High Power COTS LEDs Reliability Assessment for Robotic Applications

Juan Moreno | HRS Optoelectronics Laboratory | 26.03.2025

ACCEDE | ESCCON

2025

Seville - Spain

25 to 27th March

Introduction

Project Requirements

Evaluate performances of high optical power LEDs under the operational conditions for Moon landers -> illumination for exploration missions.

- SoW: 8 x 2 LED types to be tested according ECSS-Q-ST-60-13C guidelines
- 6 types pre-defined by ESA
  - Different packaging technologies to be evaluated (not only Glob-Top)
  - Stability testing required at room and low temperature (-110degC)
  - Lunar Regolith Testing
  - Low Temperature Vacuum Operating
  - Radiation
- Counterparts TBD by Alter

Kick-off-Meeting held January 2022

Some TBDs at SoW

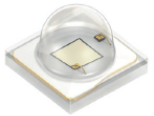
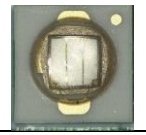
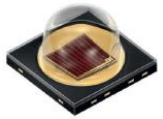
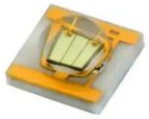
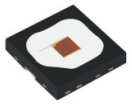
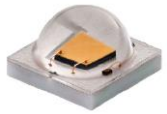
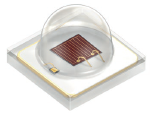
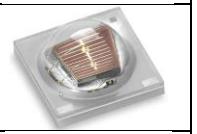
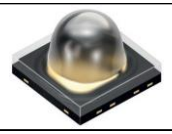
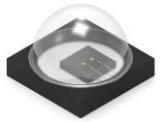
A2.2. Interface Requirements

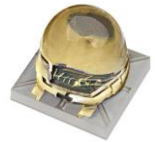
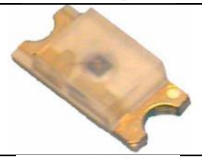
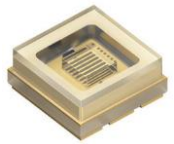
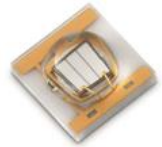
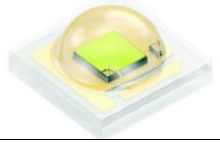
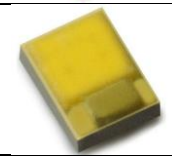
The following part numbers shall be considered during the activity

Central wavelengths	Glob top package	Other SMT package
451 nm	GD CS8PM1.14	To be defined
595 nm	LY H9GP	To be defined
730 nm	GF CS8PM2.24	To be defined
850 nm	SFH 4717AS A01	To be defined
940 nm	SMBB940D-1100-02	To be defined
970 nm	SMBB970D-1100-02	To be defined
UV spectra	To be defined	To be defined
White spectra	To be defined	To be defined

ALTER

Task 1 – Selection and Procurement of COTS LEDs

WL (nm)	Part type 1 (chip info) [substrate info] {lens info}	Package picture	Part type 2 (chip info) [substrate info] {lens info}	Package picture
451	OSRAM GD CS8PM1.14 [ceramic] {silicone lens}		USHIO EDC450V-1100 (InGaN) [ceramic] {silicone resin}	
595	OSRAM LY H9GP (thinfilm) [epoxy] {silicone lens}		Wurth 150353YS74500 (AlInGaP)	
			OSRAM LY H9PP-HZJZ-46-1 (thinfilm)	
			CREE XPEBPA-L1-R250-00B01	
730	OSRAM GF CS8PM2.24 [ceramic] {silicone lens}		Luminus SST-10-FR-B130-H730	
850	OSRAM SFH 4717AS A01 (double stack emitter) {diffuse silicone}		Wurth 15435385A9042 (InAlGaAs)	

WL (nm)	Part type 1 (chip info) [substrate info] {lens info}	Package picture	Part type 2 (chip info) [substrate info] {lens info}	Package picture
940	USHIO SMBB940D-1100-02 (AlGaAs) [Silver plated on Cu, PA9T resin] {silicone lens}		LUMILEDS 997-L1I0-094009000 90deg version	
970	USHIO SMBB970D-1100-02 (AlGaAs) [Silver plated on Cu, PA9T resin] {silicone lens}		EPIGAP EOL-970-195 [glass laminated epoxy]	
270	OSRAM OSRAM_SU CULDN1.VC (AlGaN flipchip) [ceramic] {glass cover}		OPTAN by CRISTAL IS 3535-DS OP-255-10P-SM {Glass lens}	
365	OSRAM LED ENGIN LZ1-00UV0R-0000 [ceramic] {glass lens}		Wurth 15335337AA350 (AlInGaN)	
White domain	OSRAM LUW CVBP.CE-5L8L-GMKM-8E8G-350-R18-Z (UX:3 chip) [ceramic] {silicone lens}		Lumileds LXZ1-4070	

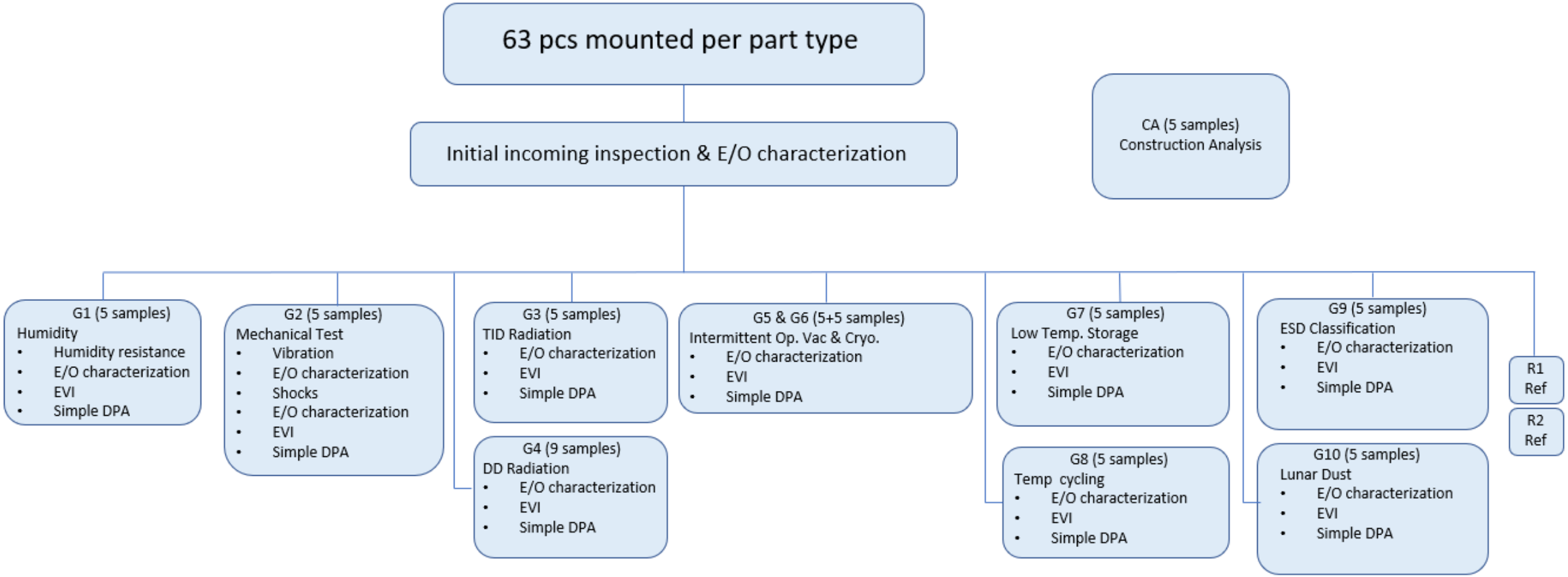
- Interest in two WL for UV LEDs -> additional WL
- Many interesting options for 595nm -> 2 additional

Considering: Technologies, same lot, MOQ, Prices, lead time, European

ALTER

Task 2 – Test plan definition and testing preparation

Number of samples and distribution: Test flow based on ECSS-Q-ST-60-13C

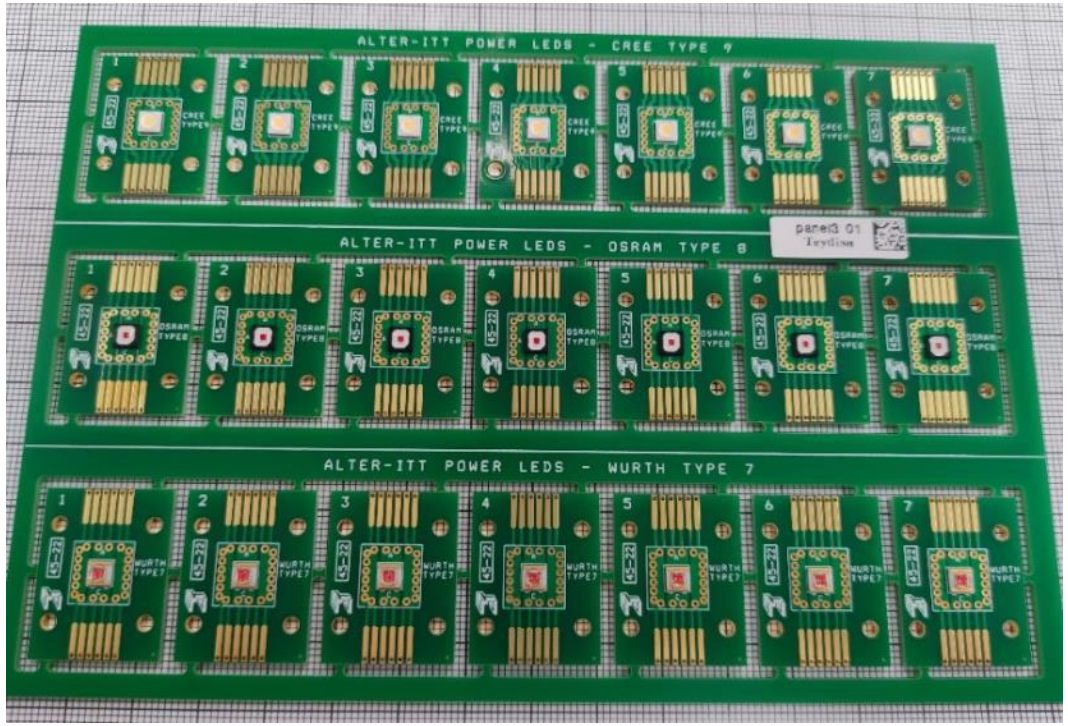


ALTER

Task 2 – Test plan definition and testing preparation

Extreme test conditions implying:

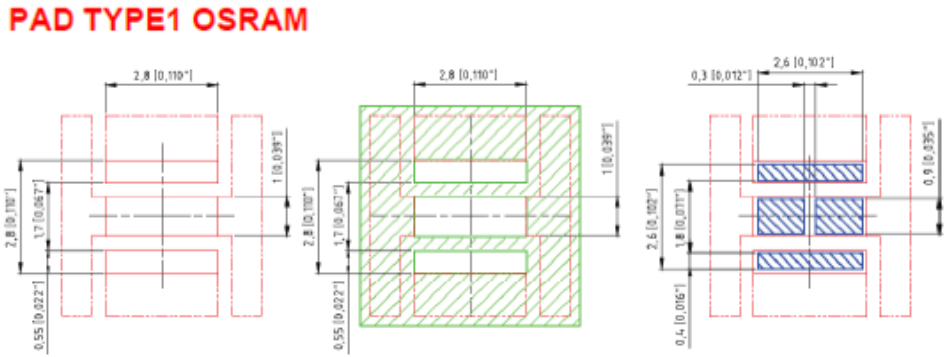
- Proper heat dissipation
- Easy plug & play characterization



- Compatible with thermal interfaces of specific tests (regolith/thermal vacuum)
- Compatible with mechanical interfaces (Shocks, Vibration)

Following mounting recommendations.

