LEONE (>50cm^2) Space Solar Cells: Qualification, Production, Cost Reduction

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ABSTRACT

Spectrolab initiated qualification of the "LEONE" (>50cm^2) UTJ solar cell with a goal of reducing cost, add-on mass, and cycle time for panel deliveries. In flight production since 2007, the UTJ LEONE design has now completed qualification to 15,549 GEO and 66,060 LEO coupon thermal cycles; ESD characterization testing at both CIC and coupon levels is also complete. The UTJ LEONE cell design (59.65cm^2) is being implemented on 3 large current production programs. LEONE has been delivered on 25 flight shipsets with a total of 27,000 cells on 150 panels for a LEO constellation.
The purpose of this paper is to provide an update on recent LEONE UTJ coupon qualification data, and to provide a relative comparison of production data for panels using the LEONE cell versus those using a heritage 26.62cm^2 solar cell design; these results will be compared to the LEONE product introduction goals. This paper will also provide an overview of LEONE XTJ qualification coupons currently in either production or test, with preliminary data where available. Finally, this paper will highlight how the LEONE product fits into Spectrolab's product configuration roadmap.

INTRODUCTION

Spectrolab has enjoyed over 50 years of experience in the solar cell industry with 15 years of multi-junction production heritage as a leader in the industry, with improvements in both the average efficiencies and the process control with each new generation.

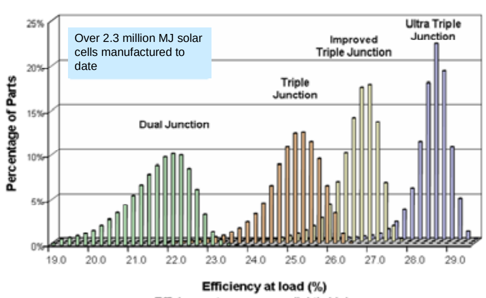

Figure 1. Spectrolab multi-junction history. Over 2.3M cells produced; over 200kW launched in 2009.

The LEONE product capitalizes on these improvements in performance and production uniformity to provide cost, mass, and cycle time savings versus panels of the same size populated with standard product. The product introduction goals for the UTJ LEONE product relative to the standard UTJ 26.62cm^2 product are depicted in Figure 2.

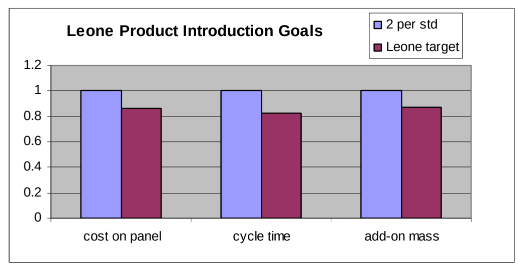

Figure 2. LEONE product introduction goals

The targets shown in Figure 2 were based on a typical large panel size, where the cost savings on panel are maximized by reduction in piece part handling, whereas the savings are more modest on a smaller panel or at a CIC or bare cell level. This is depicted pictorially in Figure 3.

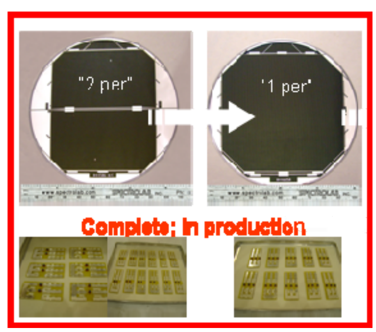

Figure 3. Spectrolab Piece Part Reduction Strategy

Although the panel packing factor is typically somewhat higher (~ 89%) for Spectrolab's standard solar cells than for the LEONE product (~ 84%), the potential benefits of the LEONE solution can be maximized when customers engage with Spectrolab on design trades for substrate size and keep-out optimization. This will become evident in the section below on LEONE production heritage.

The performance specification for the LEONE UTJ product in comparison to the standard UTJ cells with area less than or equal to 32.3cm^2 is shown in Table 1.

