from 4" Ge wafers to 6" wafers

Increase the thin solar cell efficiency BOL/EOL

to supply a more efficient device for higher power demanding missions

Explore the Integral assembly recently developed and patented at CESI, as an alternative to the standard SCA manufacturing.
(Suitable to be applied to all cell types in LEO missions (mass & cost reduction)

Boost the production capacity to reach volumes suitable to support the new emerging satellites constellations

Benefitting from the cost volumes reduction

Satisfy the current and the future aerospace market needs

More efficient thin device for both LEO and GEO orbits

Increased productivity

Acknowledgements

We wish to thank ESA and ASI and for the support to this project.

The GSTP Programme helped CESI to enhancing the confidence of the thin solar cell product and improving the Customer portfolio.

We thank Laurent Challoy for the support in the project and we are particularly grateful to Emilio Fernandez Lisbona for his continuous valuable technical support and advice.

Finally, we would like to acknowledge the valuable insights of TAS-F and AIRBUS-DE in the design of the tests in subgroup M