❑ 15 different pad types – dry N2 reflow



ALTER

Task 2 – Test plan definition and testing preparation

Bias Conditions Definition

Available specs and maximum ratings

Maximum Current (for intermediate characterization)

Wavelenght	Type	Manufacturer	Part Type	Imax(mA)
270	type 1	Osram	OSRAM_SU CULDN1.VC	500
270	type 2	Cristal IS	3535-DS OP-255-10P-SM	100
365	type 1	Osram LED Engin	LZ1-00UV0R-0000	1000
365	type 2	Wurth	15335337AA350	700
451	type 1	Osram	GD CS8PM1.14	1000
451	type 2	Ushio	EDC450V-1100	500
595	type 1	Osram	LY H9GP	1000
595	type 2	Wurth	150353YS74500	700
595	type 3	Osram	LY H9GPP-HZJZ-46-1	1000
595	type 4	Cree	XPEBPA-L1-R250-00B01	1000
730	type 1	Osram	GF CS8PM2.24	1000
730	type 2	Luminus	SST-10-FR-B130-H730	1500
850	type 1	Osram	SFH 4717AS A01	1500
850	type 2	Wurth	15435385A9042	1500
940	type 1	Ushio	SMBB940D-1100-02	1000
940	type 2	Lumileds	997-L1I0-094009000	1000
970	type 1	Ushio	SMBB970D-1100-02	1000
970	type 2	Epigap	EOL-970-195	50
white	type 1	Osram	LUW CVBP.CE-5L8L-GMKM-8E8G-350-R18-Z	1000
white	type 2	Lumileds	LXZ1-4070	1000

Nominal Values (for bias during testing)

WL	Type	Manufacturer	Inom(mA)	Vmax(V,Inom)	Op Pow min(W)	Peak WL min(nm)	Peak WL max (nm)	FWHM
270	type 1	Osram	350mA	6.00	0.030	270	280	N/Av
270	type 2	Cristal IS	100 mA	8.00	0.004	250	260	N/Av
365	type 1	Osram LED Engin	700mA	4.50	1.100	365	370	N/Av
365	type 2	Wurth	500mA	4.40	0.700	N/Av	N/Av	N/Av
451	type 1	Osram	350mA	3.25	0.660	N/Av	N/Av	N/Av
451	type 2	Ushio	500mA	4.50	0.850	440	460	N/Av
595	type 1	Osram	350mA	2.65	N/Av	N/Av	N/Av	N/Av
595	type 2	Wurth	350mA	3.00	N/Av	N/Av	N/Av	N/Av
595	type 3	Osram	350mA	2.60	N/Av	N/Av	N/Av	N/Av
595	type 4	Cree	350mA	3.24	N/Av	N/Av	N/Av	N/Av
730	type 1	Osram	350mA	2.30	0.315	N/Av	N/Av	N/Av
730	type 2	Luminus	350mA	2.60	0.310	720	750	N/Av
850	type 1	Osram	1000mA	3.30	N/Av	N/Av	N/Av	N/Av
850	type 2	Wurth	1000mA	3.60	1.100	N/Av	N/Av	N/Av
940	type 1	Ushio	350mA	1.80	0.154	930	955	N/Av
940	type 2	Lumileds	1000mA	3.40	1.125	925	955	N/Av
970	type 1	Ushio	1000mA	2.50	0.780	960	980	N/Av
970	type 2	Epigap	50mA	1.45	0.002	955	985	N/Av
white	type 1	Osram	350mA	3.50	N/Av	N/Av	N/Av	N/Av
white	type 2	Lumileds	500mA	3.25	N/Av	N/Av	N/Av	N/Av

Some reject limits

ALTER

• Task 3: Performance and reliability testing

PASS/FAIL Criteria Definition (after final selection)

Manufacturers not providing limits for many parameters

- Maximum drift value agreed with ESA: 10%
  - Better than 5% repeatability at test board measurements (Alter)
  - Typical 7% accuracy of the manufactures (up to 15% in some cases) -> Discussion on compliance with datasheet limits.

Complex tailoring of Test Methods

Examples: Humidity, Thermal Cycles,

Vacuum operation and Regolith.

Complex initial characterization

63 pcs x 20 types

From 255 to 970nm + white spectrum

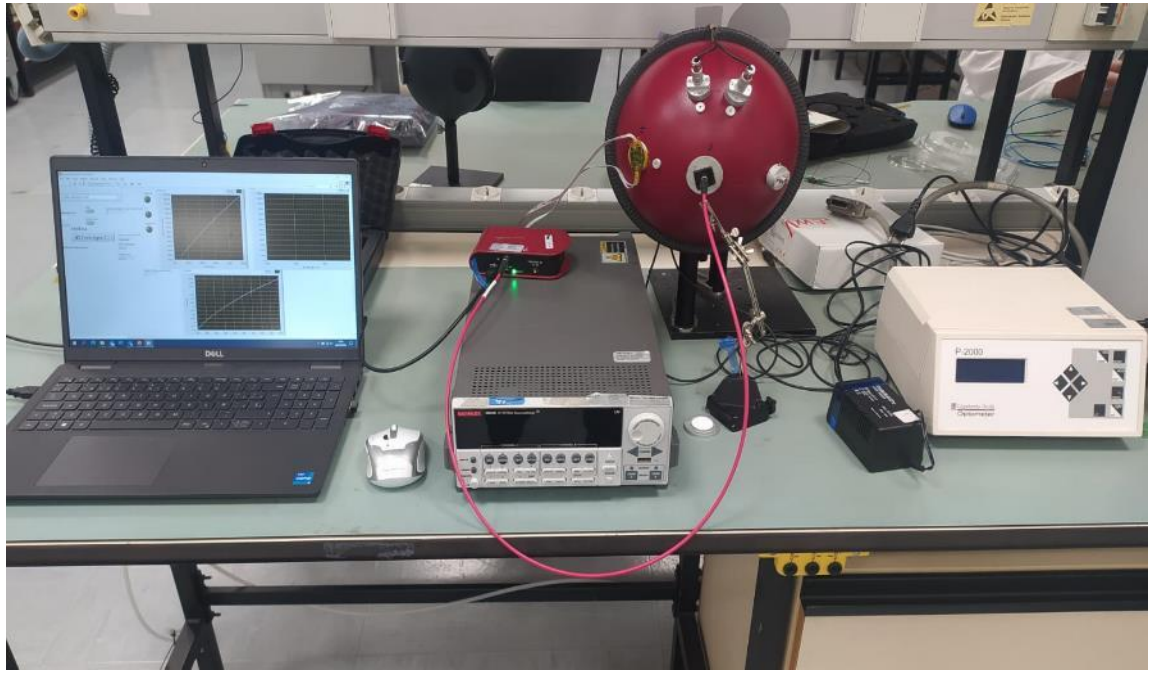
Non-compliant optical power 451nm type 1

ALTER

• Task 3: Performance and reliability testing

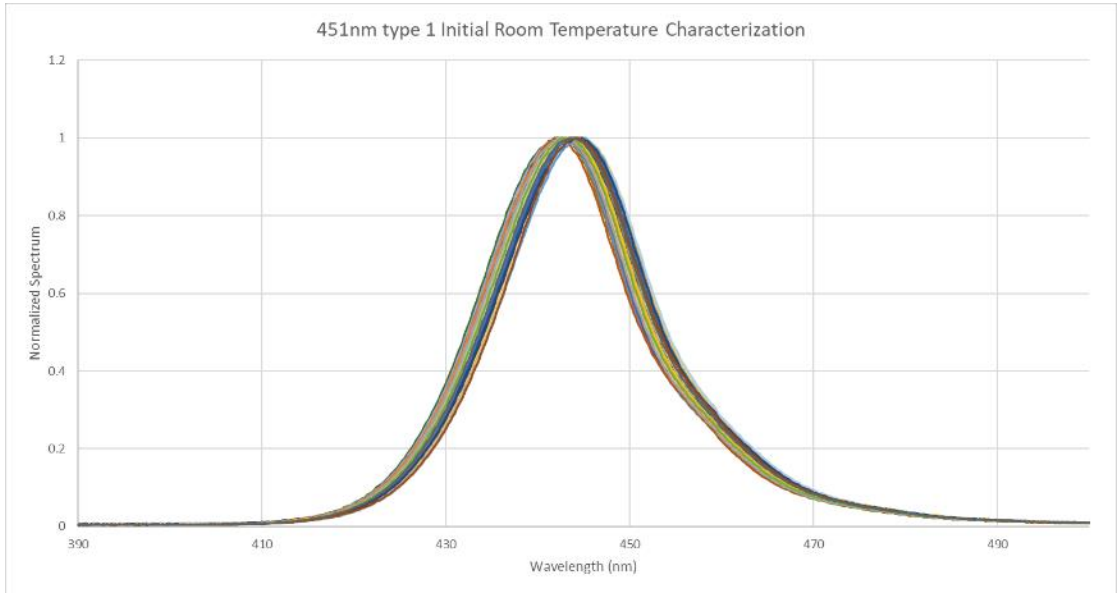
Initial Characterization

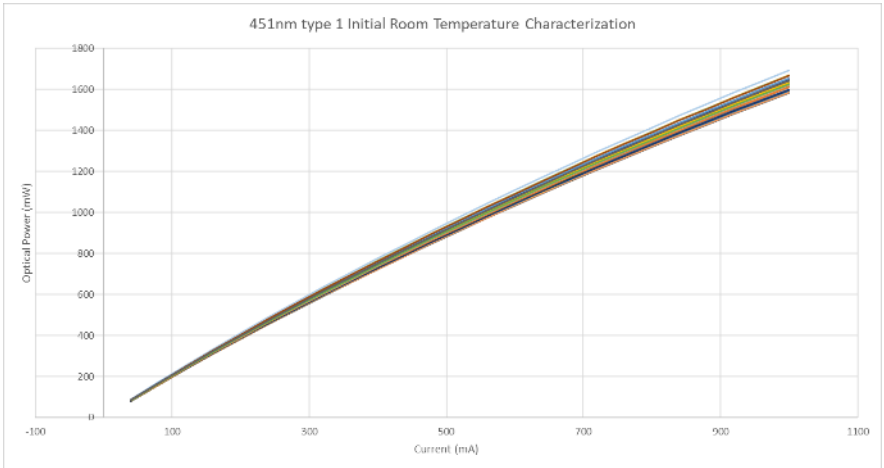
Benchtop setup overview



As well as cryo version of the setup

Example of Initial Characterization – 451nm Type 1 (63 pcs)





