Forward Technology Solar Cell Experiment First On-Orbit Data

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INTRODUCTION

This paper presents first on orbit measured data from the Forward Technology Solar Cell Experiment (FTSCE). FTSCE is a space experiment housed within the 5th Materials on the International Space Station Experiment (MISSE-5). MISSE-5 was launched aboard the Shuttle return to flight mission (STS-114) on July 26, 2005 and deployed on the exterior of the International Space Station (ISS). The experiment will remain in orbit for nominally one year, after which it will be returned to Earth for post-flight testing and analysis. While on orbit, the experiment is designed to measure a 36 point current vs. voltage (IV) curve on each of the experimental solar cells, and the data is continuously telemetered to Earth. The experiment also measures the solar cell temperature and the orientation of the solar cells to the sun. A range of solar cell technologies are included in the experiment including state-of-the-art triple junction InGaP/GaAs/Ge solar cells from several vendors, thin film amorphous Si and $CuIn(Ga)Se_2$ cells, and next-generation technologies like single-junction GaAs cells grown on Si wafers and metamorphic InGaP/InGaAs/Ge triple-junction cells.

In addition to FTSCE, MISSE-5 also contains a Thin-Film Materials experiment. This is a passive experiment that will provide data on the effect of the space environment on more than 200 different materials.

FTSCE was initially conceived in response to various on-orbit and ground test anomalies associated with space power systems. The Department of Defense (DoD) required a method of rapidly obtaining on orbit validation data for new space solar cell technologies, and NRL was tasked to devise an experiment to meet this requirement. Rapid access to space was provided by the MISSE Program which is a NASA Langley Research Center program. MISSE-5 is a completely self-contained experiment system with its own power generation and storage system and communications system. The communications system, referred to as PCSat, transmits and receives in the Amateur Radio band providing a node on the Amateur Radio Satellite Service. This paper presents an overview of the various aspects of MISSE-5 and a sample of the first measured on orbit data.

THE SOLAR CELL EXPERIMENTS

A photograph of the deck that holds FTSCE is shown in Figure 1. The experiments are described in Table 1. The primary experiments are the 3J $InGaP_2$/GaAs/Ge based technologies from Spectrolab (SPL) and Emcore. In each case, the current state-of-the-art and next generation technology are included. In addition, the Emcore ATJM devices include the new monolithic bypass diode. The SPL panel includes two DJ $InGaP_2$/GaAs/Ge solar cells that serve as control cells. The Emcore and SPL experiments were assembled by the manufacturer according to their standard practices on Al honeycomb substrates.

FTSCE includes several single-junction (SJ) GaAs solar cells grown on Si substrates that are representative of the GaAs/SiGe/Si technology being developed jointly by NASA GRC, Ohio State University (OSU), and Massachusetts Institute of Technology (MIT) [1,2]. These cells, along with GaAs/Ge control cells, are mounted on a rigid Al honeycomb substrate. There are four 3J $InGaP_2$/InGaAs/Ge metamorphic cells supplied by SPL that employ a stoichometry that results in a slightly lattice-mismatched semiconductor stack, which, in turn, results in a bandgap combination more closely optimized for the air mass zero (AM0) spectrum. These solar cells are mounted on the SPL panel.

FTSCE also includes flexible, thin-film solar cell (TFSC) technologies. The FTSCE TFSC experiments were fabricated to mimic as closely as possible functional "first-generation" thin-film blanket technology. Each experiment includes multiple, interconnected cells mounted on a lightweight array substrate. Two of the experiments incorporate amorphous silicon (a-Si) technology. One a-Si sample utilizes monolithically-interconnected cells grown by Iowa Thin Films (ITF) on a Kapton substrate. This unit was provided by Lockheed Martin and the Aerospace Corporation and represents a variety of interconnect, laydown and coating techniques. The other a-Si experiment consists of a-Si material from UniSolar grown on a stainless steel (SS) substrate using their commercial production process. The cells for this experiment were integrated by AEC-Able Engineering using an adaptation of their UltraFlex blanket design and represents a near-term attempt to "space-qualify" thin-film cell technology when integrated into a viable lightweight solar array design. This sample consists of two interconnected a-Si on SS cells affixed to a Vectran gore weave, which simulates the deployed conditions on the UltraFlex array design. It will test cell-to-cell interconnects, cell-to-array attachments and coating technology under long-term space environmental conditions.

