Solar Array (Radiated/Non-Radiated): Materials Characterization and Cryogenic Thermal Cycling Qualification for the planned Europa Clipper Mission (ECM)

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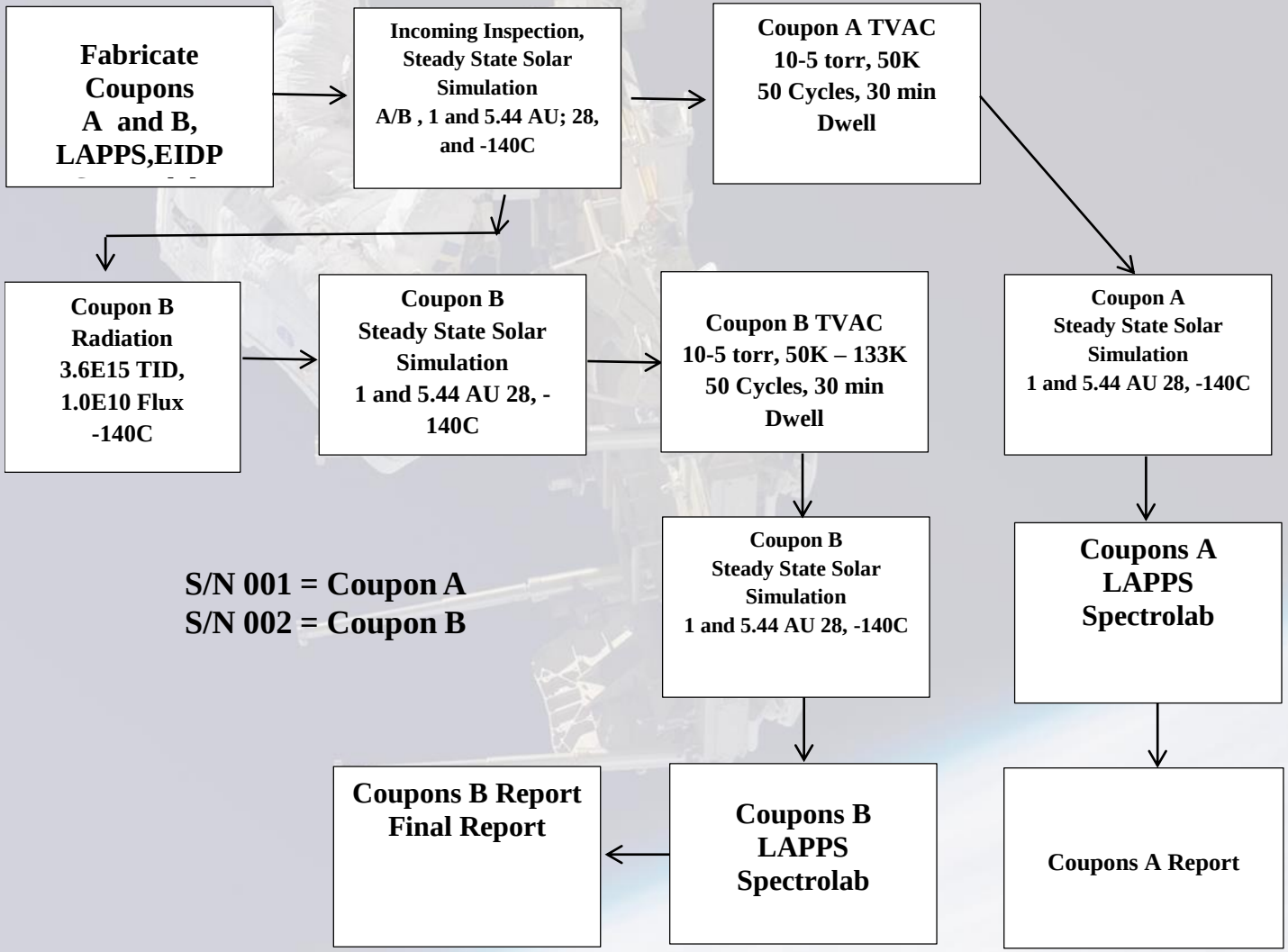
Objectives

- Determine the effects of thermal cycling and radiation exposure on carbon composite flat panel solar arrays (SA)_. Thermal cycles are from ~50 K to ~133 K and the radiation levels are equivalent to the levels that will be achieved at the end of life of the Europa Clipper Mission (ECM).

- Determine the physical properties (CTE and e-modulus) of the SA materials down to 20K temperatures.

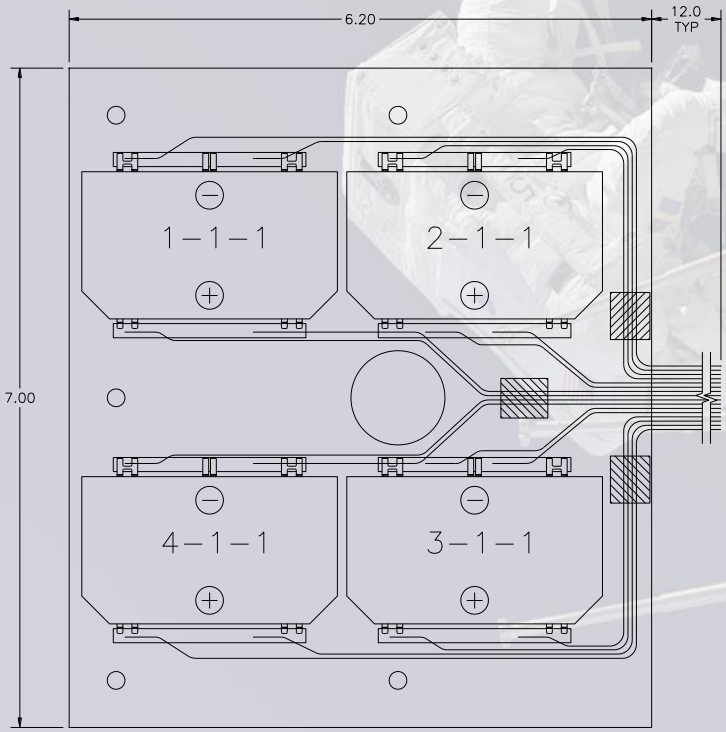
Preliminary Low Temperature Test Flow for Coupons A & B or S/N 001 and 002