ALTER

• Task 3: Performance and reliability testing

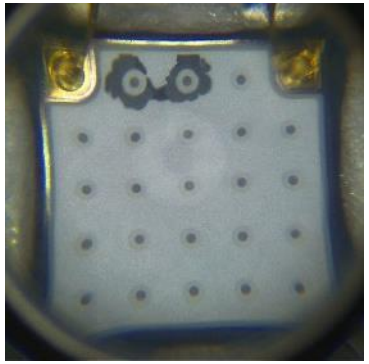
Issues at Low Temperature Characterization (-110°C)

- **Rejects at Initial Characterization (instabilities and failures)**

365nm type 1

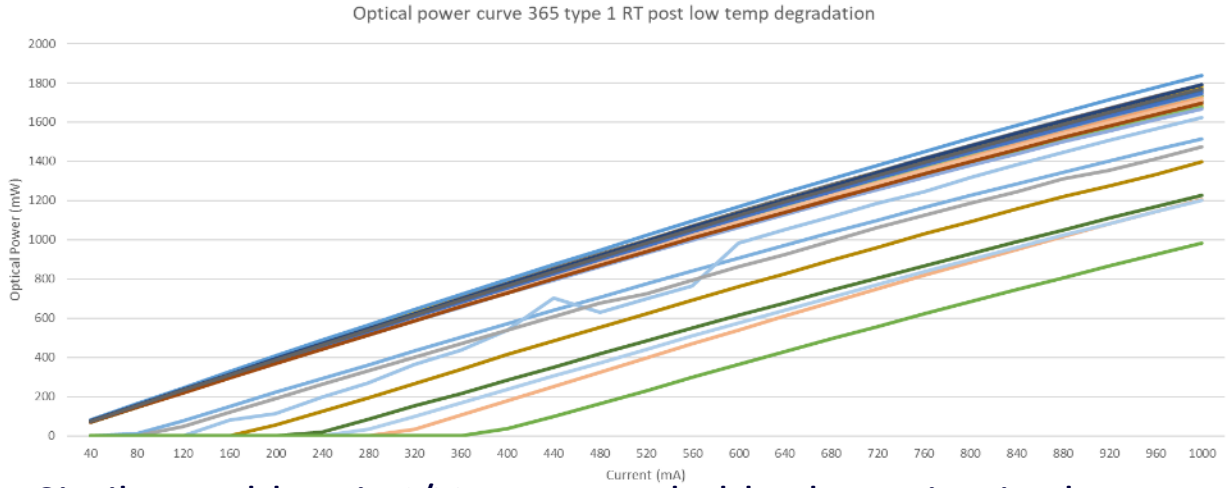
Instable at low temperature,

Degraded at RT char. (63 graphs)

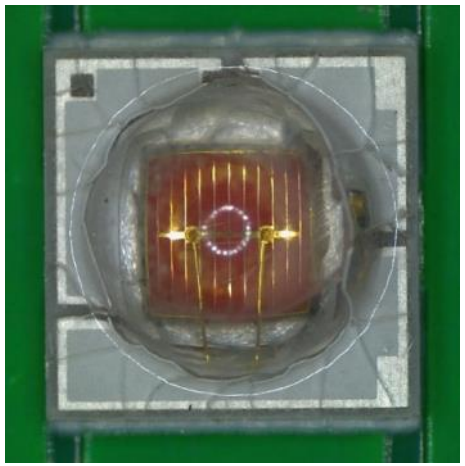


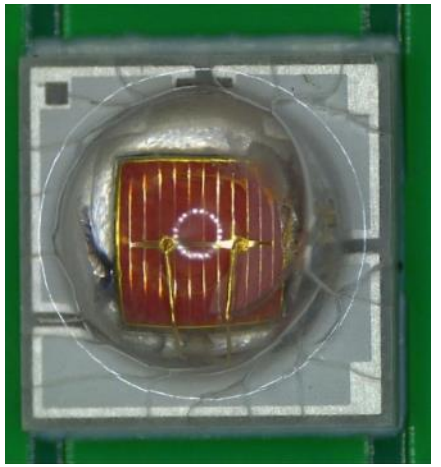
730nm type 2:

Two failures (instability at low temperature) persistent at room temperature afterwards. Mechanical Problems in most of them



Similar problem in I/V curve, probable short-circuited area





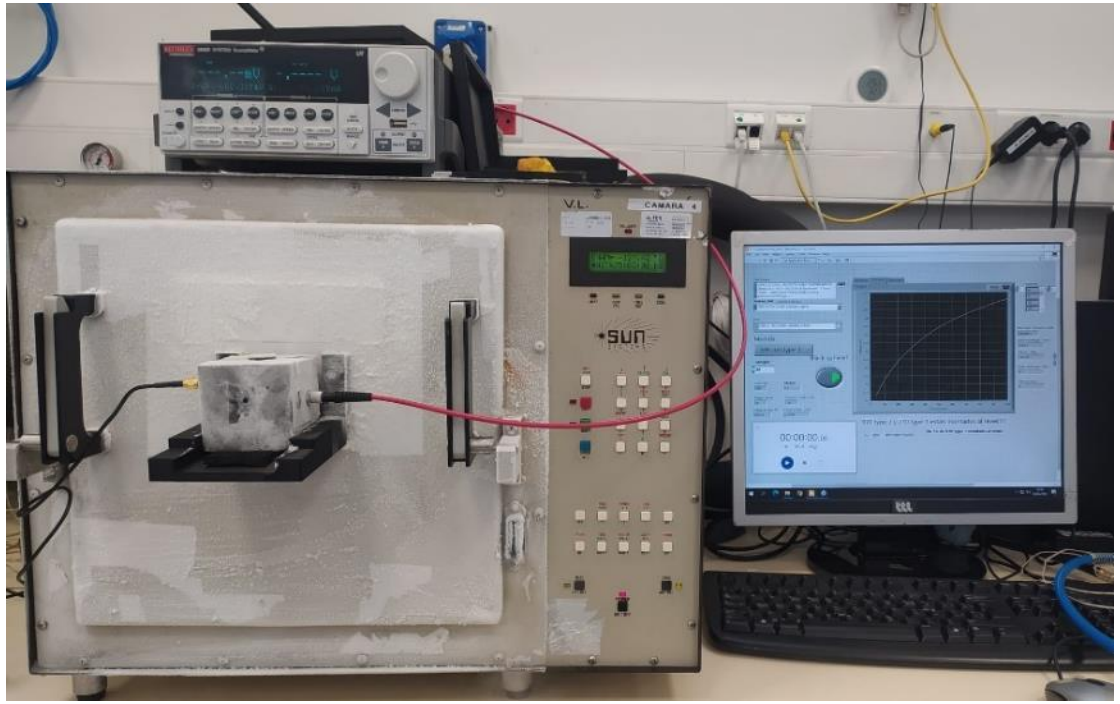
ALTER

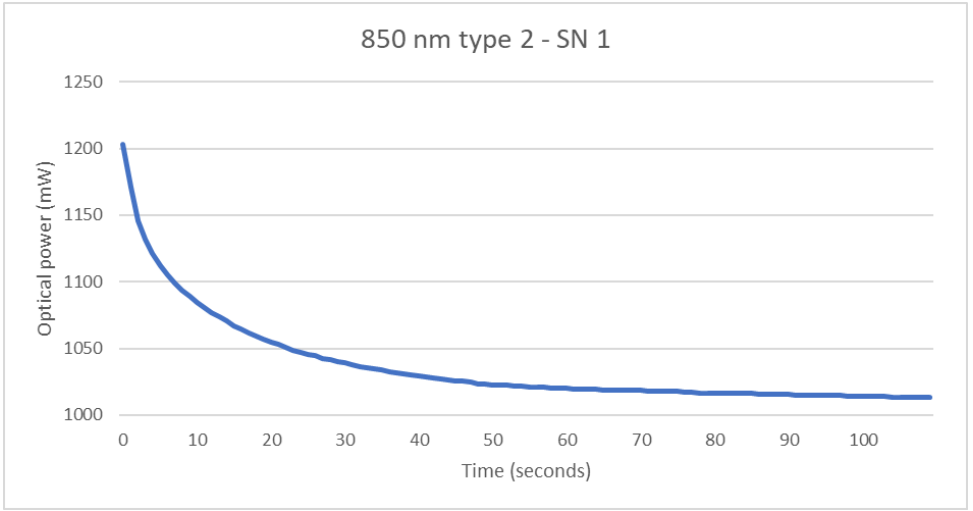
• Task 3: Performance and reliability testing