Table 1. Performance Specification for LEONE UTJ cell versus standard UTJ cells <32.3cm^2

Parameter	UTJ ≤ 32.3cm^2 product specification	UTJ LEONE product specification
Jsc[mA/cm2]	17.05	17.05
Voc [V]	2.660	2.660
Vload2	2.310	2.270
Jload@2.31V, 2.27V [mA/cm2]	16.40	16.40
Jmp [mA/cm2]	16.30	16.30
Vmp [V]	2.350	2.300
Eff @Pmp [%]	28.30%	27.62%
Eff@2.31V [%]	28.00%	27.52%
FF	0.85	0.83

QUALIFICATION HERITAGE

Table 2 summarizes all of the qualification tests performed on the UTJ LEONE product [1,2]. A picture of the LEONE CIC is shown in Figure 4.

Table 2. LEONE Qualification Summary

TEST	TEST ARTICLE	QUANTITIES	STATUS
Contact Integrity-Tape Peel	IC	1 wing per wafer	PASS
Contact Integrity-Weldability	Bare/CIC	8 wings or CICs per lot	PASS
LIV	Bare/CIC	100%	COMPLETE
Bow	Bare/CIC	10 bare and 10 CICs (1 pers)	COMPLETE
Bend	CIC	10 CICs (1 pers)	PASS
Instron	Bare/CIC	10 bare and 10 CICs (1 pers)	COMPLETE
CIC Thermal Cycle (2000 cycles, -180C to +161C)	CIC	10 CICs (1 pers)	PASS
GEO Coupon Thermal Cycle (7 tvac + 15549 thermal cycles; worst case temps -177C to +140C)	CICs on Coupons	150 1pers and 150 2 pers	PASS
LEO Coupon Thermal Cycle (10 tvac + 66060 thermal cycles, worst case temps -130C to +125C)	CICs on Coupons	72 1 pers and 36 2 pers	PASS

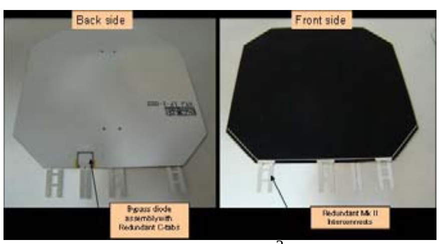

Figure 4. LEONE 59.65cm^2 CIC configuration

Table 3 summarizes the test conditions for both the GEO and LEO thermal cycle coupons. Both tests consisted of 2 coupons populated with LEONE cells and included representative backside components.

Table 3. Summary of LEONE coupon test conditions

	cell size	cell count per coupon	# vac cycles	max temp range (°C)	# ambient cycles	max temp range (°C)	continuity monitoring
2 GEO coupons	53.3cm^2	75	7	-177 to +150	15,549	-167 to +140	up to 2A through diode
2 LEO coupons	59.65cm^2	36	10	-130 to +125	66,060	-130 to +125	alternating through cell and diode, ~ 10% Isc

Testing during the breaks included visual inspections, bypass diode function, insulation resistance, continuity, forward bias imaging, and LIV (LAPSS).

In both cases, the coupons met performance requirements within specification after completion of the thermal cycle test. These results are shown in figures 5 and 6. Photos of one of the coupons tested in each environment are shown in Figures 7 and 8. The other coupon tested in each environment is similar to the one shown.