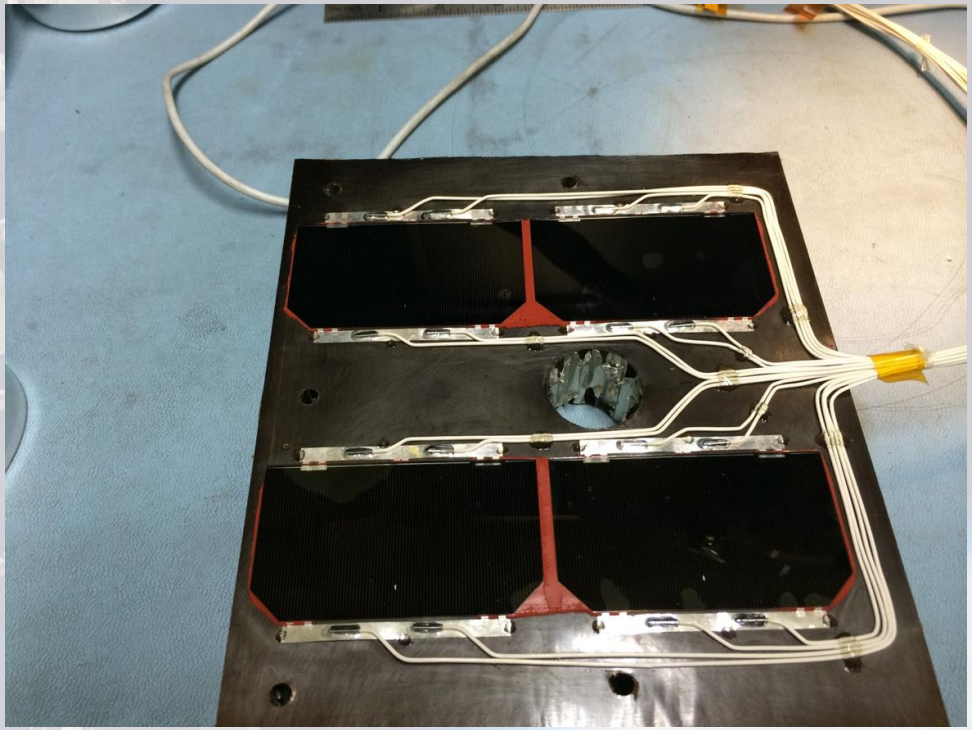


S/N 001 = Coupon A
S/N 002 = Coupon B

Note: *This report consists of Coupon A (S/N 001) and Coupon B (S/N 002)*

Solar Array (S/N 002) Hardware with 4 Solar Cells





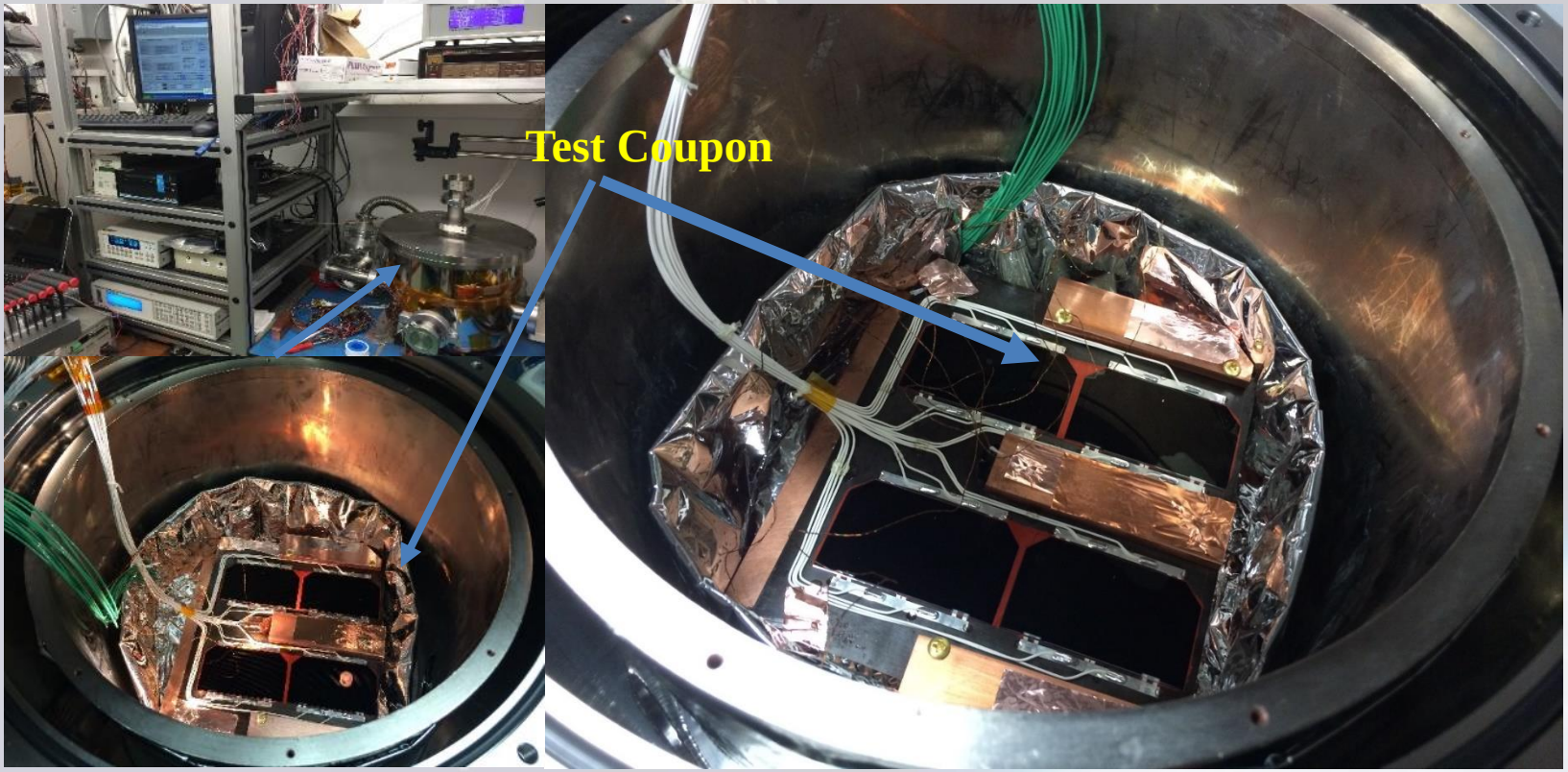
- UTJ CIC, FF≥ 0.77, 12 mil AR/ITO cover
- Juno Panel Material M55J, RS3, FM73, 1” Core

Optical Image of Test Article Prior to Testing (S/N 002)

S/N – 001 Assessment

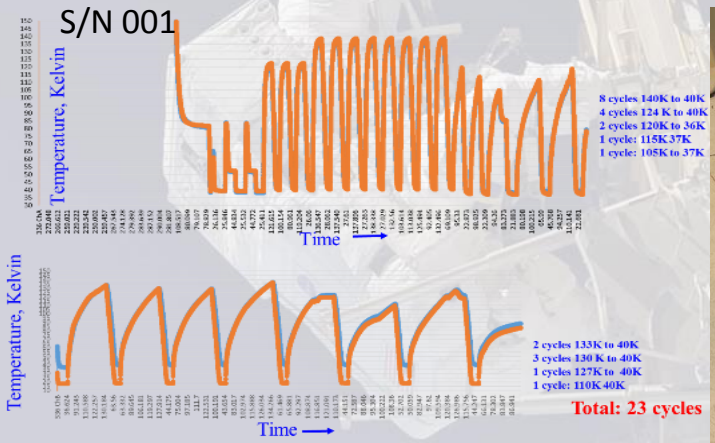
- Pre-inspection of Solar Array S/N 001
- Performed 23 thermal cycles 50 K to 133 K due to technical problems
- Final Inspection after 23 thermal cycles

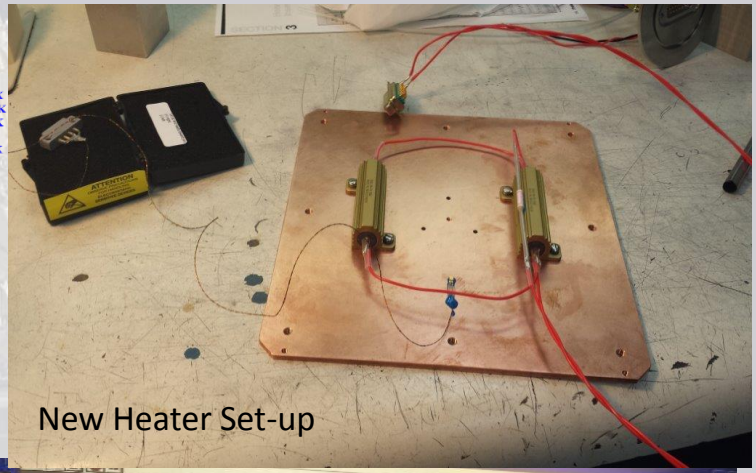
Mounted Solar Cell S/N 001/A

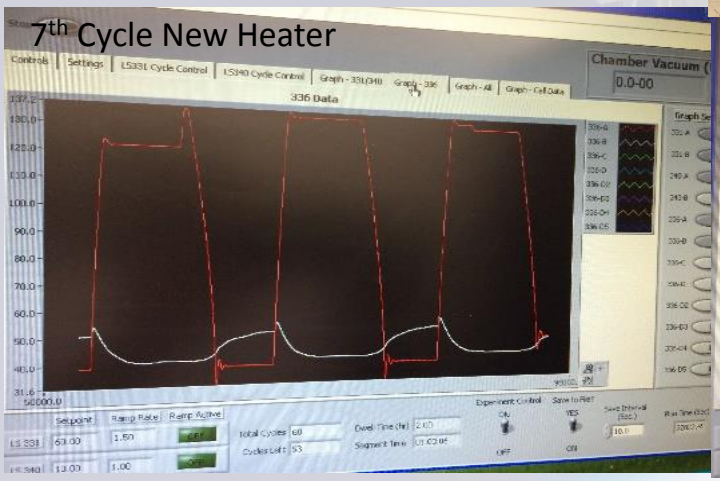


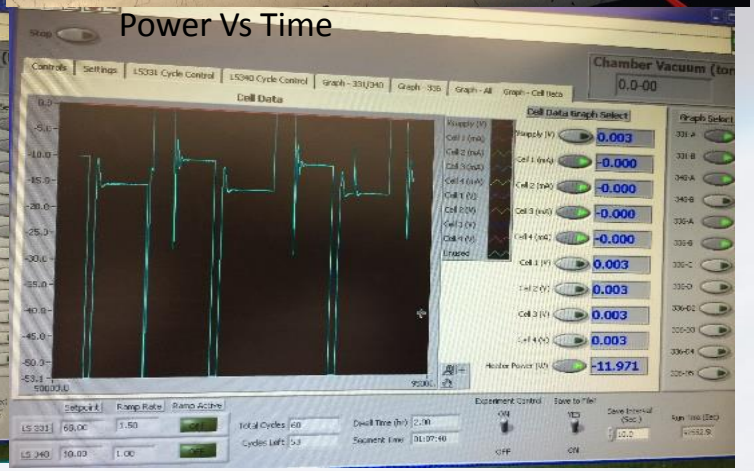
Solar Array coupon has been mounted in a high thermal vacuum chamber

Completed 23 thermal cycles S/N 001 Test Coupon, Thermal Cycling Test Run from 133K to 40K. Dale Ohm Heater Set-Up









S/N 001 SA Test Coupon Summary

- Successfully completed only 23 thermal cycles from ~50 K to ~133 K.
- Started concentrating on mitigating the problems for testing radiated test coupon.
  - Actually, thermal cycling of the radiated test coupon is more important and valuable to the project than the non-radiated test coupon.
- The condition of the SA test coupon was in good condition after 23 thermal cycles.

SA Survival Risk Reduction

Plan for S/N 002

- SA Test Coupon B or S/N 002.
- Radiated SA test coupon, S/N 002 (Coupon B) (in Dynamitron Laboratory of JPL).
- Inspection
- Experimental Radiation details
- Thermal Cycling of SA S/N 002 from ~50 K to ~133 K for 120 Thermal cycles
- Optical Inspection
- Assessment Summary

Radiation Test Parameters

TEST ARTICLE		
QTY	DESCRIPTION	S/N
1	JPL EUROPA COUPON QCHR 14-118	2
TEST SPECIFICATION		
ENERGY	1	MeV
FLUX	4.00E+09	P/CM^2/S
FLUENCE	3.60E+15	P/CM^2
TEMP	-140	° C
VACUUM	<=10E-4	TORR
TEST FACILITY	JPL DYNAMITRON	
SCHEDULE		
REQUIRED BY DATE	6/12/2014	
ESTIMATED TEST TIME	250.00	HRS
RAD START DATE	5/28/2014	
RAD END DATE	6/9/2014	

Fluency of 3.6E+15 P/CM^2, 1MeV electrons at 5.0E+9 P/CM^2/S flux rate in Dynamitron laboratory