AEC-Able/NASA Glenn also supplied a $CuIn(Ga)Se_2$ (CIGS) experiment integrated into the same UltraFlex blanket design as described above. This experiment consists of five CIGS cells interconnected in series using a "shingled" approach. The CIGS cells were provided by ITN/Global Solar. It is important to note that the three FTSCE thin film experiments are primarily thin-film blanket technology durability tests. The efficiency of some of the thin-film devices being flown do not represent the current achievable performance of that technology and were selected because of availability or adaptability to specific thin-film blanket technologies.

The FTSCE includes an experiment to test the environmental durability and long-term transmittance of silicone materials. Certain silicones are being considered for use as concentrator lens materials or coatings for advanced photovoltaic devices, so it is critical to understand the long-term performance of these materials for such applications. The Silicone Degradation Experiment consists of films of silicone (DC 93-500) attached to two different solar cell coverglasses placed over multijunction solar cells so that optical transmission (relative to the response of the MJ cells) can be monitored. Two other bare silicone samples are being flown as passive experiments and will be evaluated upon return to earth at the completion of the mission.

A passive contamination monitor is flying on the FTSCE. The monitor consists of a piece of CMX coverglass mounted such that a large surface area of the glass is exposed to the space environment. Transmission and reflectance measurements were made on the glass prior to integration, and these measurements will be repeated upon return to Earth.

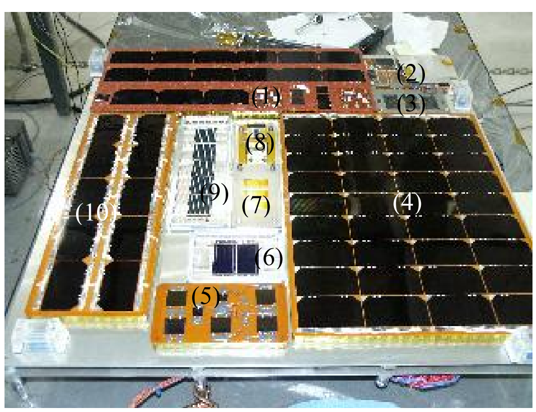

Figure 1: A photograph of the FTSCE experiments. The numbers identify the experiments (Table 1)

Table 1: Description of the experiments on FTSCE. The numbers correspond to **Error! Reference source not found.**.

#	Experiment Name	Supplier	Description	BOL Eff (%)
1	ITJ	Spectrolab	3J commercial ITJ cells, 26.6 cm^2 (10)	27.0
	UTJ	Spectrolab	3J commercial UTJ cells, 26.6 cm^2 (5)	28.6
	Metamorphic	Spectrolab	3J lattice-mismatched cells, 4 cm^2 (4)	28.5
	Control	Spectrolab	DJ $InGaP_2$/GaAs/Ge control cells, 27 cm^2 (2)	22.9
2	Si Degradation	GRC/Entech	Films of DC 93-500 silicone on coverglass over MJ cell to measure transmittance degradation of silicone, 4 cm^2, (2 active, 2 passive), covered in photograph	N/A
	USNA Cells	USNA/GRC	Commercial-off-the-shelf terrestrial solar cells, passive experiment, 2 are ~3.5 cm^2 and the third is ~7.75cm^2, (3)	7.0*
3	a-Si on Kapton	GRC/LM/ ITF	Interconnected thin film a-Si cells on Kapton substrate (3 monolithically-interconnected cells, 1 active , 2 passive)	0.24*
4	Power Panel	Emcore	Primary power panel for mission, ATJ cells	N/A
5	GaAs on Si	GRC/OSU/ MIT	SJ GaAs cells grown on SiGe/Si substrates with one GaAs/GaAs control, 1 & 4 cm^2, (7)	12.2
6	a-Si on Stainless Steel	GRC/AEC Able/UniSolar	Interconnected thin film a-Si on stainless steel on Vectran gore sheet (UltraFlex array design), ~20.5cm^2 (2 cells)	10.4
7	Contamination Monitor	NRL	Thales 5 mil CMX coverglass witness plate	N/A
8	Sun Angle Sensors	NRL	Two orthogonal sun angle sensors.	N/A
9	CIGS	GRC/AEC-Able/ITN	CIGS cells on stainless steel affixed to a Vectran gore sheet simulating UltraFlex array, ~20cm^2 (5 series-connected cells)	~3.5*
10	ATJM	Emcore	3J ATJM cells, includes monolithic bypass diode, 26.6cm^2 (5)	27.1
	BTJ	Emcore	3J BTJ cells, 26.6cm^2 (5)	27.8