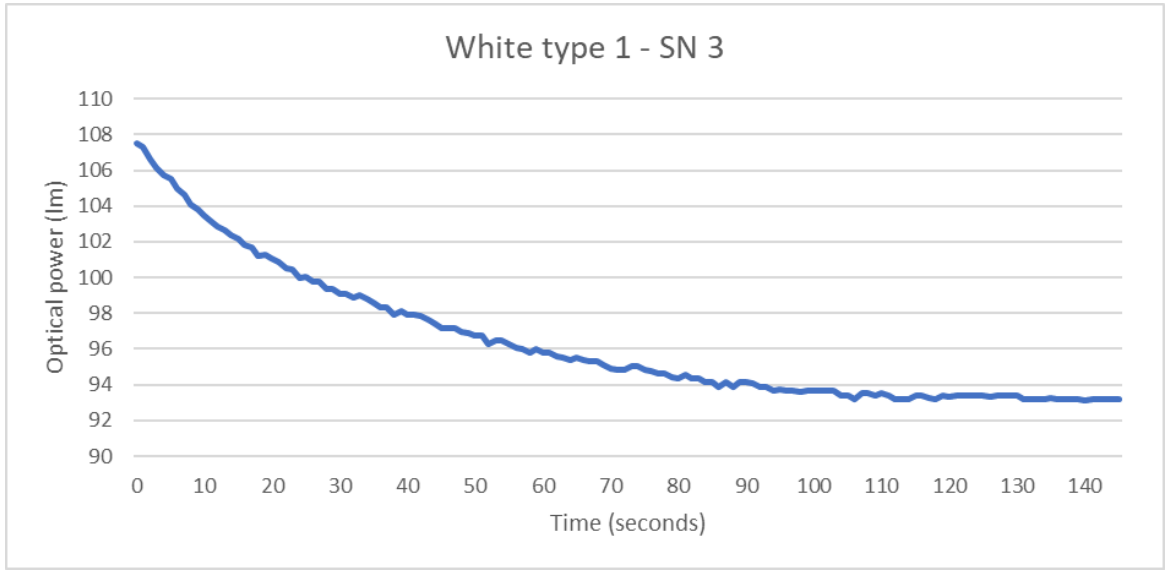
Stability Study

- Stability Test at Room Temperature
- Stability Test at -110degC

Short term stability demonstrated for all the 18 types



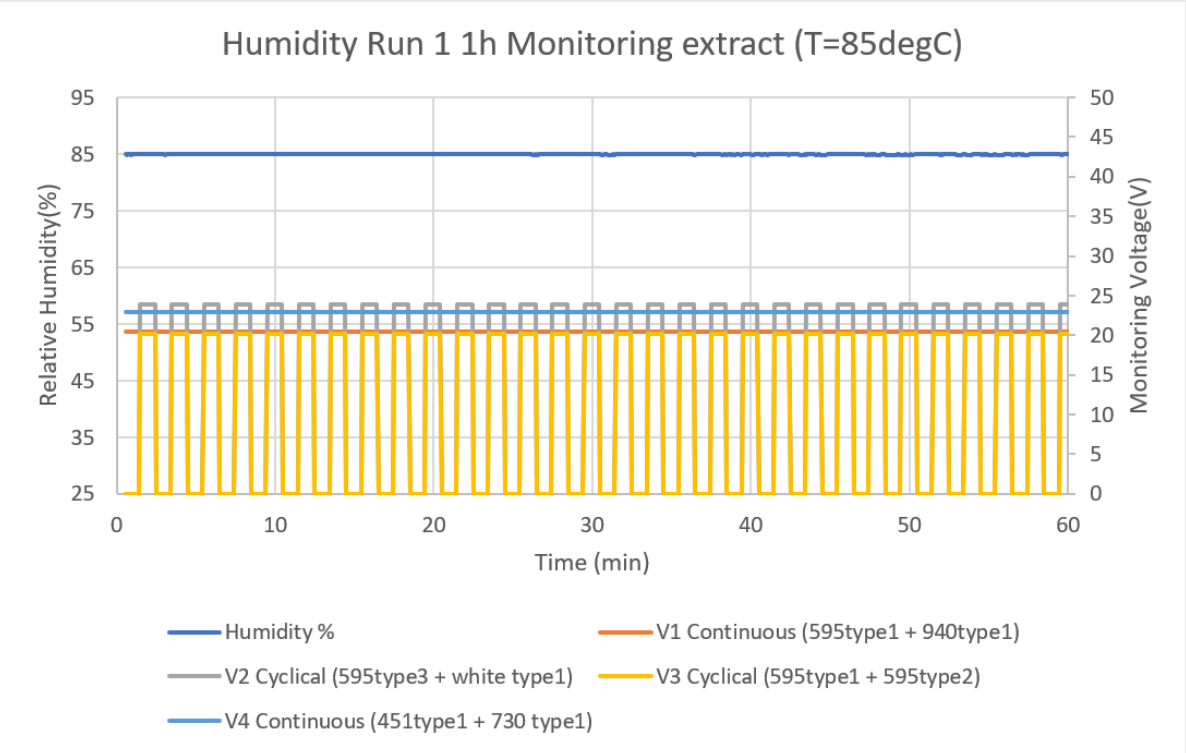




ALTER

• Task 3: Performance and reliability testing

Humidity 1000h 85RH/85degC
Bias conditions specified by *JESD22-A101*.



Wavelength	Type	Ifwd (mA)	Bias type	Run
270	type 1	350	No bias	2
270	type 2	100	No bias	2
365	type 2	500	No bias	2
451	type 1	350	Continuous	1
451	type 2	500	Cyclical	2
595	type 1	350	Cyclical	1
595	type 2	350	Cyclical	1
595	type 3	350	Cyclical	1
595	type 4	350	Continuous	1

Wavelength	Type	Ifwd (mA)	Bias type	Run
730	type 1	350	Continuous	1
850	type 1	1000	Cyclical	2
850	type 2	1000	Cyclical	2
940	type 1	350	Continuous	1
940	type 2	1000	Continuous	2
970	type 1	1000	Cyclical	2
970	type 2	50	Cyclical	2
white	type 1	350	Cyclical	1
white	type 2	500	Continuous	2

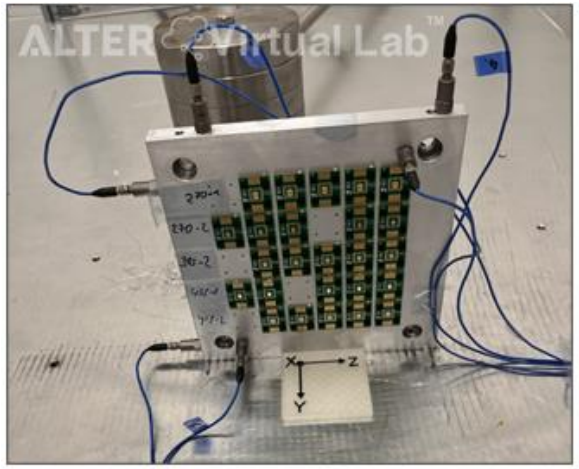
Two types failed (but remained functional):

- **595-1 near to 10% & 595-3 18.70% degradation**

ALTER

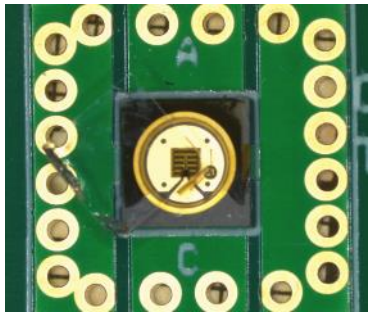
• Task 3: Performance and reliability testing

Mechanical Tests



No drift,
2 single EVI rejects

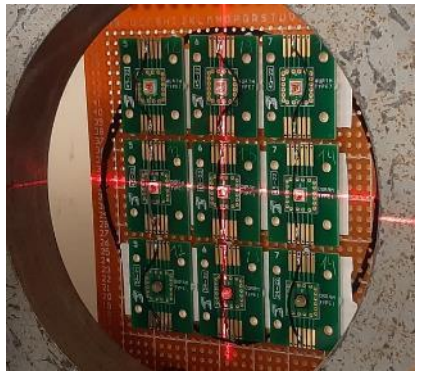
270 type 2



Radiation

TID

Up to
100Krad



TNID

60MeV up to
1.2×10^{11} p/cm²

No drift
above 10%

Low Temperature Storage

Not as damaging as thermal cycles -160ºC seems not to be so critical

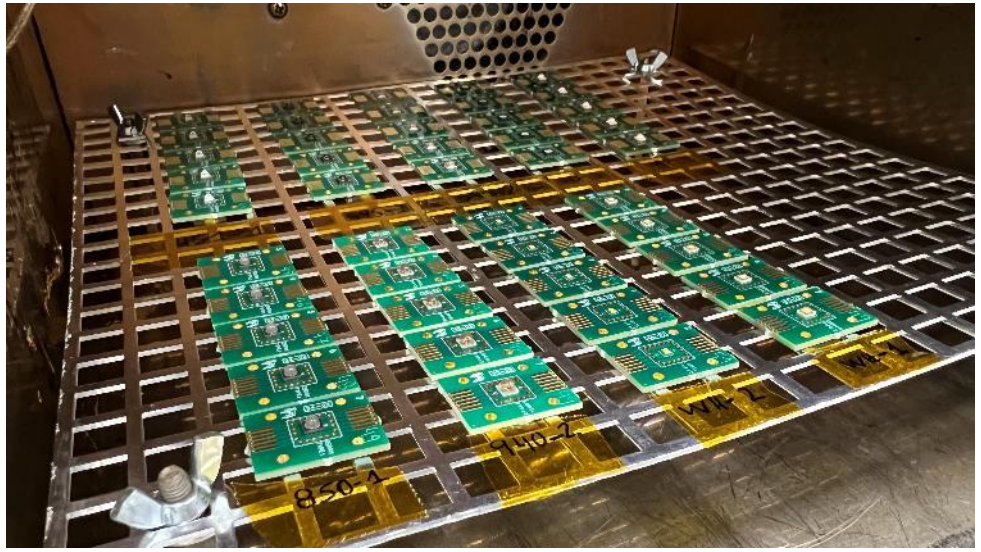
Only one LED of types 595-4 (open-circuit) and 850-1 (degraded) failed after the test.

Screening prior to further studies, seem to be faulty samples

• Task 3: Performance and reliability testing

Thermal Cycles

Number of cycles:500			
Step	**Temperature**	**Dwell time**	**Ramp time**
1 COLD	-160º (+0, -10)	≥10 min	15°C/minute
2 HOT	85ºC/120ºC (+10, -0)	≥10 min	
Not biased during cycling			



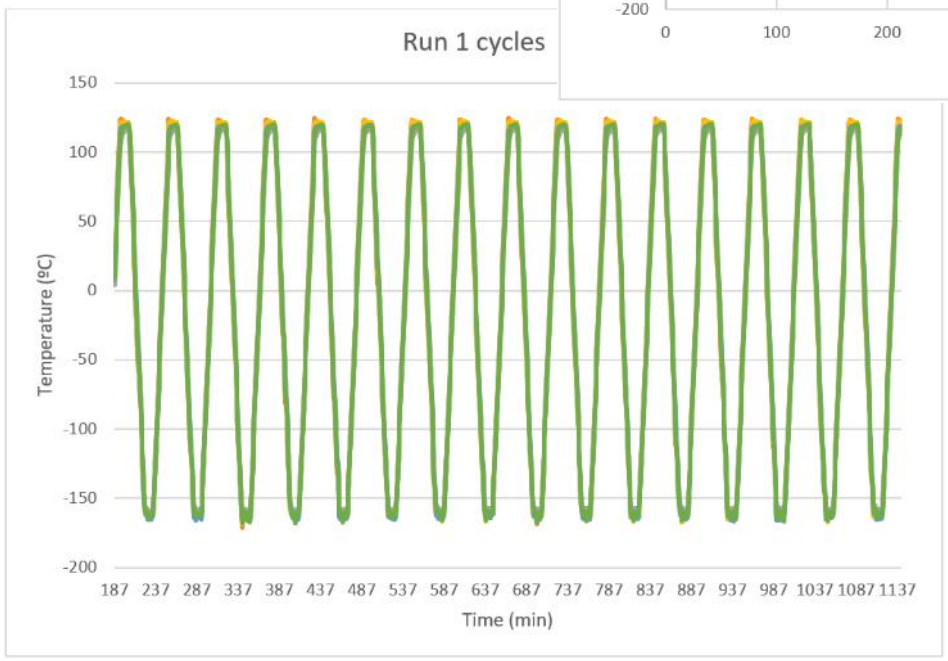
Types grouped by maximum storage temperature