Experimental Details

Vacuum

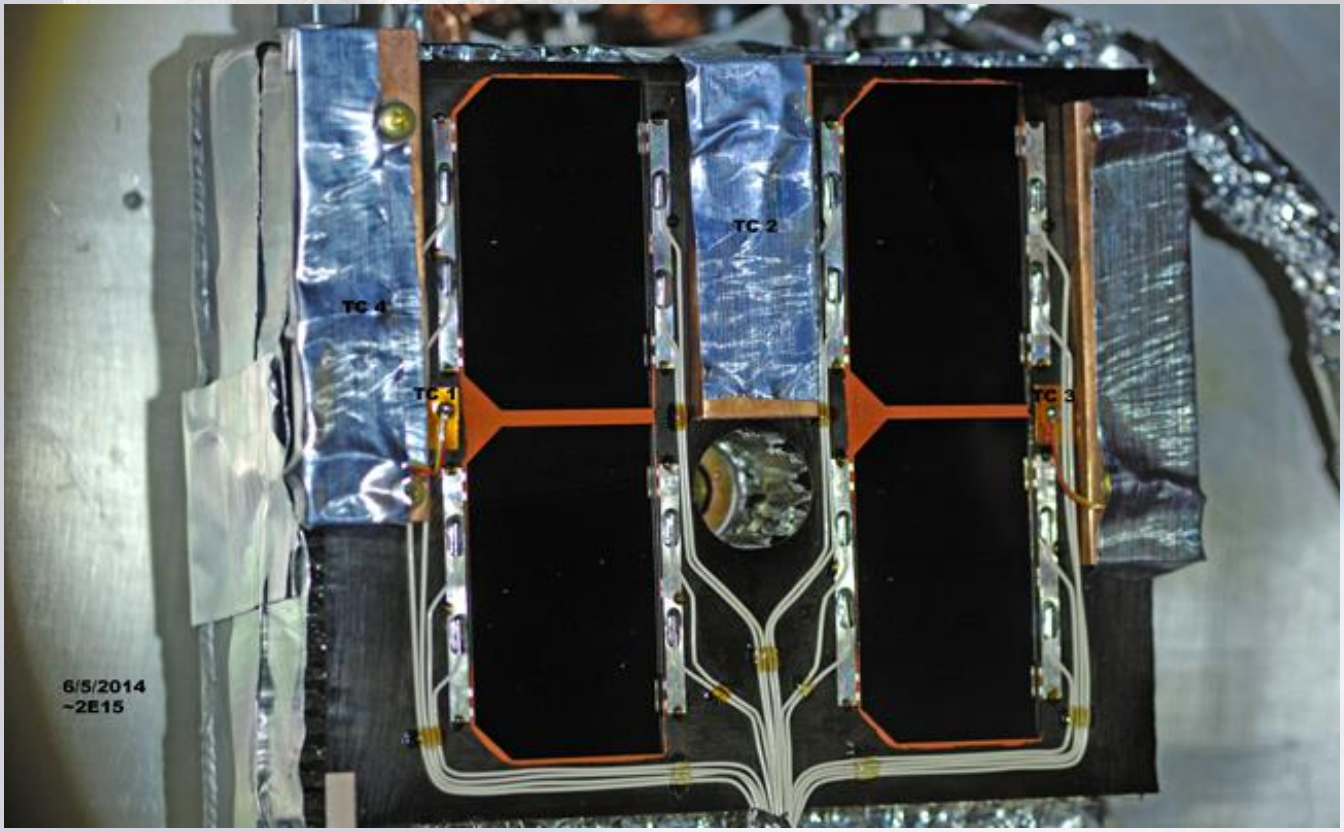
Test articles were maintained under vacuum at low temperature using LN_2 at all times during electron exposure, as well as during sample cool down and warm-up.

Dosimetry

Electron flux was measured at the center of the test article cluster with a Faraday cup of 0.624 cm^2. The flux and accumulated fluence (e/cm^2) were monitored in real time. The dose at the surface of the cells was presumed to be 5% greater than the measured value due to the set back of the Faraday cup.

Test Coupon (S/N 002) at fluence 2e15 e/cm^2

(JPL: Dyamitron Laboratory)



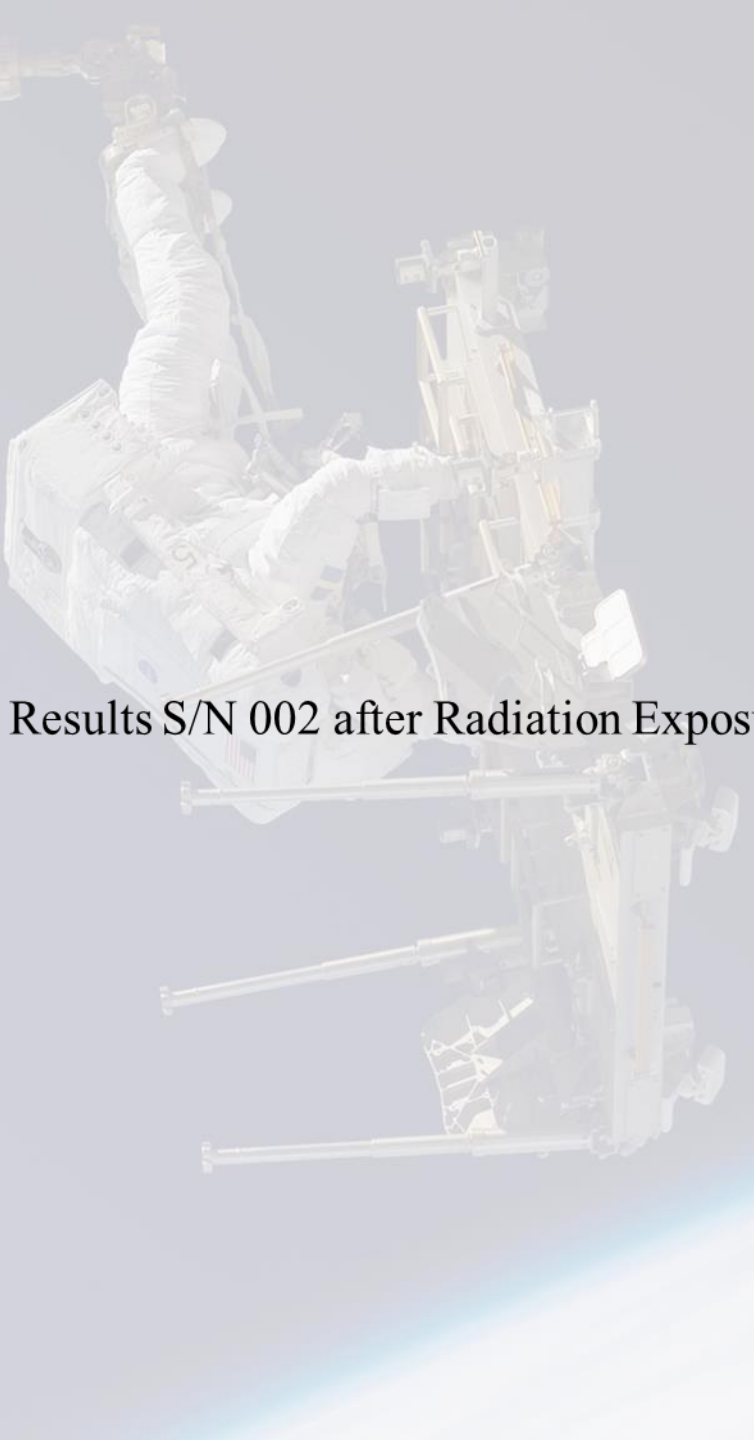
Radiation Summary of Test Results

- The solar cell test coupon (S/N 002) was exposed to 1 MeV electrons to the target fluence of 3.6E15 e/cm^2, at a nominal flux rate of 4E9 e/cm^2/s. This was achieved after 244 hours of exposure runtime over a period of thirteen days.
- The test article was observed to show no signs of physical change to the cells throughout exposure to the target fluence of 3.6E+15 P/CM^2.
- Some darkening of the electrical wires was observed, which is to be expected.
- As the chamber began to gradually warm-up, the first indication of physical change in the cell structure was observed at -80°C.
- The test articles began to show signs of void like structures which had developed below the cover glass.
- These symptoms appeared to increase with the rise in temperature.
- Upon achieving ambient temperature, the chamber was slowly brought to atmosphere.
- No noticeable effects to the test article were observed during the venting process.

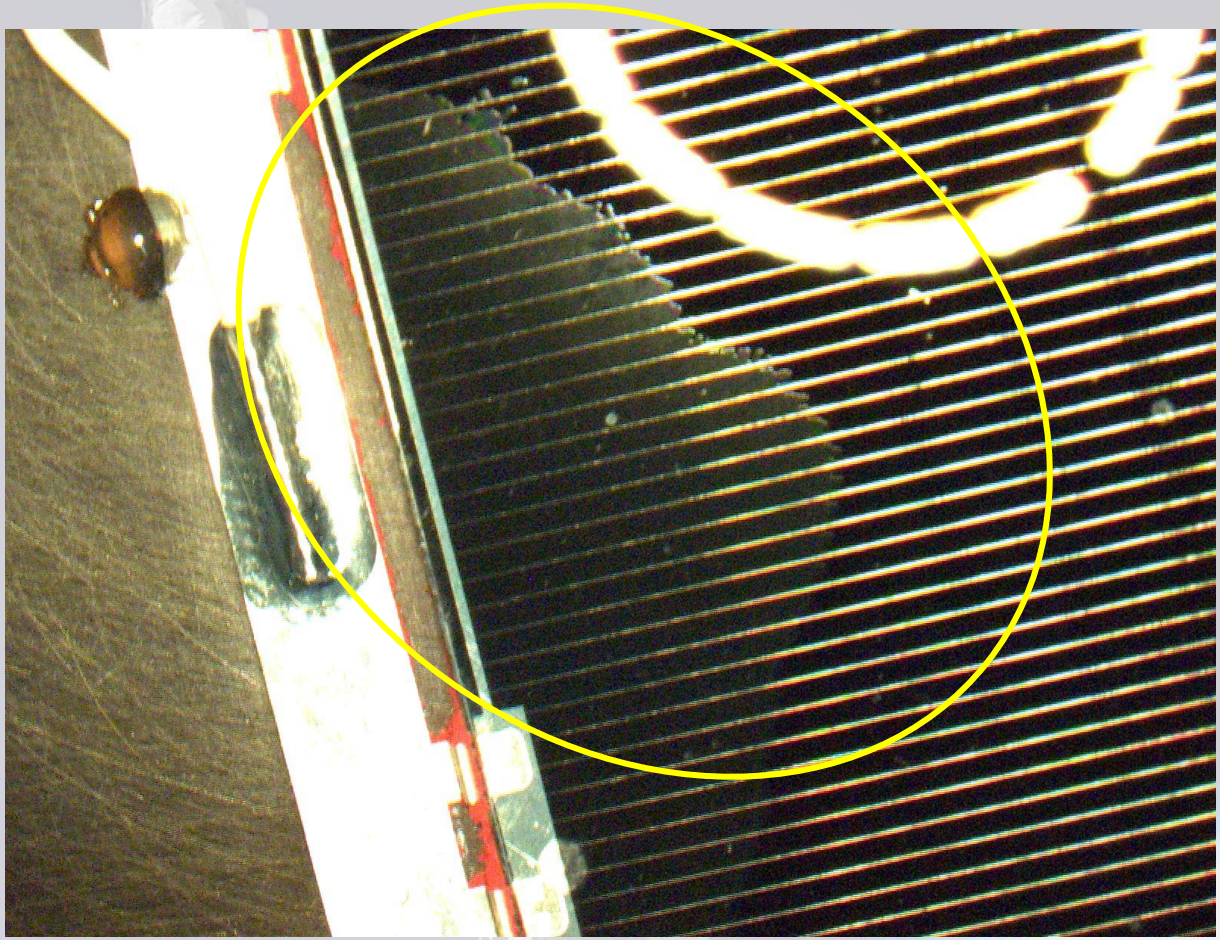
Radiation Effort Conclusion

S/N-002 went through radiation exposure. This test coupon went through 122 thermal cycles from ~50 K to ~133 K.