* - Denotes atypical cell efficiency due to available selection/modification of cells for flight experiment

THE THIN FILM MATERIALS EXPERIMENTS

A team lead by NASA Langley Research Center has transformed the outer layer of a MISSE-5 thermal blanket into a three and one half ounce experiment to evaluate the in-space survivability of 200 advanced materials that are being developed to enable future US space missions. A photograph of the experiment blanket is shown in Figure 2. Table 2 at the end of the document gives a list of the materials, and a diagram giving the locations of specific experiments is shown in Figure 3. The survivability of these materials will be established by comparing pre- and post- flight characterization test data. Since these specimens will be almost always facing the anti-solar direction when mounted on the ISS, they will receive very little UV radiation that can rupture chemical bonds and provide reactive free-radical sites. They will be subjected to thermal cycling, particulate radiation and atomic oxygen bombardment. With limited UV exposure, all reactions that do occur will be essentially chemically driven oxidation.

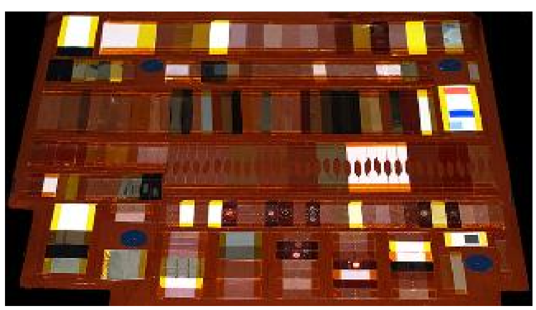

Figure 2: A photograph of the Thin-film Materials Experiment flown on MISSE-5

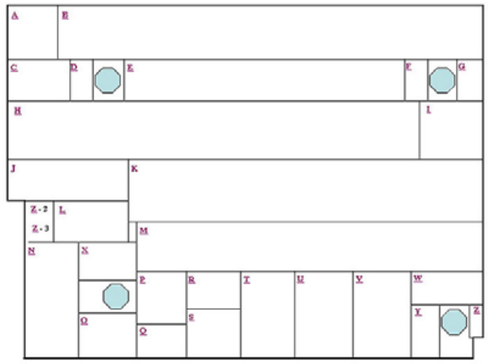

Figure 3: Diagram of the layout of the materials on the Thin-film Materials Experiment. The materials are identified in Table II.

DATA ACQUISITION

The data acquisition electronics were designed and built by the NASA GRC team (**Figure 4**). The electronics are mounted to the Electronics Deck, which is mounted on stand-offs on the opposite side of the Thermal Deck from the solar cell experiments. The electronics consists of one "main" microprocessor board and nine data acquisition (DAC) boards. The main microprocessor board provides the communications link with the communication subsystem, serves as the command interpreter, and controls the DAC boards. In addition, the main microprocessor includes dual redundant flash memory so that not only is data transmitted to ground, but is also archived on board. Upon return to Earth, and in the event of communication downlink failure, the mission will still have data available.