Wavelength	Type	Part Type	Imax(A)	Vfwd(V)	Pmax(W) @25degC	storage Tmin	storage Tmax	Operation Tmin	Operation Tmax	Cycles group
270	type 1	OSRAM_SU CULDN1.VC	0.5	6 @350mA	3	-40	100	-40	60	2 (85°C)
270	type 2	3535-DS OP-255-10P-SM	0.1	8 @100 mA	0.8	-40	100	-5	55	2 (85°C)
365	type 2	15335337AA350	0.7	4.4 @500mA	3.08	-40	85	-40	85	2 (85°C)
451	type 1	GD CS8PM1.14	1	3.25@350mA	3.25	-40	125	-40	125	1 (120°C)
451	type 2	EDC450V-1100	0.5	4.5 @500mA	2.25	-40	100	-40	100	2 (85°C)
595	type 1	LY H9GP	1	2.65 @350mA	2.65	-40	125	-40	125	1 (120°C)
595	type 2	150353YS74500	0.7	3 @350mA	2.1	-40	125	-40	125	1 (120°C)
595	type 3	LY H9GPP-HZJZ-46-1	1	2.6@350mA	2.6	-40	125	-40	125	1 (120°C)
595	type 4	XPEBPA-L1-R250-00B01	1	3.5 @350mA	3.28	---	150	---	150	1 (120°C)
730	type 1	GF CS8PM2.24	1	2.30 @350mA	2.3	-40	120	-40	120	2 (85°C)
850	type 1	SFH 4717AS A01	1.5	3.3 @1000mA	5.325	-40	125	-40	125	1 (120°C)
850	type 2	15435385A9042	1.5	3.6 @1000mA	5.8	-40	85	-40	85	2 (85°C)
940	type 1	SMBB940D-1100-02	1	1.8 @350mA	2	-40	100	-40	100	2 (85°C)
940	type 2	997-L1I0-094009000	1	3.4 @1000mA	3.4	-40	125	-40	125	1 (120°C)
970	type 1	SMBB970D-1100-02	1	2.5 @1000mA	2.5	-40	100	-40	100	2 (85°C)
970	type 2	EOL-970-195	0.05	1.45 @50mA	0.0725	-40	85	-40	85	2 (85°C)
white	type 1	LUW CVBP.CE-5L8L-GMKM-8E8G-350-R18-Z	1	3.25 @500mA	3.5	-40	125	-40	125	1 (120°C)
White	type 2	LXZ1-4070	1	3.50 @350mA	1.395	-40	135	-40	135	1 (120°C)

ALTER

• Task 3: Performance and reliability testing

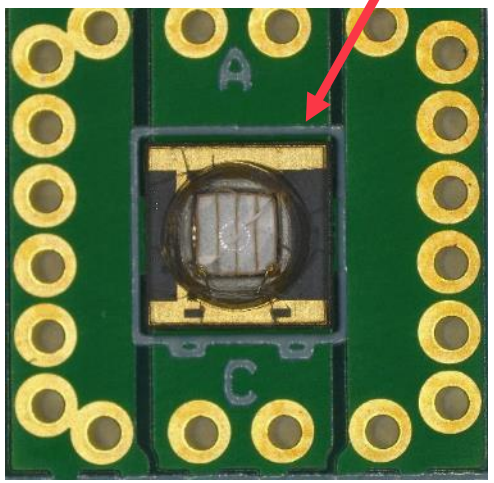
Thermal Cycles



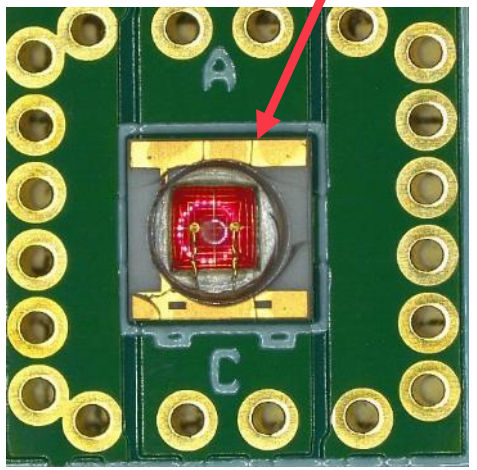
Issues observed after 200 cycles
EVI -> Characterization

Still functional:
Continues cycles

Open-circuit



451 type 1



595 type 2

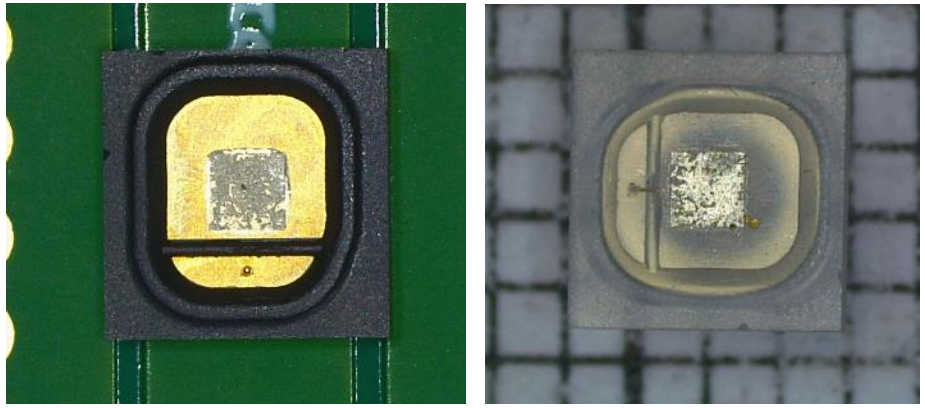
ALTER

• Task 3: Performance and reliability testing

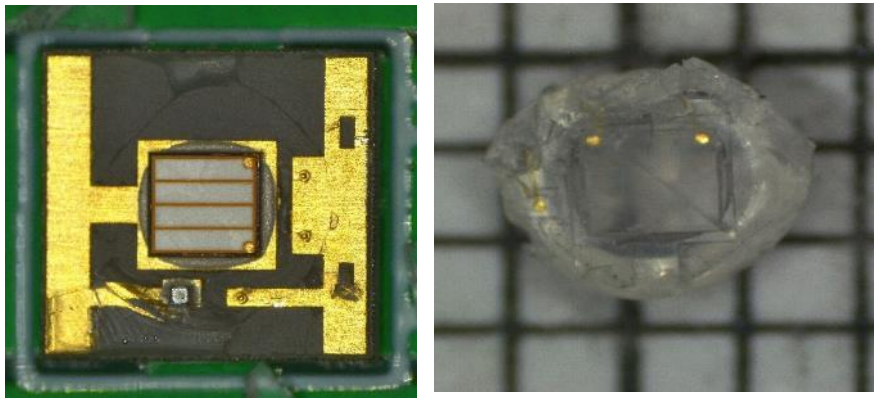
Thermal Cycles

Failures summary:
Many open-circuits
12 out of 12 Silicone Domed types failed

Thermal Cycling detailed summary			Cycles Run	Completed Cycles	Failure Description	Failure Analysis
WL	Type					
270	1	4.1	2	500		
270	2	-1.0	2	500		
365	2	-100	2	200	5 rejects (Open circuit) after 200 cycles	Dome lifted with wires. Die attach OK (SN47)
451	1	-100	1	500	All the samples have passed 200 cycles. 5 rejects at 500 cycles (Open circuit).	Dome lifted with wires. Die attach OK (SN45)
451	2	-100	2	500	5 Rejects (Open-circuit) after 200 cycles	Dome lifted with wires. Die attach OK (SN45)
595	1	-100	1	500	Delamination but functional after 200 cycles. 4 Rejects after 500 cycles (Open circuit).	Dome lifted with wires. Die attach OK (SN49)
595	2	-100	1	200	5 Rejects (Open circuit) after 200 cycles. EVI: Delamination	Dome lifted with wires. Die attach OK (SN49)
595	3	-1.6	1	500		
595	4	-100	1	500	4 Rejects (Open circuit) after 500 cycles	Dome lifted. Die attach OK. Wires partially contacting inside dome (SN49)
730	1	-100	2	200	5 Rejects (Open circuit) after 200 cycles	Dome lifted with wires. Die attach OK (SN49)
850	1	-100	1	200	5 Rejects (Open circuit) after 200 cycles EVI: delamination	Dome lifted with die. (SN48)
850	2	-100	2	200	5 Rejects (Open circuit) after 200 cycles EVI: delamination	Not found
940	1	-100	2	500	4 Rejects (Open circuit) after 500 cycles	Dome lifted with wires. Die attach OK (SN48)
940	2	-100	1	200	5 Rejects (Open circuit) after 200 cycles. EVI: delamination and cracks in the dome	Dome lifted with wires. Die attach OK (SN49)
970	1	-1.6	2	500	1 Reject (Open circuit) after 500 cycles.	
970	2	3.1	2	500		
White	1	-100	1	500	5 Rejects: 4 Open-circuit. 1 blinking sample	Dome lifted with wires. Die attach OK (SN45)
White	2	-1.5	1	500		