In view of the physical effects seen through the cover glass, the potential delamination appears to be dependent on dose and the temperature.

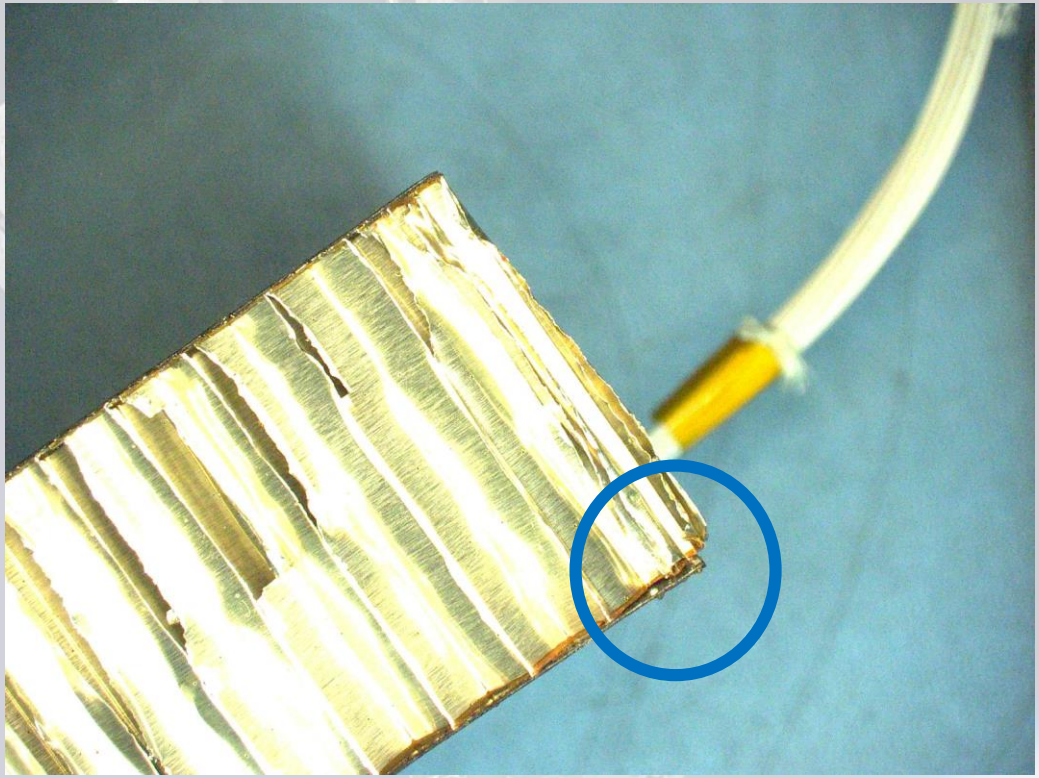


Inspection Results S/N 002 after Radiation Exposure and Before Thermal Cycling



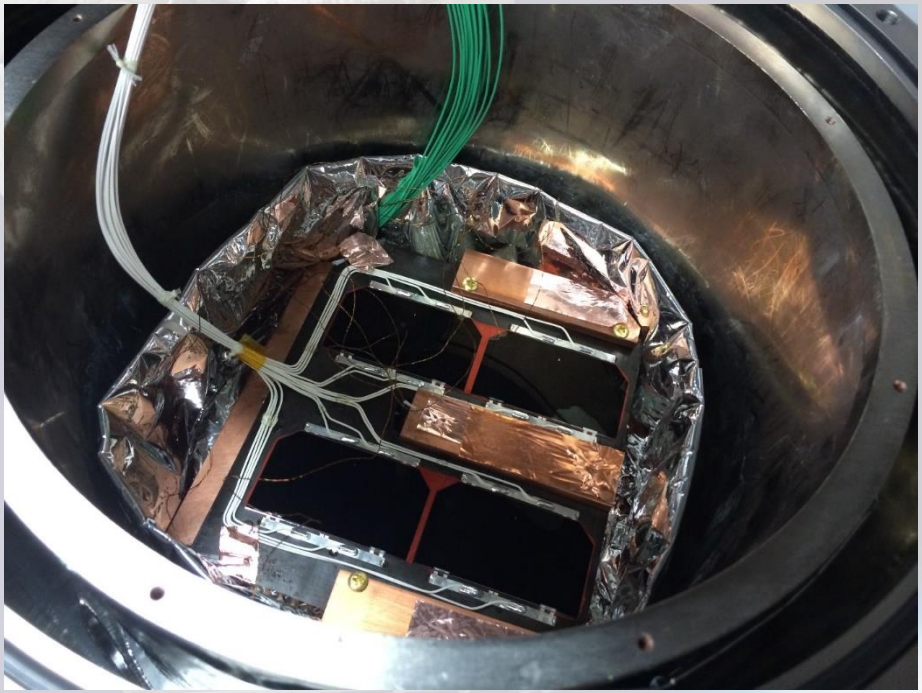
Optical image of some sort of bubble found in the solar cell test coupon (before thermal cycling), S/N 002.

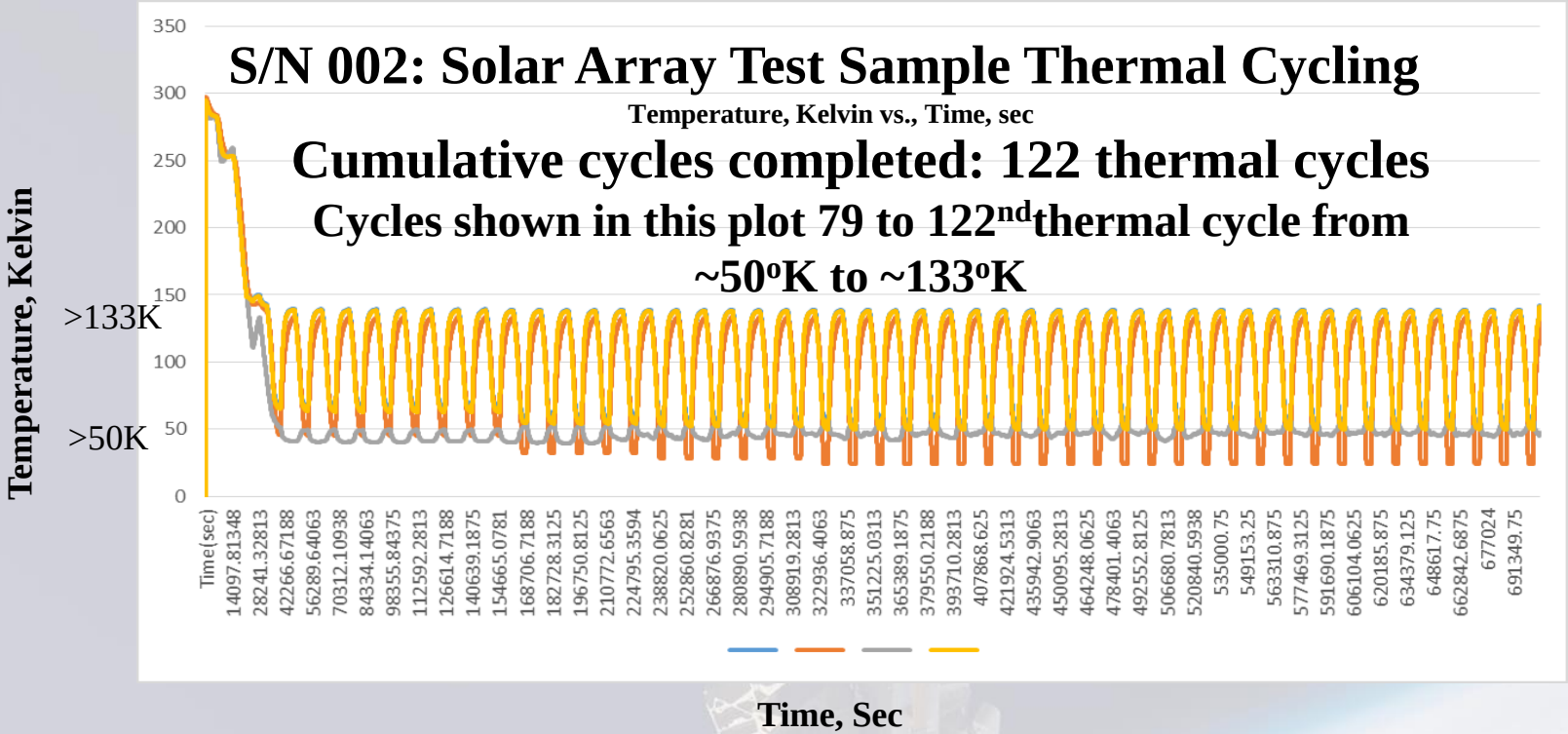
Ram



Optical image of the phase sheet separation from the corner of the test coupon prior to the thermal cycling. (S/N 002)