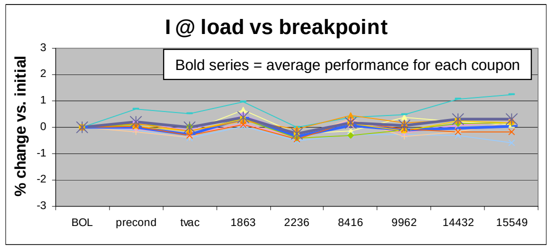

Figure 5. GEO coupon electrical performance

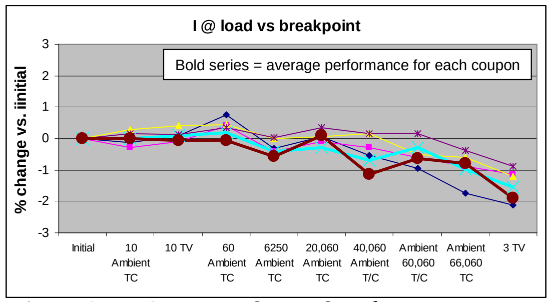

Figure 6. LEO coupon electrical performance

Figure 7. GEO coupon

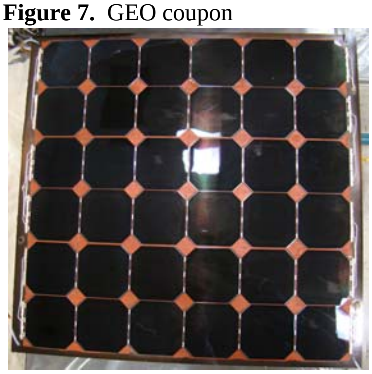

Figure 8. LEO coupon

LEONE UTJ CICs have also completed ESD characterization at both CIC and coupon levels [3-6], as summarized in Table 4. The coupon tested at Boeing El

Segundo had previously seen over 15,000 thermal cycles, and was thus representative of EOL condition of the hardware, whereas the coupons tested at ONERA were fabricated specifically for this test with simulated defects in the grouting between CICs. In all cases, the coverglass was CMG/AR. No sustained arcs were observed in any of the tests. Temporary sustained arcs of 32ms total duration were observed on one coupon at 130V and an overstress of 3.5A; these caused a loss of coupon power on one of the ONERA coupons. No power loss was observed on the EOL condition coupon tested at Boeing.

Table 4. Summary of UTJ LEONE ESD test results.

	Test Configuration							
#	Test Type	Excitation	Location	Coupon Cell Count	IC Config.	Test Objective	Available Current	Gap Config.
1	Inverted Gradient	Electron Guns	Boeing	40 (5 CICs x 8)	Exposed	Flight Qualification	Isc	Some Defects
2	Normal Gradient	Electron Guns	Boeing	40 (5 CICs x 8)	Exposed	Flight Qualification	Isc	Some Defects
3	Inverted Gradient	Plasma	ONERA	2, 3 Coupons	Covered	Gap Defect Effects	Isc	Created Defects
4	Inverted Gradient	Plasma	ONERA	2, One Coupon	Exposed	Gap Defect Effects	Isc x 4 (4.5 A)	Created Defects
5	Overstress Current	Plasma	ONERA	2, One Coupon	Covered	Gap Defect Effects	Isc x 3 (3.5 A)	Created Defects
6	CIC Current Injection	Electronics	Boeing	1, 27 CICs	NA	Flight Qualification	Isc	NA
	Results							
	Test Type	Gap Test Voltage Range	Electrical Test Type	Avg Pmp Change 28C	Avg Pmp Change 80C	IC Config.	Primary Arc Locations	Results Summary
1	Normal Gradient	55 to 110	LAPSS	not measured		Exposed	Interconnects	Passed
2	Inverted Gradient	55 to110	LAPSS	0.9% Gain	0.4% Loss	Exposed	Interconnects	Passed
3	Inverted Gradient	130 to 300	LAPSS	2.1% Loss	1.9% Loss	Covered*	Gaps	OK at 1.1 x Isc
4	Inverted Gradient	130	LAPSS	2.5% Gain	2.5% Loss	Exposed	Interconnects	OK at 3.5 x Isc
5	Overstress Current	130	LAPSS	Shunted	Shunted	Covered*	Gaps	Failed at 3.5 A
6	CIC Current Injection	NA	X-25	0.2% Loss	NA	NA	N/A	No Change >3%

Figure 9 shows a photo of the EOL condition coupon in the ESD test chamber at Boeing. The inverted gradient test results were similar to the results for the ONERA testing, with no secondary arcs observed, and with no arcs in the gaps between columns of cells. ESD originated from the interconnects and from the edge of the panel. The test voltages between strings were set to either 55 or 105 V, with a current limit of 1 A. The gradient was 3.5kV.