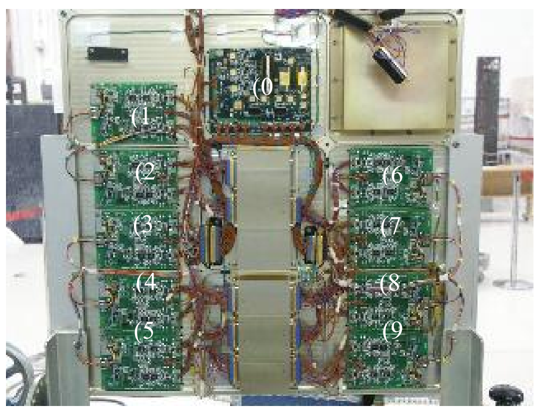

Figure 4: Photograph of the DAC boards (1-9) and main microprocessor board (0) that perform the FTSCE electrical measurements. The metal box in the upper right of the photograph is the power control unit (PCU). The metal boxes in the center route wires from the solar cells mounted on the opposite side and serve to maintain a Faraday cage around the measurement electronics.

Each DAC board is approximately 4x6 in^2 and is capable of measuring a 32 point IV curve on four individual solar cells, making two temperature measurements using AD590 temperature sensors, and taking data from one sun angle sensor. The temperature channels can be combined to measure temperature using a resistance temperature device (RTD), which provides a wider operating range than the AD590. A single temperature channel can also be configured to make a single IV point measurement on a cell.

The IV curve is created by using a field-effect-transistor (FET) as a variable resistor and thereby sweeping the load resistance while measuring the solar cell current and voltage. A comparison of data measured in a 3J $InGaP_2$/GaAs/Ge solar cell by one of the DAC boards with data measured by laboratory equipment is shown in **Figure 5**. These measurements were made consecutively while the solar cell was illuminated by the X-25 solar simulator in the NRL Solar Cell Characterization Laboratory, and the agreement can be seen to be excellent. Considering that most solar cell experiments employ a bank of switched load resistors for making the IV measurement, which requires much more space and weight, these measurement boards are a significant improvement.

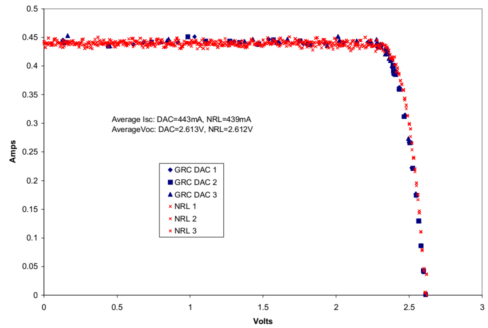

Figure 5: IV data measured on one of the FTSCE 3J InGaP/GaAs/Ge solar cells by a flight DAC board and software compared with measured by laboratory equipment.

The data acquisition software was also designed and written by the NASA GRC team. The DAC board software is responsible for taking commands from and returning data to the main microprocessor and measuring the IV curve, temperature, and sun angle. The software is designed to autonomously take data when user defined conditions of sun angle and temperature are met or on demand. Each DAC board can be commanded individually with a specific set of measurement criteria granting scientists flexibility in creating experimental data sets. For example, the DAC boards can be commanded to measure data once the sun angle is below a set threshold or once the temperature has exceeded a set threshold value.

The software resident on the main microprocessor board is responsible for receiving commands from the communication subsystem, decoding the commands, and passing the appropriate commands to the DAC boards. The main microprocessor software also receives data from the DAC boards, translates it into printable ASCII characters and passes it to the communications subsystem for down-linking. The main microprocessor software must also "oversee" the autonomous operation of the experiment, which consists of periodically recording readings from all of the temperature sensors to give a temperature profile for the PEC during each orbit and monitoring the temperature and sun angle data and determining if the measurement conditions have been reached.