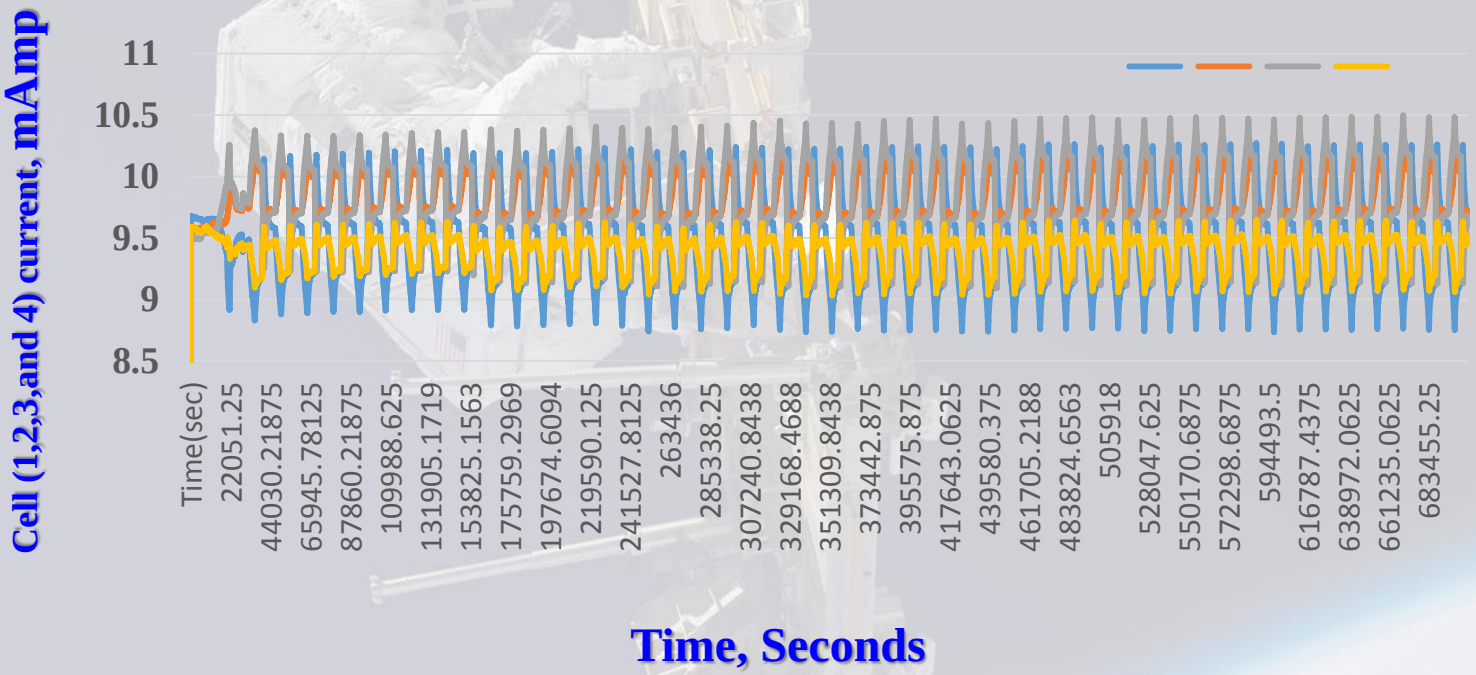
Solar Cell S/N 002 in Cryogenic Thermal Chamber





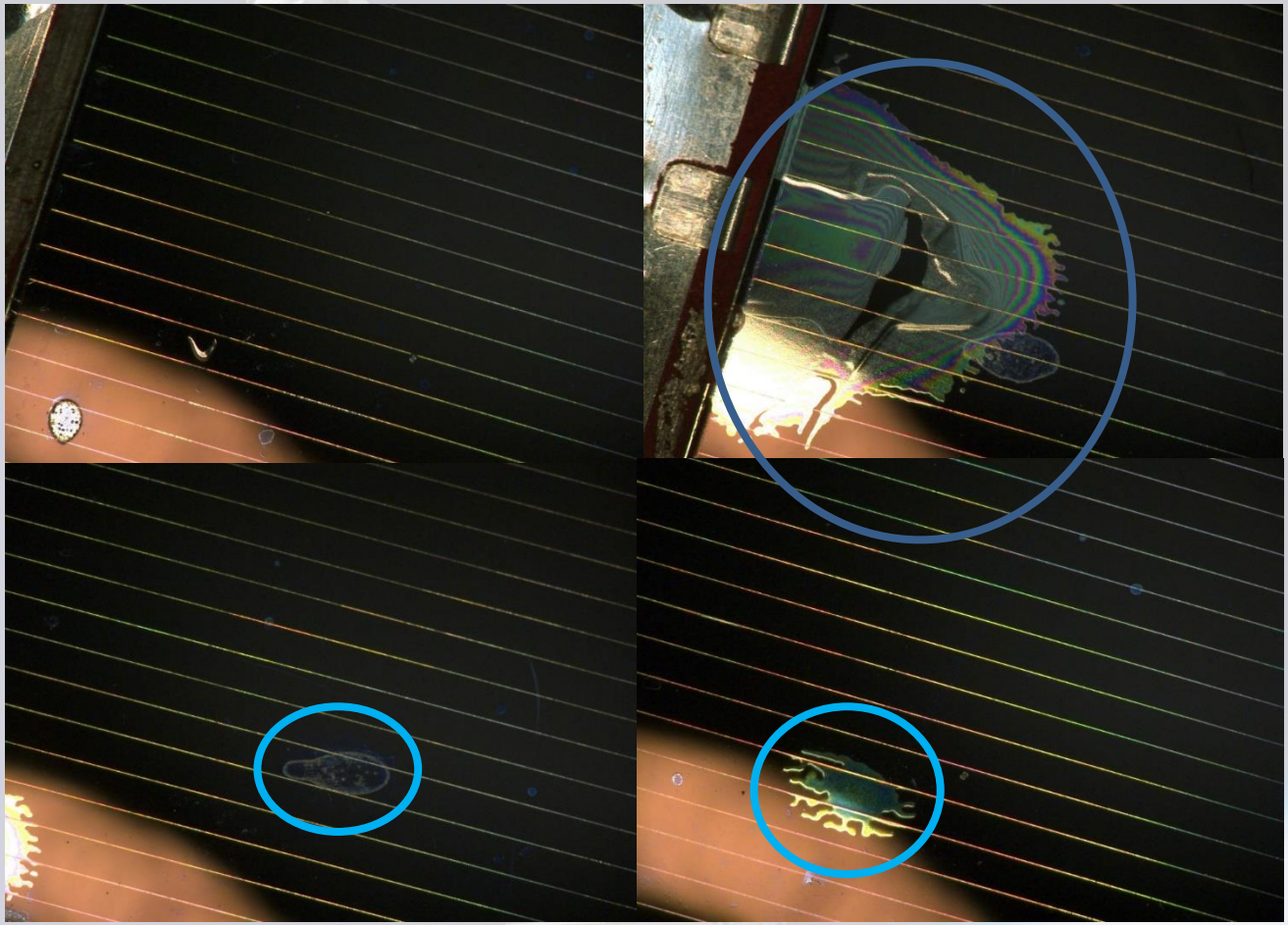
Thermal cycling was performed from below 50 K to above 133 K successfully. Low and high temperature limits were tweaked during the thermal cycling to cover entire temperature range that the project is interested.

S/N 002: Solar Array Test Sample Thermal Cycling
Cumulative cycles completed: 122 thermal cycles
Cell current 1-4 from 79th cycle to 122nd cycle

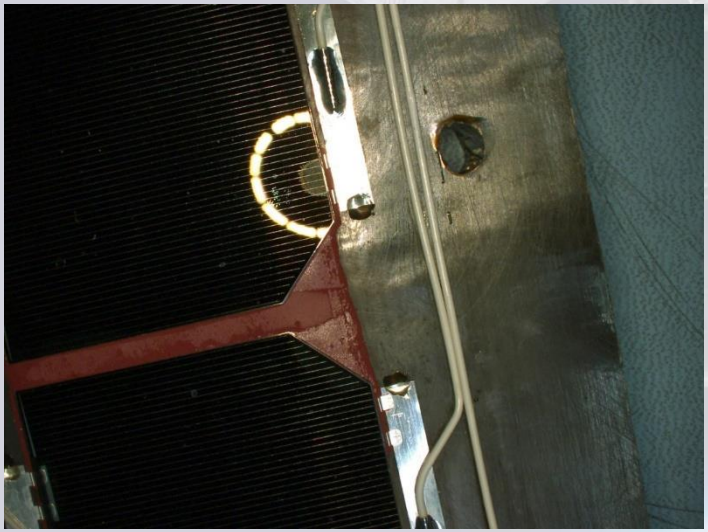


The cell current was unchanged as a result of thermal cycling. This is an indication that the solar cells are intact from the performance point of view. No degradation was found in cell current.

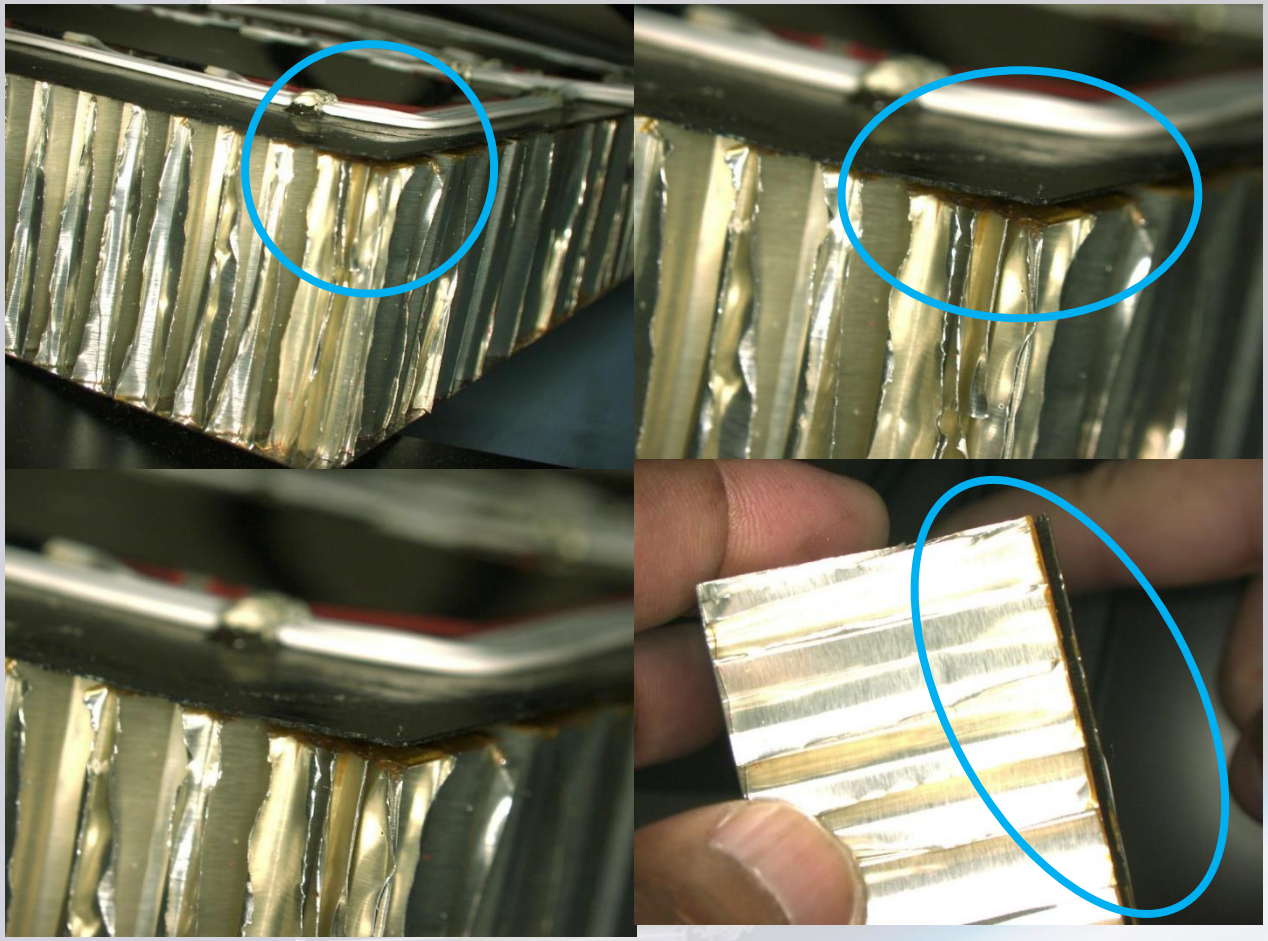
Inspection of S/N 002 after 122 thermal cycles



