Advanced Solar Cell Testing and Characterization

SPRAT Workshop Summary

Chaired by:
Sheila Bailey, Henry Curtis
and Michael Piszczor

The topic for this workshop stems from an ongoing effort by the photovoltaic community and U.S. government to address issues and recent problems associated with solar cells and arrays experienced by a number of different space systems. In April 2003, a workshop session was held at the Aerospace Space Power Workshop to discuss an effort by the Air Force to update and standardize solar cell and array qualification test procedures in an effort to ameliorate some of these problems. The organizers of that workshop session thought it was important to continue these discussions and present this information to the entire photovoltaic community. Thus, it was decided to include this topic as a workshop at the following SPRAT conference.

The Advanced Solar Cell Testing and Characterization Workshop was divided into two areas of discussion. The first topic focused on the Air Force effort to standardize qualification and testing procedures. Brad Reed from the Aerospace Corporation has led the Air Force effort and was invited to lead that portion of the workshop. After that discussion, Sheila Bailey discussed recent progress in test procedure guidelines at the international level.

Brad Reed started the first part of the workshop with a short talk on the rationale behind the Air Force push to establish standardized test procedures. He noted that the Aerospace Corporation, under direction from the Air Force, is engaged in a project to create military-specifications for inclusion in future Air Force RFPs. He explained that this initiative was borne out of an investigation of recent on-orbit and ground performance problems with military and commercial "space-qualified" solar arrays.

In support of this project, Aerospace is submitting a proposed set of qualification tests to the industry for comment. A preliminary version of these proposed tests were discussed during the workshop and are included in the following three tables. The tables address two primary areas: 1) combined effects testing for solar cell and/or solar panel coupons and 2) accelerated life testing for solar cells for the purpose of determining reliability.
The discussion during the workshop session proceeded to address the individual points in the tables, with a focus on soliciting comments/improvements to the proposed guidelines from the workshop participants. Specifically, input was being sought on:

1. Appropriateness of the tests.
2. Acceptability of the test procedures and standards to the space photovoltaic community.
3. Suggestions for new tests that would enhance the qualification process.
4. Data that could be included by the solar cell manufacturers to enhance the design process.

Brad concluded the discussion by noting that further input from the community would be solicited and this process would continue.

Solar Cell Qualification Test

Environment/Reason	Level	Test Procedure	Test Condition	Criteria/Report
1. Weld or Solder Joint Qualification	Cell	Forward and Reverse Dark Electrical Characterization	28C, sample size determined by TBD	Build Cell to manufacturer's specification and record process
		Weld or Solder Interconnect		Per Manufacturer's Weld or Solder Schedule
		Forward and Reverse Dark Electrical Characterization	28C	Measure 10x
		Reverse Bias	Dark Reverse Bias @ 2.0 V for 10 Seconds @ 80C	
		Forward and Reverse Dark Electrical Characterization	28C	Measure 10x
		NDE of Weld or Solder Joints		
		Pull Test	Pull at 45 degrees	
		100% DPA		Evaluate weld or solder interface micro structure
2. Pre-Launch and On-Orbit Degradation or Failure	2 Coupons with Bypass Diodes	Hotbox Electrical Characterization/Visual Inspection	AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight @ 80C, coupon size TBD. Visual inspect at 1x at 1 foot.	Build Coupons with Composite Substrate and Aluminum core, Standard Interconnect, and 6 mil Ceria-doped microsheet Coverglass, using standard production processes
		Humidity Exposure	90 days @ 95+/- 4% Relative Humidity @ 45C	
		Hotbox Electrical Characterization/Visual Inspection	AM0 @ 1353 w/m2, characterized by JPL Balloon Flight, 80C. Inspect with 1x eyeball at 1 foot.	
		Combined Effects Test	Thermal Cycle first coupon between -180 to +80 for 15,000 cycles. Thermal cycle second coupon between -95 and +110 C for 5000 cycles. In hot cycle either (1) illuminate at AMO under load, or (2) dark forward bias.	
		Hotbox Electrical Characterization	AM0 @ 1353 w/m2, characterized by JPL Balloon Flight @ 80C. Visual inspect 1x at 1 foot.	< 2% Maxiumum Power Degradation
		NDE of Weld or Solder Joints		
		Pull Test	Pull strength at 45 degrees	
		100% DPA	TBD	
3. Stack Reliability Measurement, Verify Ohmic Contacts, Verify Tunnel Junction performance	Bare Cells	X-25 Electrical Characterization	AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight, 28C,	
		Accelerated Life Test	TBD	
		X-25 Electrical Characterization	AM0 @ 1353 w/m2, characterized by JPL Balloon Flight, 28C	
		DPA		