POWER SUBSYSTEM

In sunlight the experiment is powered by an array of 4 strings of Emcore ATJ solar cells (Figure 1). Each string has 9 cells wired electrically in series to produce an open circuit voltage (Voc) of approximately 23.09 Volts. Power from the 4 strings is fed into the Power Control Unit (PCU). The PCU distributes power to the data acquisition electronics and the communications subsystem and regulates charge current to the battery.

When the power array is shadowed, by either the ISS itself or normal orbit eclipses, the experiment is powered by 4 high capacity (55 A-hr) prismatic Lithium Ion (Li-ion) batteries. This will be the first flight of this battery technology and one of the first flights of a Li-ion battery system in a low Earth orbit (LEO) space environment. Lithion of Pawcatuck, Connecticut, manufactured the battery cells. The cells are wired together in series to provide a bus voltage of 12.0 to 16.0 volts. The PCU uses a shunt regulator to reduce the charge current to the battery when the battery voltage reaches 16.0 volts. An under-voltage detection circuit sheds all non-critical loads when the battery voltage drops below 11.5 volts.

COMMUNICATIONS SUBSYSTEM

The communications subsystem was designed and built by the US Naval Academy (USNA). The system is called PCSat2, is an Amateur Satellite Communications system similar to what it is flying on PCsat (http://www.ew.usna.edu/~bruninga/pec/pc2ops.html). The PCSat2 subsystem operates in the ITU Amateur Satellite Service in cooperation with ARISS and provides a PSK-31 multi-user transponder, an FM voice repeater for possible use with ISS Crew communications, and an AX.25 packet system for use as a UI digipeater and for TNC. PCSat2 uses the same dual redundant AX.25 command and control system as used on PCsat (NO-44) offering 8 on/off commands, 5 telemetry channels and a serial port for the FTSCE telemetry. It also supports the Digital Comms Relay support of the PCsat2/APRS mission. The packet uplink is on 145.825 MHz and the default downlinks are in the 435 MHz band to avoid any possible interference with existing ARISS missions. PCSat2 has quad redundant transmit inhibits for EVA safety issues, thus it is easy to deactivate to avoid any issues with other UHF ARISS experiments that may be activated in the future.

One of the key issues with any Amateur Radio experiments on ISS is the requirement to avoid any mutual interference between systems. For this reason, ARISS will need to eventually move all uplinks and downlinks into separate bands. This is so that multiple uplinks and multiple downlinks can be going on simultaneously. As it is, with both uplinks and downlinks on 2 meters, that band cannot be shared without mutual interference. Thus PCSat2 is designed as with VHF uplinks and UHF downlinks to avoid transmitting on 2 meters, even though mode B (downlinks on 2 meters) is far superior to reaching schools and low-tech stations and meeting our mission objectives. There is much UHF equipment being planned for ISS, but until it is operational and ARISS has a long range plan, this dual frequency mode must be used.

MISSE PROGRAM

The MISSE Program is a NASA program designed to provide access to space for new materials and devices being considered for use in space (http://misse1.larc.nasa.gov/). Experiments are placed into a Passive Experiment Container (PEC) which is a metal box approximately 2x2 ft^2 x 4 inches thick fabricated by NASA LaRC (**Figure 6**). The experiments are mounted on custom designed trays that mount within the PEC. When closed, the PEC provides the container for the experiments for launch on the Shuttle and transfer to the ISS. For deployment, the PEC is clamped to a handrail on the exterior of the ISS by an astronaut who then opens the PEC to expose the experiments. After a period of time, an astronaut closes the PEC, and it is returned to Earth allowing post-flight analysis of the experiments.

ASSEMBLY OF MISSE-5 WITHIN THE PEC AND DEPLOYMENT ON ISS

The fully assembled MISSE-5 experiment is shown in Figure 7. The FTSCE is seen on one side of the PEC, and the Thin-film Materials experiment is seen on the other side. Beneath the FTSCE deck are mounted the measurement electronics and the PCU. The Thin-film Materials experiment is attached to the thermal blanket that covers the PCSat2 transmitter, receiver, and TNC boxes. The Li-ion batteries also reside within the side of the PEC covered by the Thin-film Materials experiment.