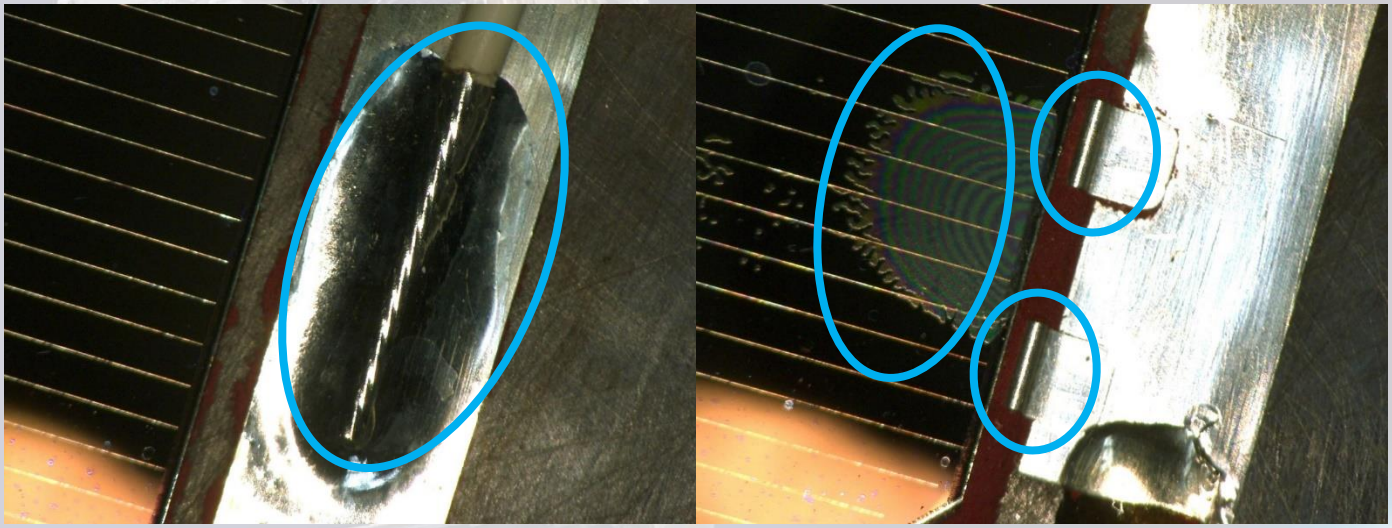
Bubbles in Southeast Sample (S/N 002), after 122 thermal cycles



Bubble in Southeast Sample (S/N 002) after 122 thermal cycles



Southwest Corner: Face sheet separation after 122 thermal cycles (S/N 002)

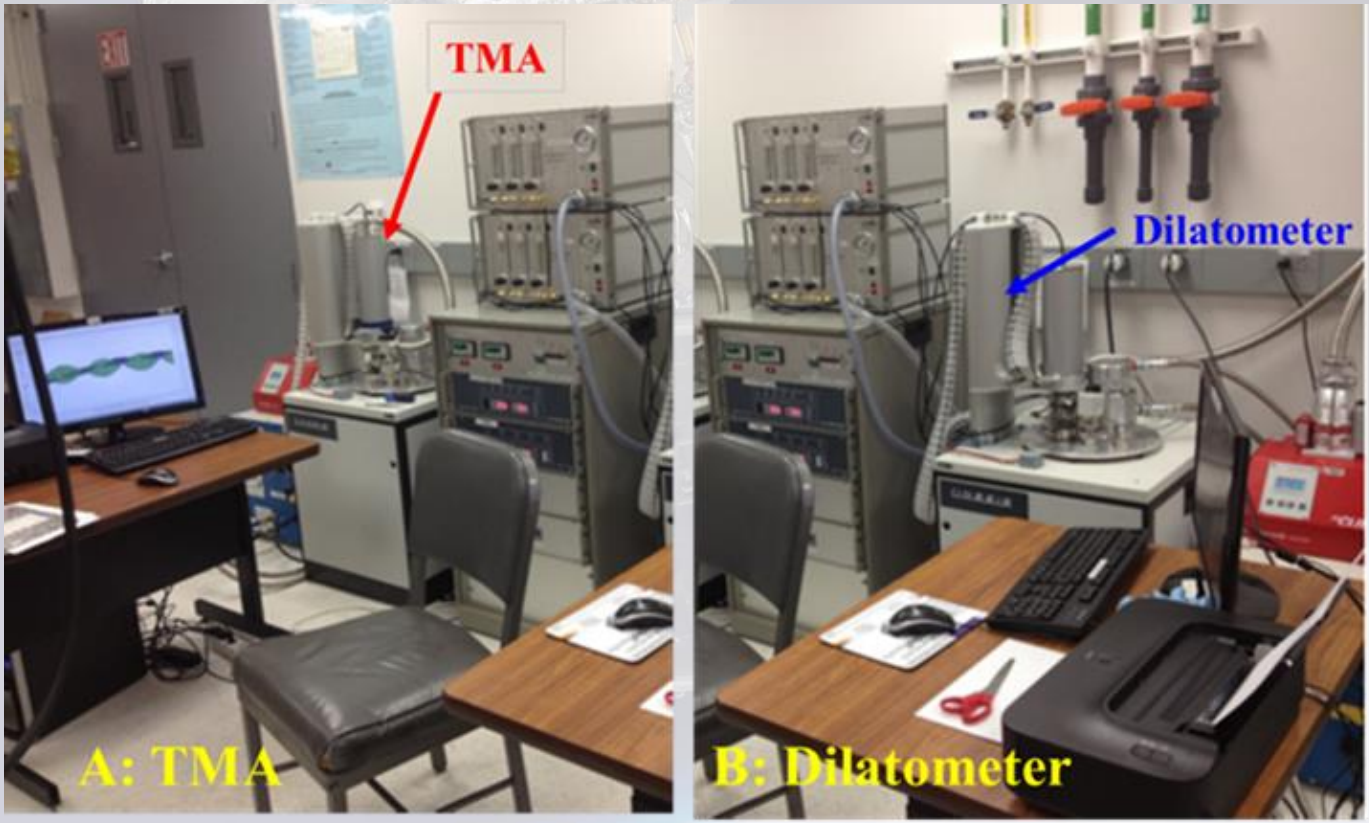


Southwest Sample: solder joints and bubbles (S/N 002), after 122 thermal cycles

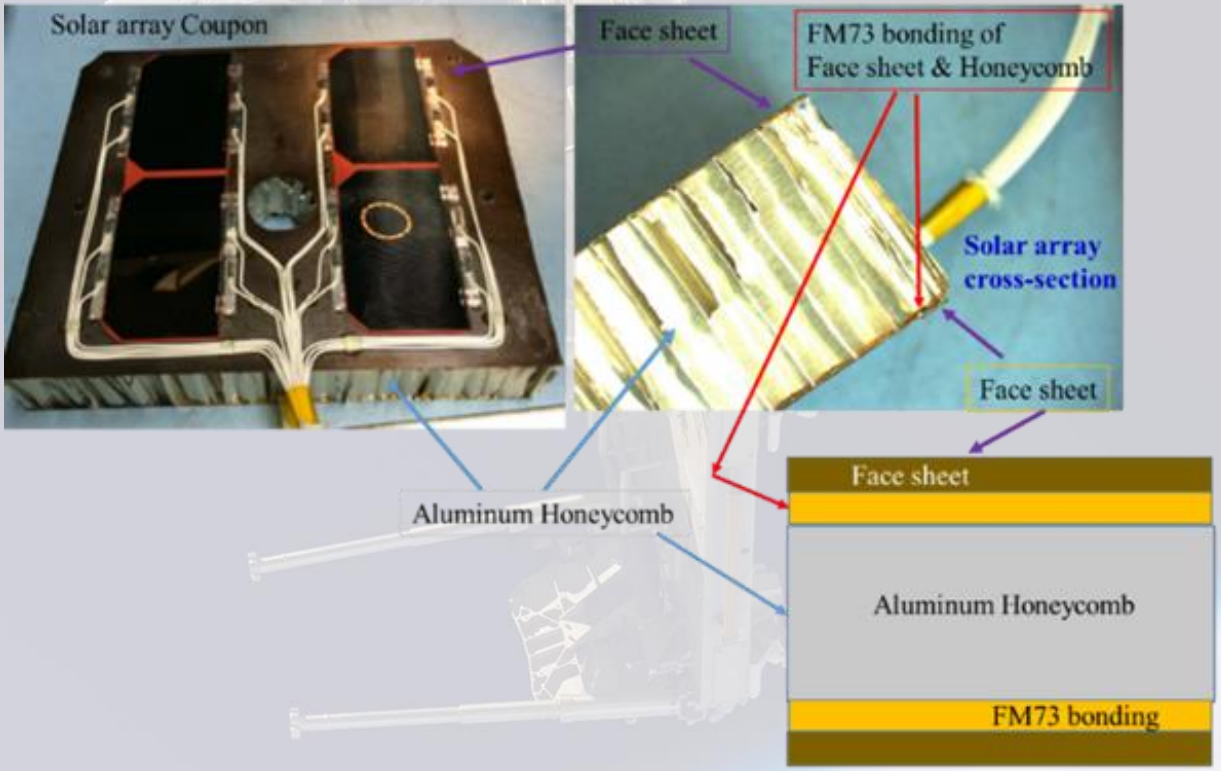
S/N 002 SA Test Coupon Summary

- Bubbles were present on the samples prior to thermal cycling.
- Completed the thermal cycle testing of test Coupon-B (S/N 002) for 122 thermal cycles.
- No expansion of bubbles after 122 thermal cycles was observed.
- No new delamination was observed as a result of cryogenic thermal cycling.
- No continuity failures were observed as a result of thermal cycling. Cell current was within the cell current limits at each temperature. Interconnects were intact (as highlighted/circled in images) as a result of thermal cycling. No cracking of solder joints and interconnects was observed.
- Adhesive materials were intact after thermal cycling. The materials have survived 3X ECM project life thermal cycles.
- The condition of solar panels after radiation and thermal cycles is satisfactory. The bubbles were formed as a result of long time radiation exposure. Fortunately, those bubbles did not expand as a result of thermal cycling and the cell current did not show any anomaly. The formed bubble did not have any adverse effect on the cell performance as a result of thermal cycling.