850 nm type 1 SN 48



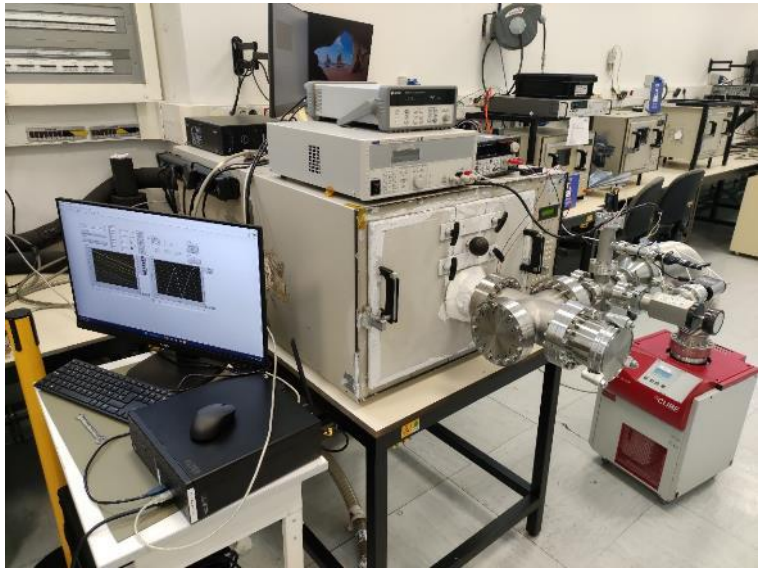
365 nm type 2 SN 47

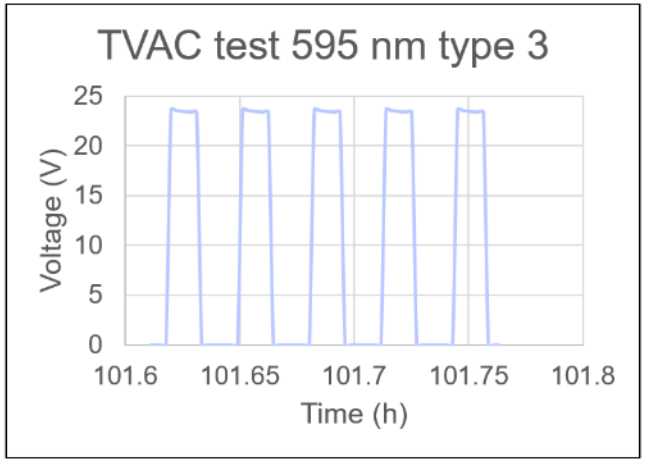
ALTER

• Task 3: Performance and reliability testing

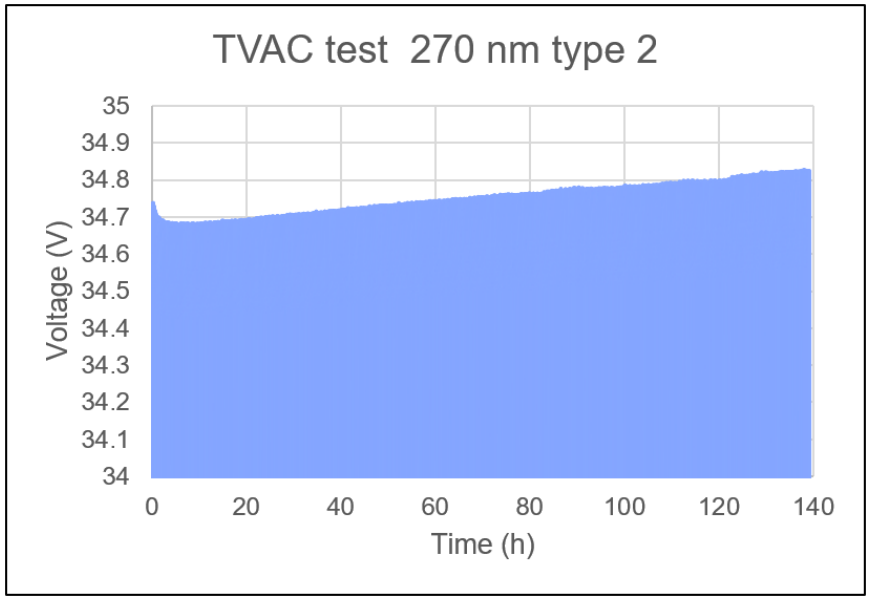
Cryogenic Vacuum Intermittent Testing

Test setup: Nominal bias 5000 ON/OFF cycles
@-110deC @p<1E-5mbar ~5 days per type





Slight drift observed in some of the types
(0.2V onto 10 samples in series)



270 nm type 1: failed, with all samples showing performance below 10%.
270 nm type 2: 3 samples failed (below 10% Op power), while 7 passed.
595-3 passed (1 drifted sample) and 970-2 passed the test

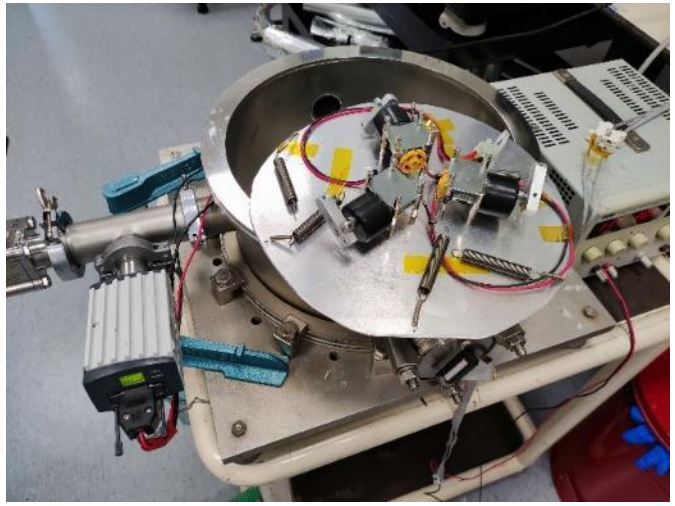
ALTER

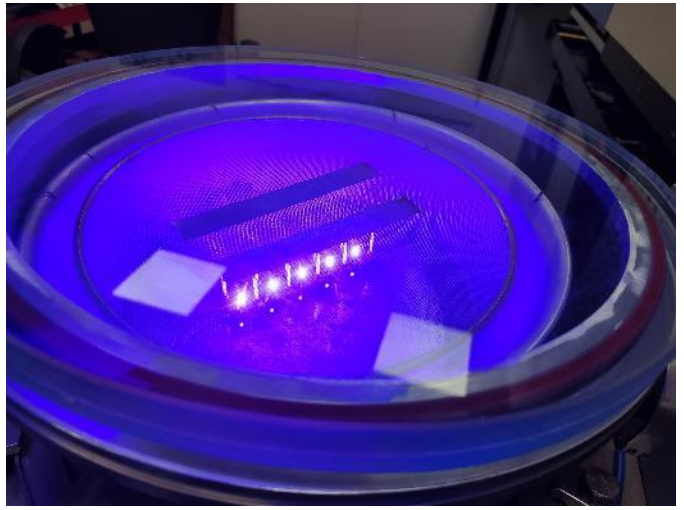
• Task 3: Performance and reliability testing

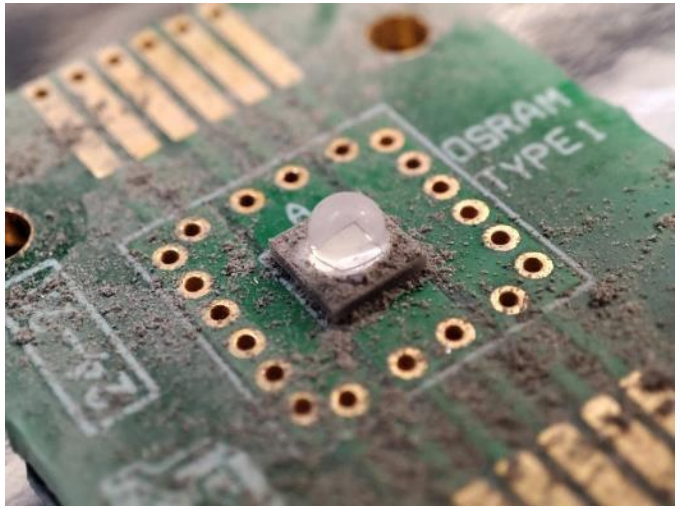
Regolith Test

EAC-1A Regolith Simulant provided by ESA SACF (Sample Analogue Curation Facility)

Test logic agreed with ESA: E/O char -> Mass measurement -> Mounting –> bias check –> regolith preparation –> vacuum -> bias (operation) –> **1min regolith test** -> final checks



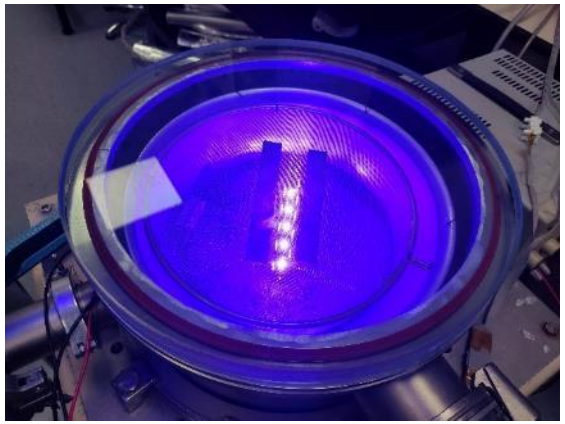




ALTER

• Task 3: Performance and reliability testing

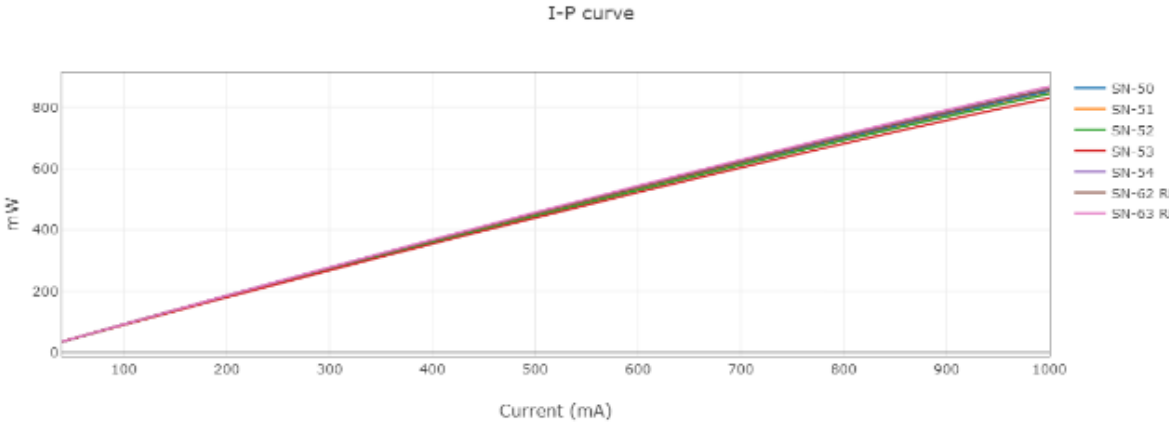
Regolith Test



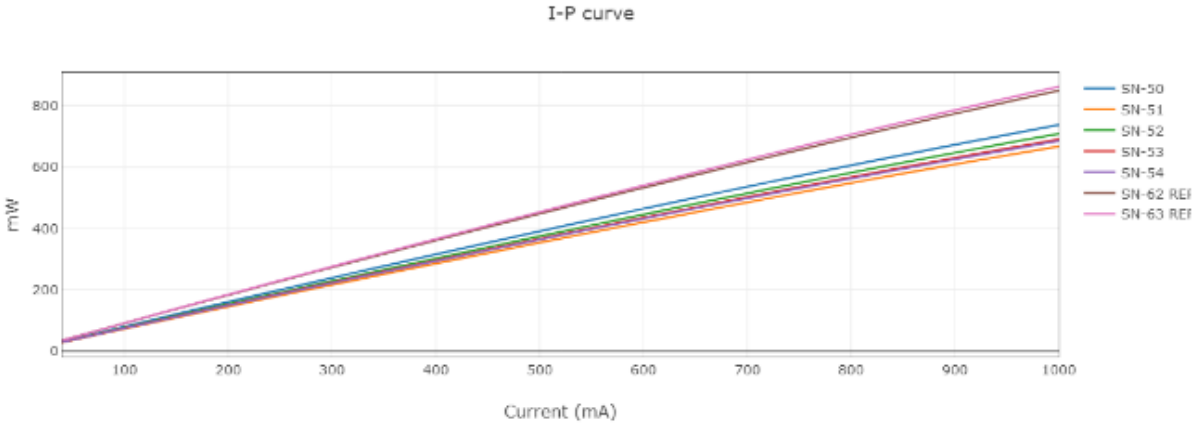
Parameters recorded during regolith test and test logic (E/O char not included)