Visible at the hinged corners of the PEC under the thermal blanket are the two antenna assemblies. On deployment, the astronaut grasps the white triangular pieces to fold the antennas into the deployed position. The “on/off” power switch is visible in the cut-out of the thermal blanket near the bottom of the photograph along with the green “safe-plug” on the side of the PEC. There is also a red “arm-plug” next to the “safe-plug” that is not visible in the photograph. These plugs and the switch are safety features to inhibit power from the experiment until after deployment. Once deployed, the astronaut swaps the “safe/arm-plugs” and toggles the power switch from “off” to “on”. Upon power-up, an 8 hour count-up timer is initiated, which inhibits power to the PCSat2 transmitters. This allows 8 hours for the astronaut to clear the area prior to RF transmissions, which may interfere with the astronaut’s space suit.

The team lead by Mr. David Hess of the US Air Force Space Test Program (STP) OLAW Office located at the Johnson Space Center in Houston directed and coordinated the integration and launch and is presently supporting the ongoing operation onboard ISS and the eventual retrieval and return of MISSE5.

MISSE5 was deployed by Astronaut Soichi Noguchi during the third space walk of STS-114 on August 3, 2005. Astronaut Noguchi attached the PEC to a handrail on the top of the P6 truss, between the main ISS solar arrays. A still-shot from the Astronaut Noguchi’s helmet camera showing him deploying MISSE5 is shown in Figure 8 where his hand is visible grasping the PEC on the lower left corner. A photograph of MISSE5 deployed on the P6 truss taken from the Shuttle is shown in Figure 9.

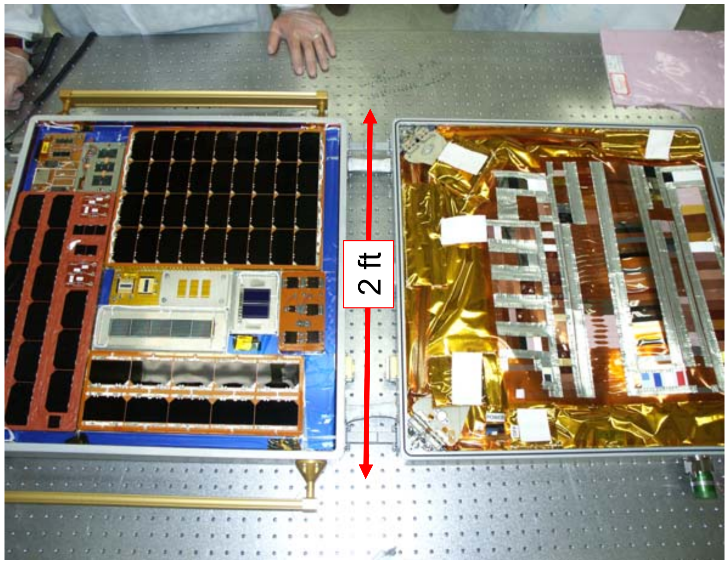

Figure 7: Photograph of MISSE-5 fully assembled within the PEC

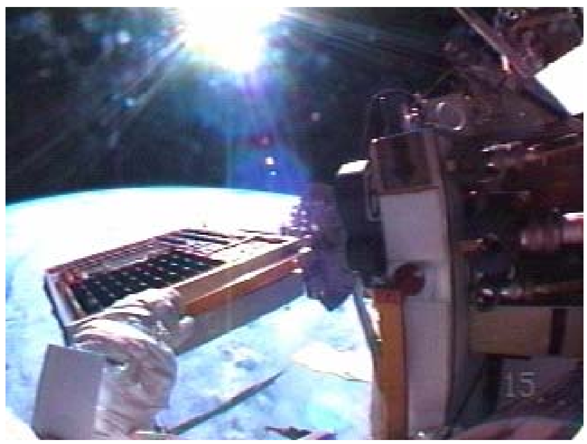

Figure 8: A still shot from Astronaut Soichi Noguchi's helmet camera showing him deploying MISSE5 on the top of the ISS P6 truss