For the normal gradient test, the test voltages between strings were again set to either 55 or 110 V, with a current limit of 1 A. The gradient was greater than 8 kV. Again, the majority of the ESD originated at the interconnects, with some ESD locations observed in the cell column gaps. No sustained arcs occurred.

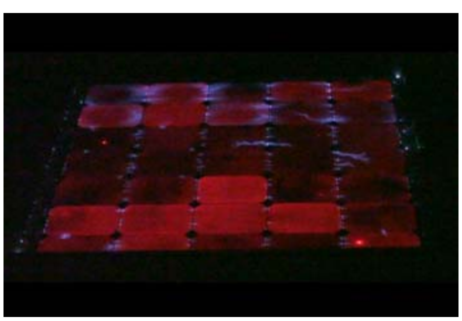

Figure 9. EOL condition coupon in Boeing ESD Chamber with ESDs originating at interconnects

The data confirms that the Leone product is robust to ESD and that Spectrolab's standard design with exposed interconnects and grouting in between the cells mitigates against ESD arcing.

Panel level Acoustic and Vibration testing has been successfully completed for a LEO program.

Concurrent with completion of the XTJ device qualification to AIAA-S-111, Spectrolab has initiated qualification of the LEONE product for the XTJ cell. The LEONE XTJ product has already completed 7 thermal vacuum cycles and 2200 ambient pressure thermal cycles at an engineering confidence coupon level, see Figure 10. Results of the XTJ device qualification in accordance with AIAA-S-111-2005 will be presented elsewhere. [7] Table 5 summarizes the XTJ LEONE qualification coupons that are currently in work or planned in support of various programs.

Table 5. XTJ LEONE Coupons.

Test Article	*# of cells*	*Test Plan Summary*	*Summary*
Engr Confidence	35	7 Tvac (+150 C to -172 C) 2,200 GEO Cycles: 2,000 cycles (+140 C to -170 C) 100 cycles (+150 C to -170 C) 100 cycles (+160 C to -170 C)	Passed
LEO Qual	36	13 Tvac (+125 C to -130C) 27,400 LEO Cycles (+125 C to -130C)	Passed Tvac Thermal Cycling in progress
GEO/LEO Combined	22	2,070 GEO Cycles (+90 C to -172 C) TBD LEO Cycles Vibration	In Production
LEO Flex Coupons	12 24	Vibration 15,000 Thermal Cycles (+100C to -100C)	In Production

Preliminary results for the XTJ LEONE Engineering confidence coupon – CKT 2 had a cracked cell that was intentionally left on the coupon for data analysis purposes

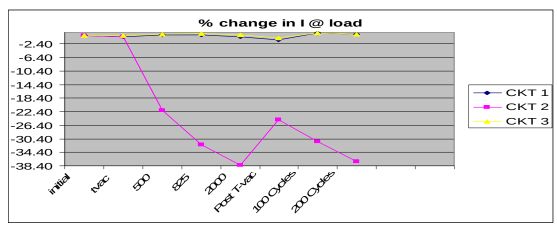

Figure 10. Preliminary test results for XTJ LEONE Confidence Coupon

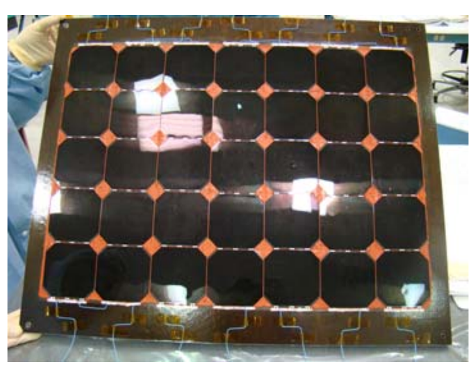

Figure 11. XTJ LEONE Engineering Confidence Coupon

PRODUCTION HERITAGE

The performance histogram for over 32,000 UTJ LEONE production cells is shown in figure 11.