Wavelength/ type	SN	Initial mass [g]	Vacuum level (stable) [mbar]	start voltage [V]	1st V-fwd (5minutes stabilization) [V]	V-fwd after the test [V]	V-fwd after 5 minutes [V]	Final mass [g]	Deposited mass [mg]	AVG Deposited mass [mg]	Vacuum leve (after measur [mbar]
451-1	50	1.6945	0.8	14.91	14.588	14.54	14.494	1.6964	1.9	2.58	3.4
	51	1.6858						1.6886	2.8		
	52	1.6804						1.6837	3.3		
	53	1.6745						1.6767	2.2		
	54	1.6749						1.6776	2.7		
451-2	50	1.6413	0.8	15.41	14.93	14.85	14.799	1.646	4.7	5.84	1.9
	51	1.6462						1.6542	8		
	52	1.6453						1.6529	7.6		
	53	1.6339						1.6394	5.5		
	54	1.6308						1.6342	3.4		
	50	1.698						1.7011	3.1		

730nm type 1 Initial



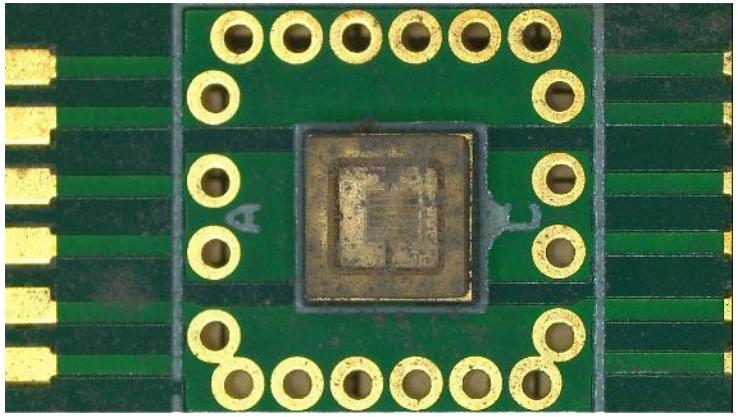
730nm type 1 after regolith



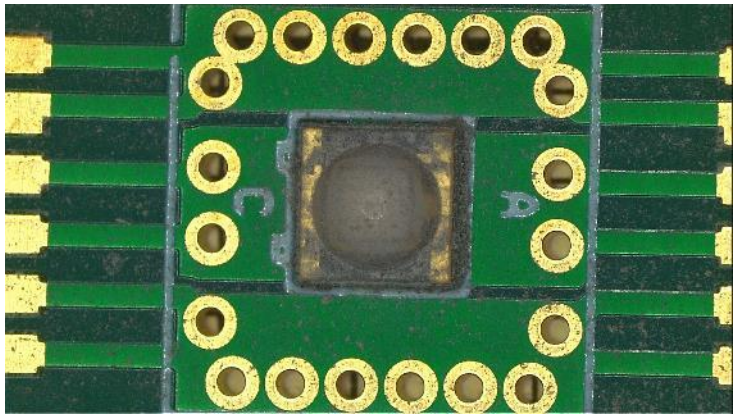
ALTER

• Task 3: Performance and reliability testing

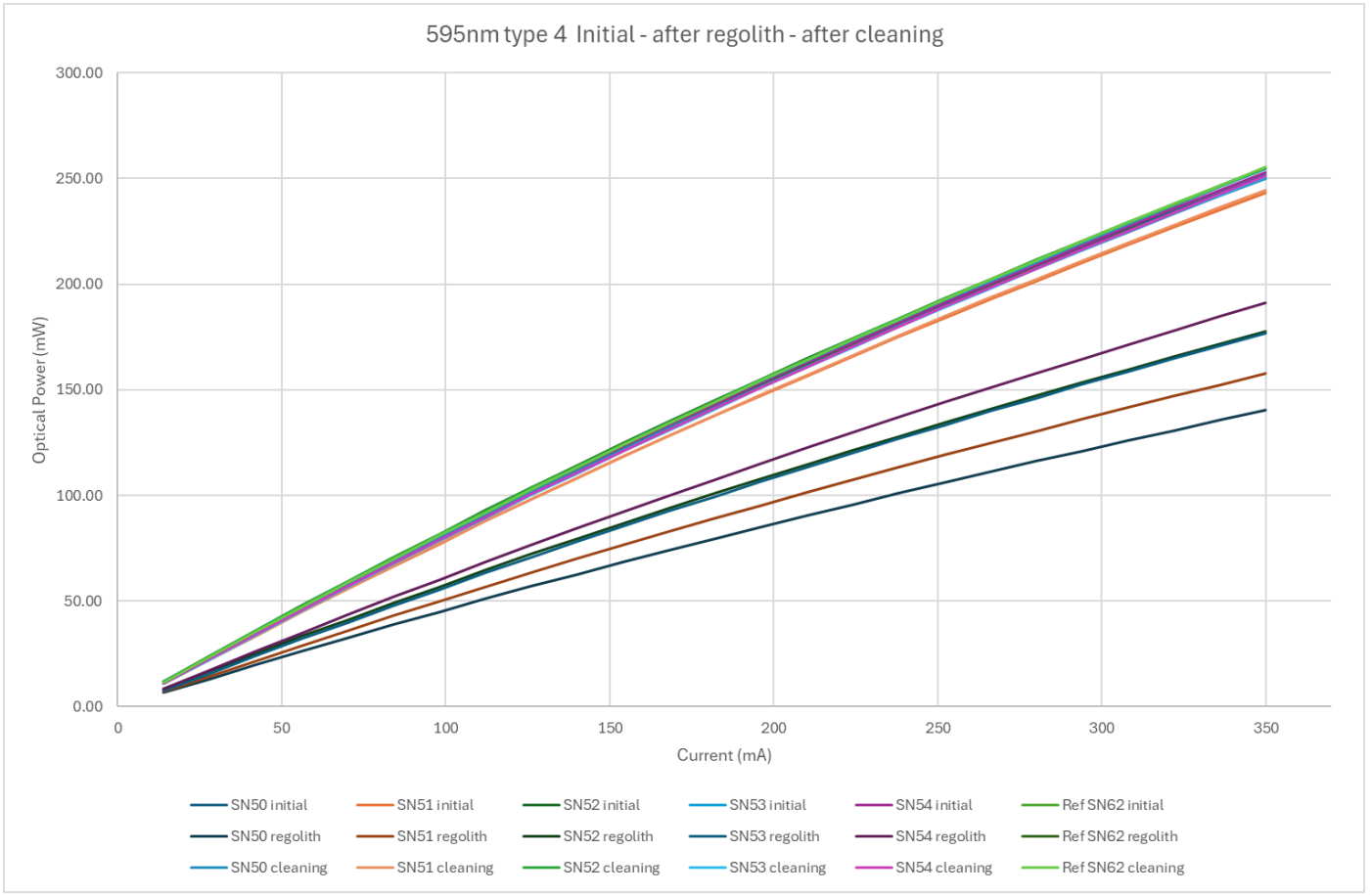
Regolith Test



270 type 1



365 type 2



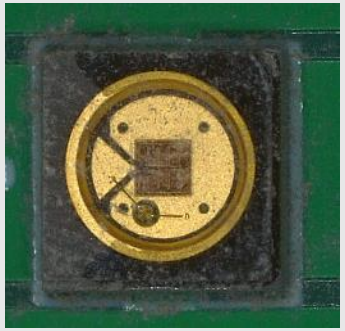
IPA cleaning + dry air blowing recovers optical power

ALTER

• Task 3: Performance and reliability testing

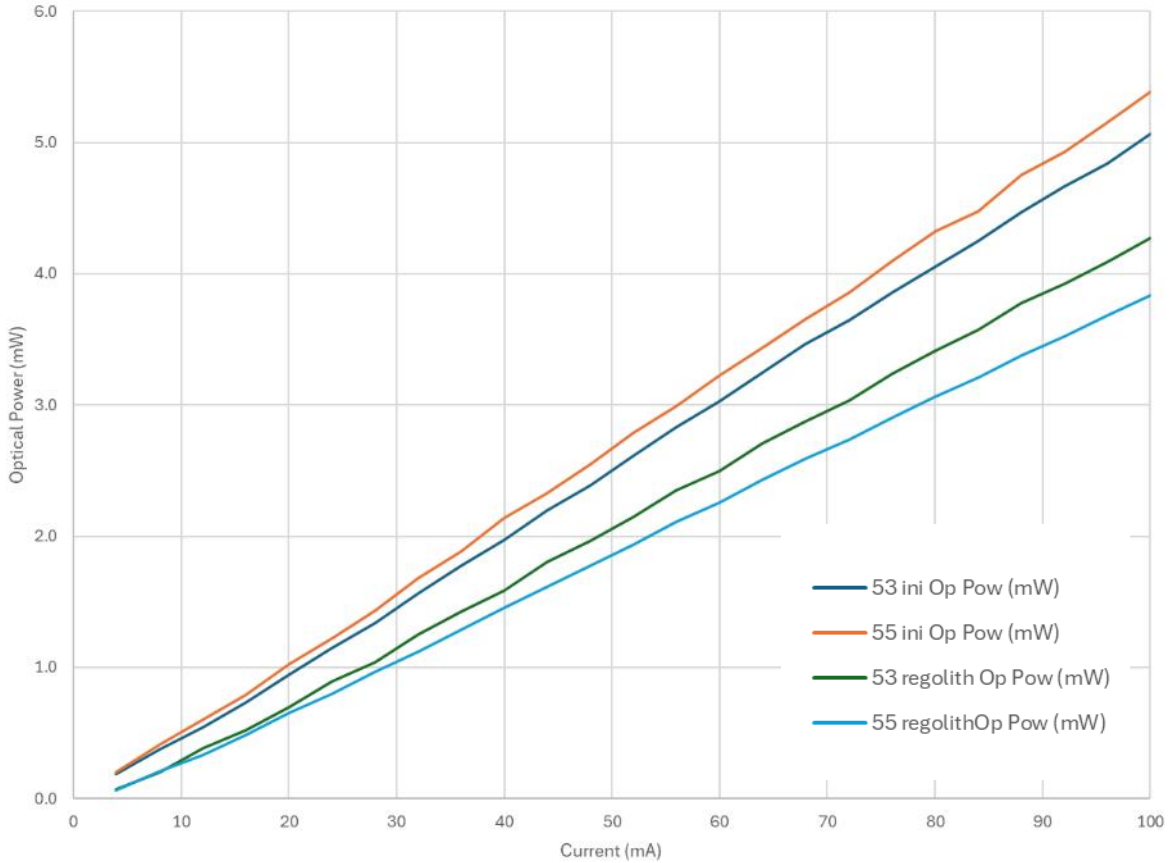
Regolith Test

Example of Test Results dispersion due to regolith deposition homogeneity

270nm type 2	SN53	SN55
Power Reduction (%)	-15.60	-28.8
Deposited mass (mg)	2.6	5.1
		