LinSeis: (A) TMA and (B): Dilatometer i

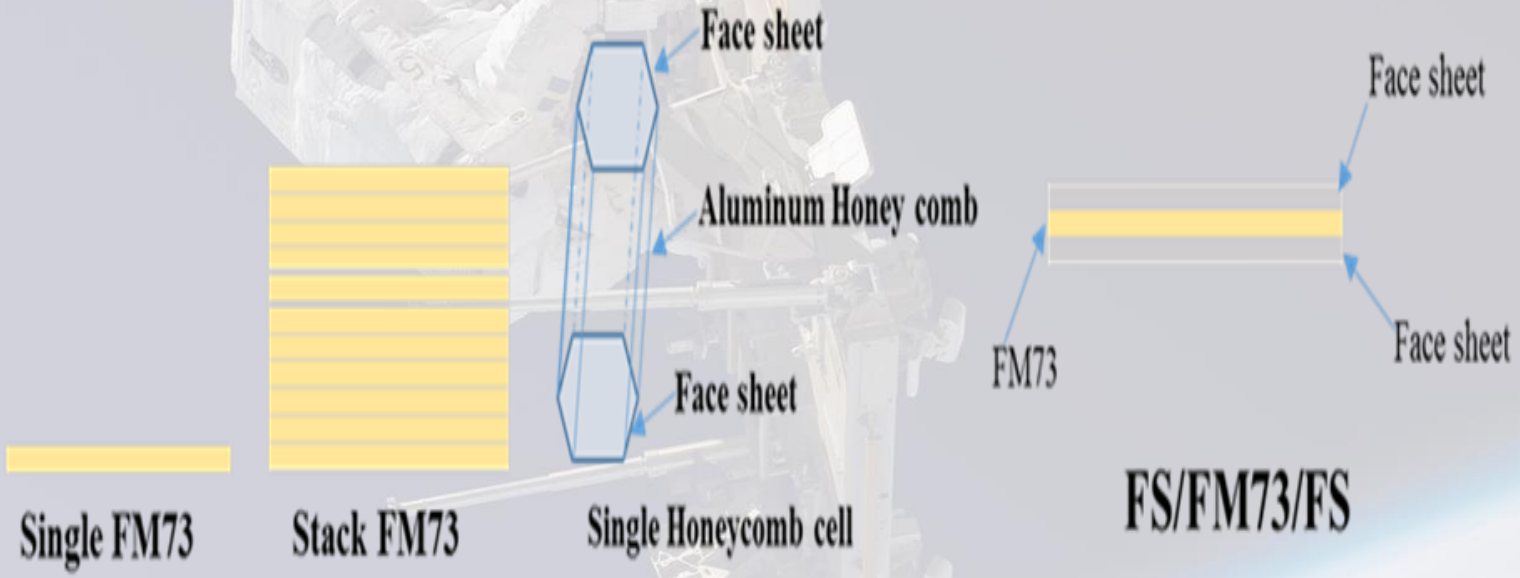


Solar array coupon with a face sheet, FM73 bonding or adhesive material, and aluminum honeycomb.