Solar Cell Characterization				
Environment/Reason	Level	Test Procedure	Test Condition	Criteria/Report
1. Electron Radiation Effects	Bare Cell with n-interconnect, p-interconnect, diode interconnects	X-25 Electrical Characterization	AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight Calibration Cell, 28C and 80C, sample size TBD	Baseline Test - Cell group shall not exceed 5% spread at Pmax
		Electron Radiation	Radiation energies of .6, 1.0, and 12 MeV at Fluences of 1e14, 3e14, 1e15, 3e15, 1e16	
		X-25 Electrical Characterization after each Radiation Fluence	AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight Calibration Cell, 28C and 80C, sample size TBD	Cell group shall not exceed 5% spread at Pmax
		Reverse Bias Characterization	Dark Reverse Bias @ 2.0 V for 10 Seconds @ 80C after each fluence	Perform Reverse Bias/Electrical Characterization for maximum of 10 times
		X-25 Electrical Characterization	AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight Calibration Cell, 28C	< 2% Average Efficiency Degradation from Baseline and < 3.5% for any Individual Cell
		100% DPA	TBD	
2. Proton Radiation Effects	Bare Cell with n-interconnect, p-interconnect, diode interconnects	X-25 Electrical Characterization	AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight Calibration Cell, 28C and 80C, sample size TBD	Baseline Test - Cell group shall not exceed 5% spread at Pmax
		Proton Radiation	Radiation energies of 20 KeV, 50 KeV, 100 KeV, 300 KeV, 1MeV, 3MeV, and 10 MeV at Maximum Fluences of TBD	
		X-25 Electrical Characterization after each Radiation Fluence	AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight Calibration Cell, 28C	Cell group shall not exceed 5% spread at Pmax
		Reverse Bias Characterization	Dark Reverse Bias @ 2.0 V for 10 Seconds @ 80C after each fluence	Perform Reverse Bias/Electrical Characterization for maximum of 10 times
		X-25 Electrical Characterization	AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight Calibration Cell, 28C	< 2% Average Efficiency Degradation from Baseline and < 3.5% for any Individual Cell
		100% DPA	TBD	
3. UV Radiation Effects	CIC	X-25 Electrical Characterization	AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight Calibration Cell, 28C, sample size TBD	
		UV Soak	TBD Hours at 200 nm irradiation in a Vaccuum of 10-5 torr until electrical degradation plateaus < 1% per hour. Exposure for another TBD2 Sun-Hours	Report TBD1 hours, and TBD2 % degradation
		X-25 Electrical Characterization	AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight Calibration Cell, 28C	< 2% Average Efficiency Degradation from Baseline and < 3.5% for any Individual Cell
4. Peeling Gridlines after thermal cycle	Cell	Tape Peel Test	Pull with 3M type 600 cellulose tape to Evaluate Contact Adhesion. Visual inspection at 10x under fluorescent illumination	<1% AR and <1% metal peeling
5. Humidity in Storage	Cell	X-25 Electrical Characterization	AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight Calibration Cell, 28C, sample size TBD	
		Humidity Test	30 days @95% RH @ 45C	
		X-25 Electrical Characterization	AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight Calibration Cell, 28C	Average efficiency degradation of < 1.5% from baseline and no individual cell >2.5%
		Visual Inspection	1x at 1 foot distance	no obvious anomalies
6. Breakage of Cells on Curved Array	CIC	Bend Test	multiple radius bend test	measure bend radius up to cell fracture
7. Mechanical Strength - Handling Issues	Cell	Yield Test as per ASTM E 855-90 (2000), Test Method C	TBD samples	yield strength distribution curve
8. Photogeneration Response vs. Wavelength	Cell	Internal or External Quantum Efficiency	Spectral Response from 250 to 2000 nm for TBD energies after electrical radiation fluences of 1e14, 3e14, 1e15, 3e15, 1e16	
9. Off-Normal Electrical Response to Pointing Angle	Cell	Vary Angle of Incidence and provide X-25 Electrical Characterization	Measure response at 5, 10, 20, 30, 40, 50, 60, 70, 80, 85, 90 degrees. Measure cells at AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight Calibration Cell, 28C	
10. Temperature Coefficient	Cell	Vary Temperature and Provide X-25 Electrical Characterization	Measure I-V curve to include Isc, Voc, Imp, Vmp between -180 and 150 C in 10 degree increments on cells with no fluence, and after fluences of e14, e15, e16. Provide AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight Calibration Cell, 28C.	
11. Thermal Design	CIC	Hemispherical Emissivity	from 5 to 50 um	
12. Thermal Design	CIC	Solar Absorptance	from 250 to 2500 nm	
13. Electrical Characterization	Cell	Dark I-V characterization between I = Isc to - Isc at 28C		
14. Electrical Characterization	Bypass Diode	As per Mil-S-19000		

Solar Panel Qualification Test

Environment/Reason	Level	Test Procedure	Test Condition	Criteria/Report
1. Problems During Storage at Launch; Problems On-Orbit	Coupon	Electrical Characterization	AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight, 28C, coupon size determined by TBD	Build Coupon with parts and processes to be used in flight
		Humidity Exposure	30 days @ 95+/- 4% Relative Humidity @ 45C	
		Electrical Characterization	AM0 @ 1353 w/m2, characterized by JPL Balloon Flight, 28C	< 2% Average Efficiency Degradation
		Visual Inspection	TBD	TBD
		Acoustic Test	TBD	
		Electrical Characterization	AM0 @ 1353 w/m2, characterized by JPL Balloon Flight, 28C	< 2% Average Efficiency Degradation
		Combined Effects Test	Thermal Cycle between predicted low non-operational temperature -16C and predicted high non-operational +16C at 1.5 x mission cycles. In hot cycle either (1) illuminate AM0 under load, or (2) dark forward bias. Reverse bias TBD directly after forward bias.	
		Electrical Characterization	AM0 @ 1353 w/m2, characterized by JPL Balloon Flight, 28C	< 2% Average Efficiency Degradation
2. Panel-Level VCM	Panel	Electrical Characterization	AM0 @ 1353 w/m2 as characterized by JPL Balloon Flight, 28C, coupon size determined by TBD	Build Coupon with parts and processes to be used in flight
		Measure VCM on cold surface	Thermal Soak predicted high non-operational temperature + 16C.	Measure as per ASTM 595. Input VCM results to vehicle contamination analysis.
		Electrical Characterization	AM0 @ 1353 w/m2, characterized by JPL Balloon Flight, 28C	< 2% Average Efficiency Degradation