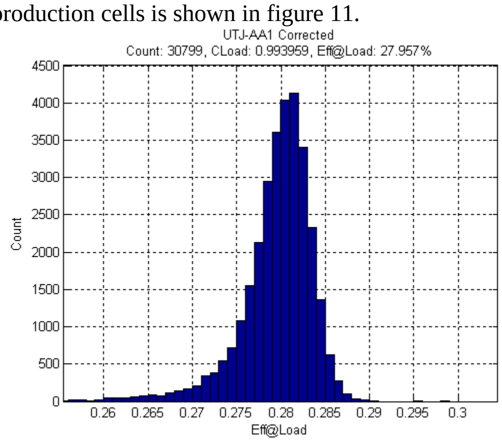

Figure 11. Production histogram for over 32,000 UTJ LEONE cells, average I @ load 1004mA against spec of 978mA @ 2.27V (1.65% over specification).

Spectrolab currently has 3 large production programs in house that have adopted the LEONE cell as their baseline. The number of cells on panel represented by these programs is summarized in Table 6.

Table 6. Current production programs using LEONE

Orbit	cell size	#cells on panel	equiv. # of "standard" size cells
LEO	59.65cm^2	61440 total 27000 delivered	122880
GEO	53.3cm^2	33872	67744
TOTAL		**95312**	**190624**

Due to differences in panel size and mission environment for delivered product on recurring programs using Spectrolab's standard 26.62cm^2 cell and the delivered hardware to date using the 59.65cm^2 LEONE cell, production actuals have been normalized to the available panel area in figure 12 for comparison purposes.

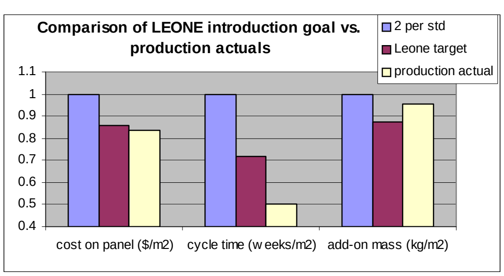

Figure 12. LEONE production actuals versus product introduction goals and standard 26.62cm^2 product

The improvement in cycle time depicted in Figure 12 is mostly due to the reduced piece part handling and reduced wiring, but is also partly due to implementation of a LEAN manufacturing philosophy for the solar panels, and comparison will vary based on requirements. This can be discussed in more detail with individual customers, based on the specifics of the mission requirements and the flexibility allowed in their substrate dimensions and keep-out locations.

SUMMARY

The UTJ LEONE product has successfully completed extensive qualification on both GEO and LEO coupons, as well as ESD characterization, and has been integrated into large volume production. Furthermore, it has been demonstrated in production to offer mass savings vs. heritage designs based on a 26.62cm^2 cell (mass savings scales with panel size and complexity), and has been shown to exceed its product introduction goals for both cost on panel and manufacturing cycle time.

The XTJ LEONE cell is currently in qualification for various programs, based upon the success of both the LEONE UTJ cell configuration and the completion of the XTJ device qualification.

An overview of Spectrolab's product configuration roadmap is depicted in Figure 13.

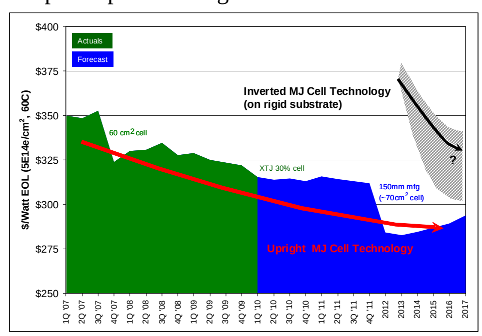

Figure 13. Spectrolab product configuration roadmap

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