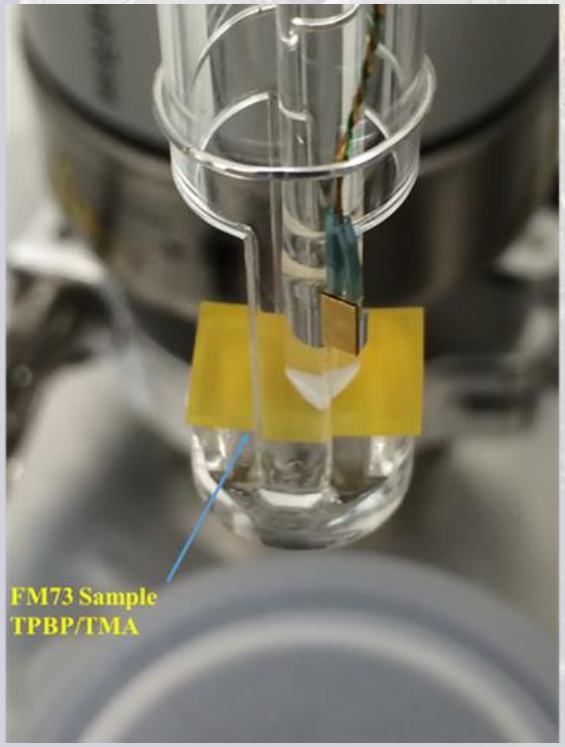


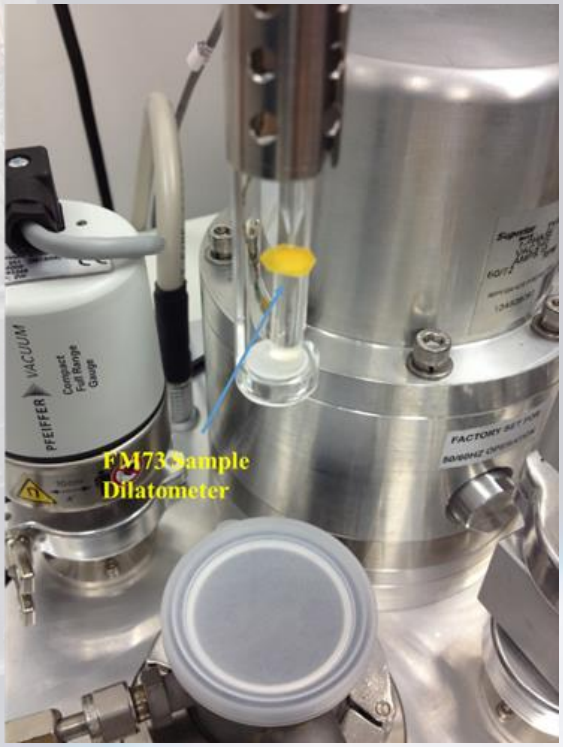
Schematics of solar array cross-section

Solar array test coupon configurations

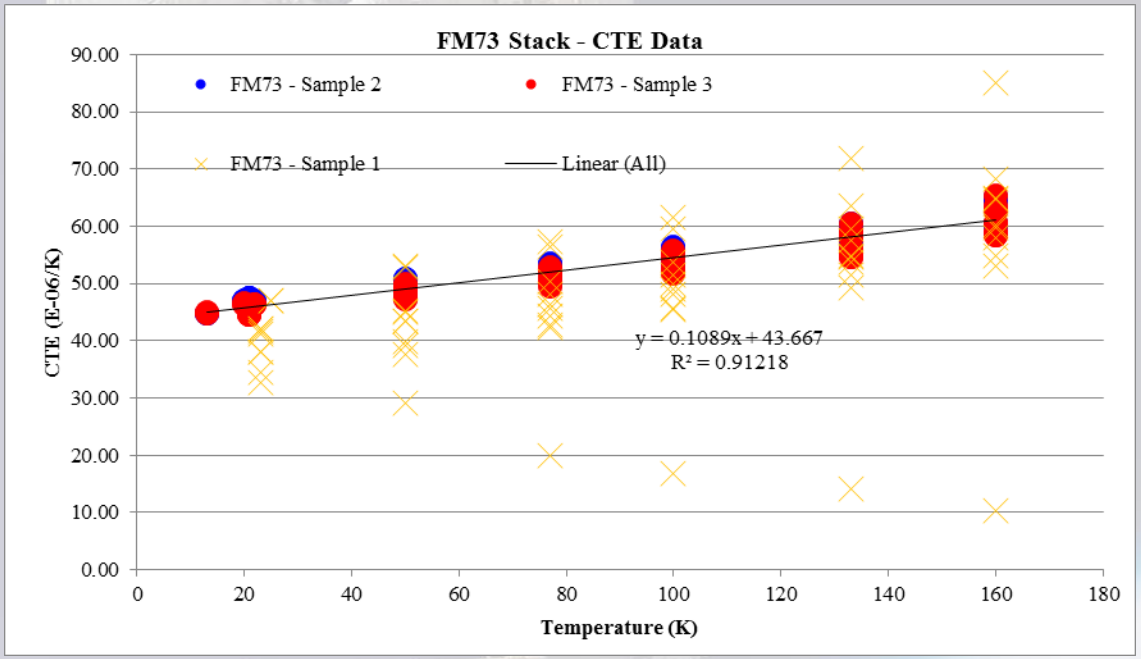


Mounting of the test coupons in the TPBP/TMA and Dilatometer

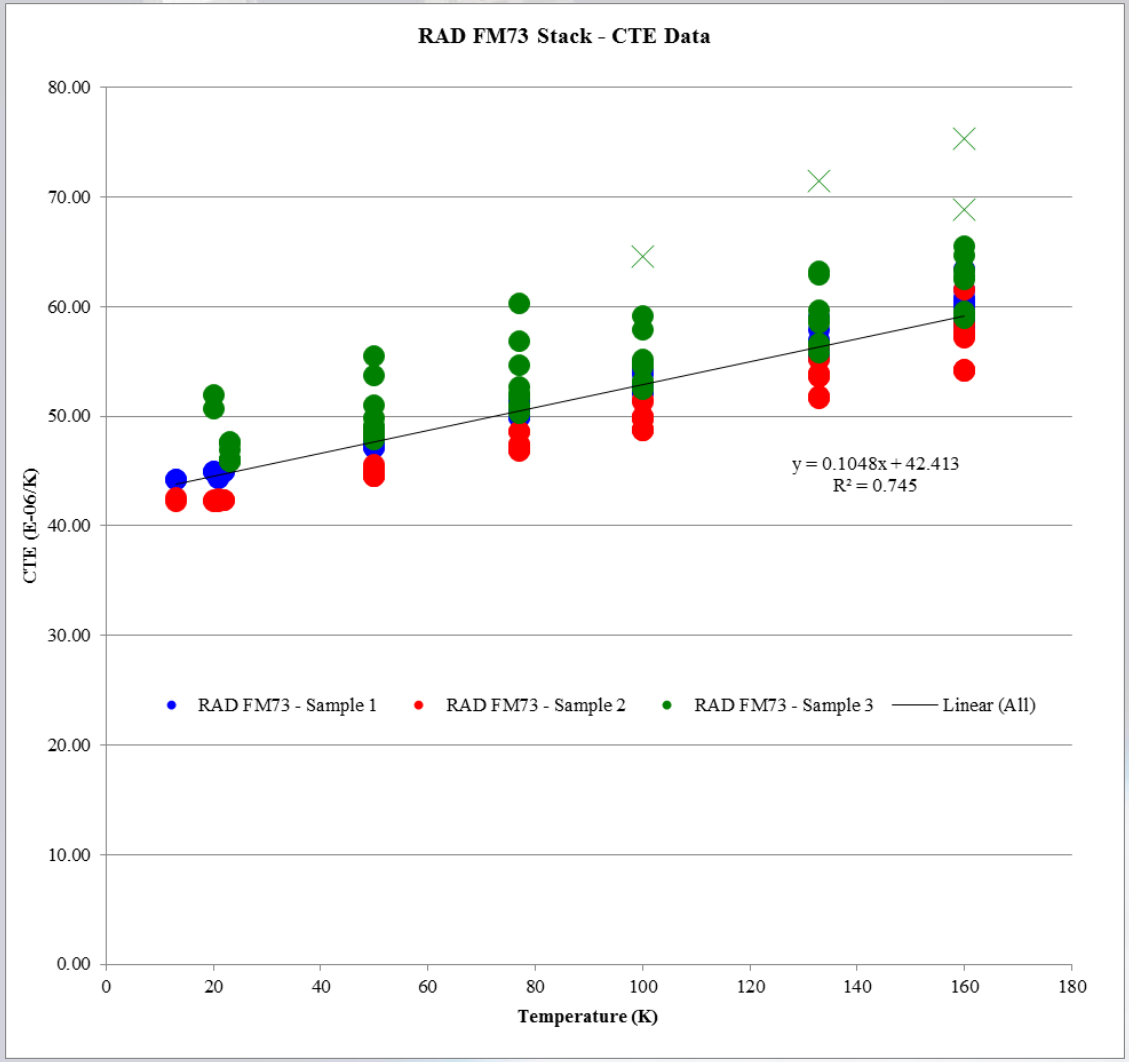




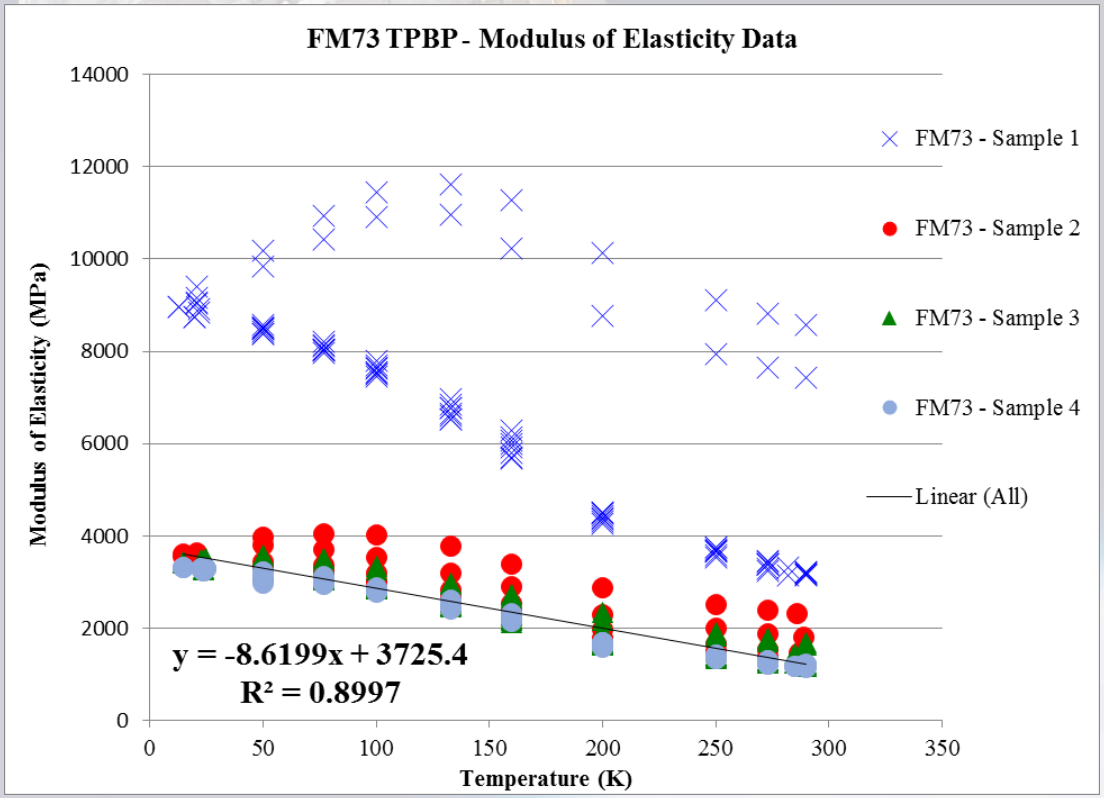
CTE of FM73 stack material samples #1, #2, and #3



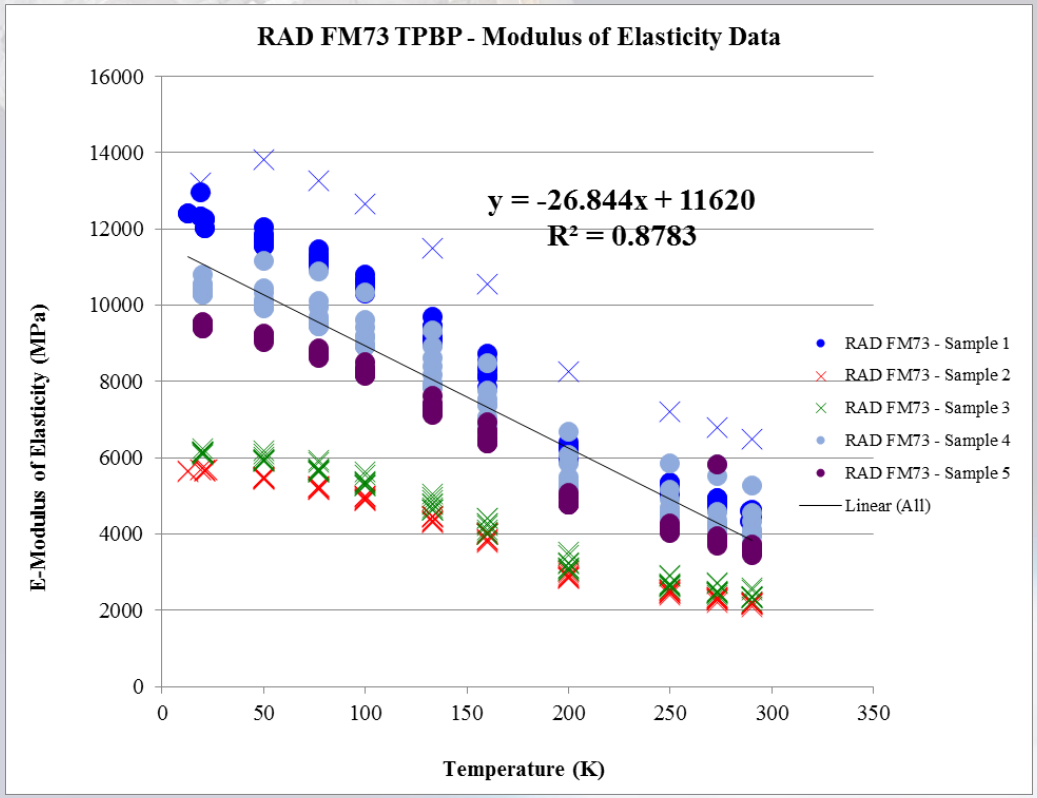
CTE of radiated FM73 stack material samples #1, #2, and #3.



e-Modulus of non-radiated FM73 material samples #1, #2, #3, and #4.



e-Modulus of radiated FM73 material samples #1, #2, #3, #4, and #5.



Summary of Physical Characterization of SA materials

Physical Property of SA Materials	CTE, ppm*	CTE, ppm	e-Modulus, GPa**	e-Modulus, GPa
Measured @ Temperature, K	293 K	≤25 K	293 K	≤25 K
FM73 Adhesive	62	45	1	3
Radiated FM73	59	44	4	11
Single Solar Cell Honeycomb	10 to 22 @ 170 K	6 to 15	-	-
Graphite Face Sheet	42	32	-	-

**parts per million*

***Giga Pascal*

Physical Characterization Summary

- Coefficient of Thermal Expansion of non-radiated FM73 adhesive materials has been measured for various test samples to cryogenic temperatures. The CTE has been measured to be from 45 ppm to 62 ppm in the temperature range studied (15 K to 293 K).

- Coefficient of Thermal Expansion of radiated FM73 adhesive materials has been measured for various samples to cryogenic temperatures. The CTE has been measured to be from 44 ppm to 59 ppm (15 K to 293 K).

- *e*-Modulus of non-radiated FM73 adhesive materials has been measured for various samples vs. temperature down to cryogenic temperatures. The e-modulus/Young's modulus of SA material has been determined to be 1 GPa (300 K) to 3 GPa (~20 K).

- *e*-Modulus of radiated FM73 adhesive materials has been measured for various samples vs. temperature down to cryogenic temperatures. The e-modulus of the material has been determined to be ~4 GPa (300 K) to 11 GPa (~20 K).

Acknowledgements

- The research work described in this report was carried out at the Jet Propulsion Laboratory, Caltech, Pasadena, CA. The Europa Clipper Mission is highly appreciated for supporting us to work on this risk mitigation task.
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- Thanks are due to Ryan Pickard, a summer intern who assisted in processing the experimental test data. Thanks are also due to Michelle Tran (high school intern, 2015) who supported a literature survey of solar array qualification methodologies for extreme thermal environments.
- Thanks to Charles Rhoades for his help in preparing test samples and characterization-related effort/support. Radiation team members (section 514, section 513, and others) are acknowledged for their support in preparing the radiated samples for this risk reduction effort. Thanks are due to Michael Gregory for his help in review, format and editorial support.