Significant dispersion in deposited quantity

270nm type 2 samples comparison



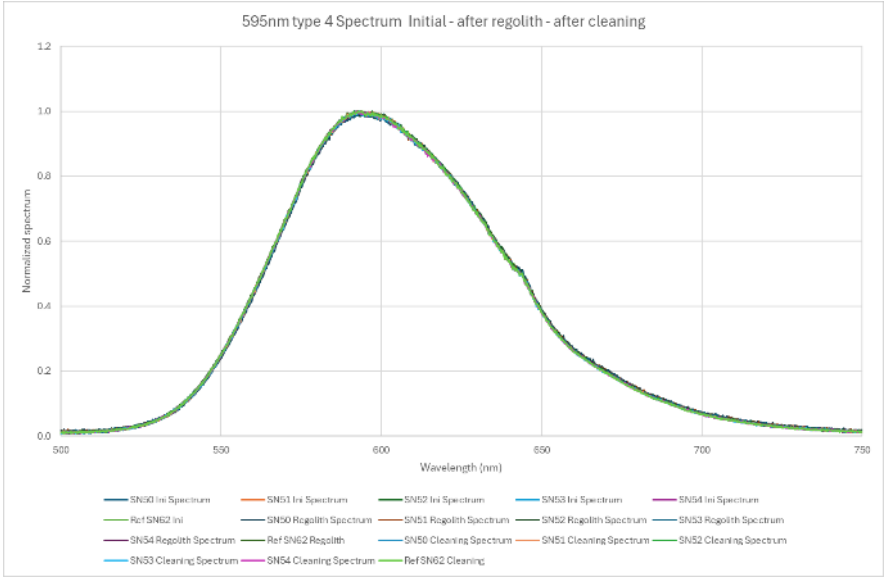
ALTER

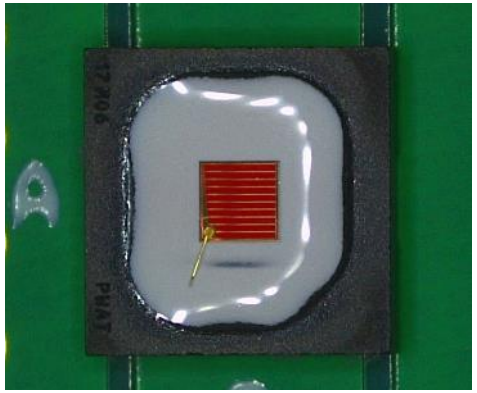
• Task 3: Performance and reliability testing

Regolith Test

Conclusions of regolith test with EAC-1A simulant, affected to optical power:

- Optical power is recovered after cleaning.
- Devices were stable in low pressure operation (1mbar approx.) during 5 mins.
- Devices were stable in low pressure operation (1mbar approx.) during 5 mins with regolith deposited (Vfwd).
- No changes could be observed in spectrum.
- No corrosion or permanent damage.
- **Homogeneity of the deposition to be improved.**
- **Other regolith simulant types should be used.**





595nm type 3 after cleaning

• Task 4: Failure modes and conclusions

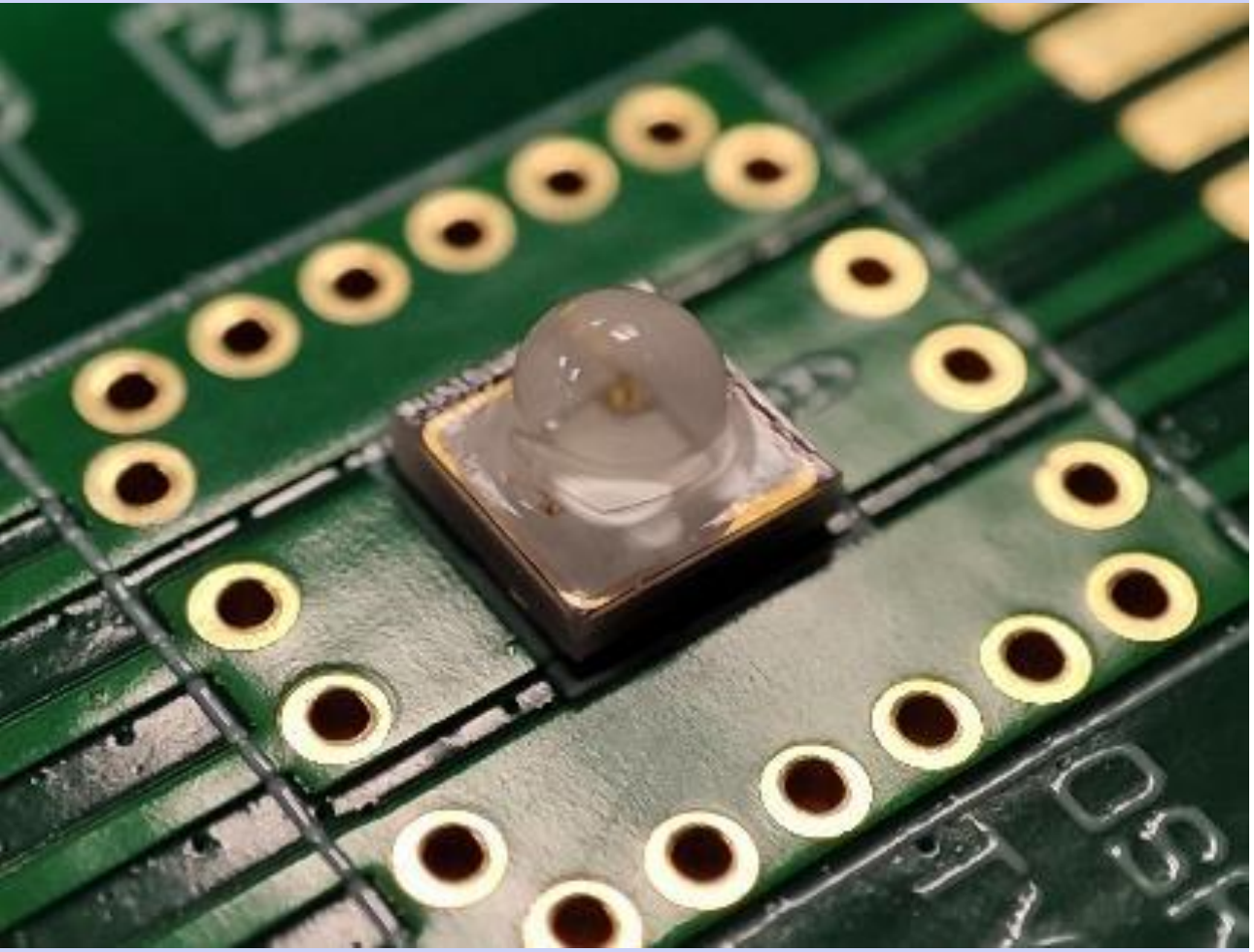
FAILURE SUMMARY	FAILURE SUMMARY		INITIAL	HUMIDITY	MECH	RAD TID (unbiased)	RAD TID (biased)	RAD TNID	CRIOVAC	LOW TEMP STORAGE	TEMP CYCLES	ESD	Regolith	CA
	Samples		63	5	5	2	3	9	10	5	5	5	5	5
RL	Wavelength	Type												
2022901053	270	1	62	5	5	2		9	0	5	5	5	5	3
2022901276	270	2	61	5	5	2		9	7	5	5		5	5
2022901181	365	1	55											5
2022901048	365	2	63	5	5	2		9		5	0		5	5
2022900178	451	1	63	5	5	2	3	9		5	0		5	3
2022901388	451	2	63	5	5	2	3	9		5	0		5	3
2022900390	595	1	63	0	5	2		9		5	1		5	5
2022901175	595	2	63	5	5	2	3	9		5	0		5	5
2022901044	595	3	63	0	5	2	3	9	9	5	5		5	0
2022901046	595	4	63	5	5	2	3	9		4	1		5	5
2022900394	730	1	63	5	5	2	3	9		5	0		5	3
2022901174	730	2	61											5
2022900395	850	1	63	5	5	2		9		4	0		5	3
2022901170	850	2	63	4	5	2	3	9		5	0		5	5
2022900806	940	1	63	5	5	2	3	9		5	1		5	5
2022901050	940	2	63	5	5	2		9		5	0		5	5
2022900807	970	1	63	5	5	2	3	9		5	4		5	5
2022901707	970	2	63	4	5	2	3	9	10	5	5		5	3
2022901047	White	1	63	5	5	2	3	9		5	0		5	5
2022901045	White	2	61	5	5	2	3	9	0	5	4		5	5

Temperature cycles are critical for Silicone Dome LEDs (Glob Top).

Extreme test conditions were applied.

Further test in real mission thermal profile + real bias operation could PASS Thermal Cycles

ALTER



Thanks for your attention

And thanks to M. Brondi and H. Brahimi (ESA) for your support in this project:

- 20 types of LEDs procured and tested
- 63pcs each
- 9 Wavelengths (8 + white)
- 15 types of footprints to accommodate all types
- Testing according ECSS-Q-ST-60-13C
- Additional tests like lunar regolith and vacuum cryo testing carried out
- Conclusions on LEDs usage, may be used in slightly less demanding conditions

ALTER