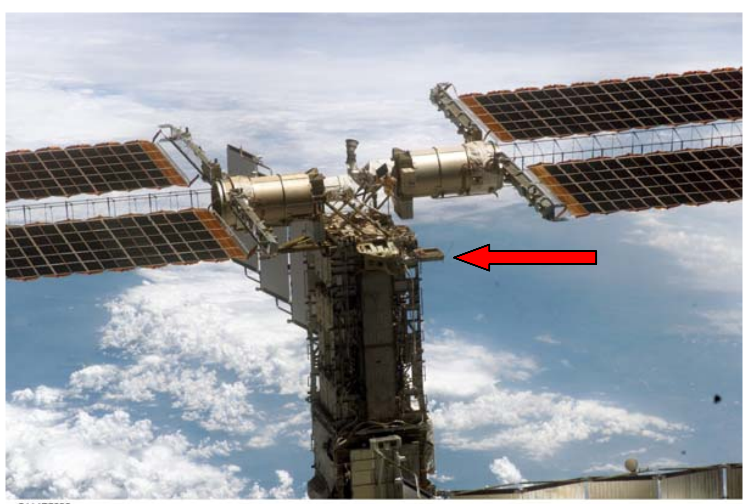

Figure 9: A photograph of the P6 truss and solar arrays of the ISS in which MISSE5 is visible in the center. This was taken by the

CONCEPT OF OPERATIONS

The general concept of operations for MISSE5 is for PCSat2 to regularly beacon the measured data for reception by any amateur radio station. Once received, the data packets are fed live via the global amateur satellite ground station network to NASA GRC via the internet. At NASA GRC, the raw experiment packets are converted to engineering data. These data are then transferred to NRL for analysis. The data are then distributed to the individual experimenters.

The USNA station (WB4APR – Bob Bruninga) serves as the primary command station with NASA GRC serving as the alternate command station (KC8SRG – Phil Jenkins). The MISSE5 team would like to specially acknowledge the following ground stations that currently serve as backup command stations, and without whom, this mission could not have been accomplished:

N6CO, David G. Larsen, California backup command
G4DPZ, David Johnson, London backup command
VK2XGJ, John Simon, Australia backup command
ZL1AOX, Ian T. ASHLEY, New Zealand backup command
G6LVB, Howard Long, London backup command

In addition, the MISSE5 team would like to specifically acknowledge the following ground stations that have participated in capturing the FTSCE data. Again, without their participation, MISSE5 could not have achieved its current level of success.

DK3WN, N6NR, VA2LT, PD0RKC, G1ONC, W7DAS, KA2UPW, F6BYJ, CT1EAT, YV5KXE, DL8DR, ZL1AOX,JA6PL, ZR1CBC, ZR1ARN, G0ORX, WA4SSP, JJ1WTK, W7KKE, KG4WMF, ZL1KM, P43L, N8MH, JE9PEL, OK2AQK, IK5QLO, YV-6-PM ,K1ICO, ON5PV, JN35UI, ZL3RX, WB4APR, KC8SRG, ZL3RX, 9W2QC, HB9SKA , WB6CYP, JE4SMQ, JH4DHX, KE6DZD, DK3TL, and VE2DWE

This concept of operations highlights how PCSat2 provides a communications system in the Amateur Satellite Service that in turn provides an off-the-shelf solution for Telemetry Command and Control for MISSE5. However, the disadvantage of this system is the lack of complete global coverage of the ground stations. The USNA and NASA GRC serve as primary ground stations, but this does not provide global connectivity. Therefore, it is not expected that every data transmission will be captured in full. To compensate for this, the system is designed to make redundant data transmissions every three minutes.

In addition to the FTSCE data, the spacecraft telemetry is also transmitted in beacon mode once every 10 to 30 seconds again for collection via volunteer ground stations. This live data is fed to web pages so that operators at any time can check on the health and performance of the spacecraft. The following links are used:

Live Telemetry Snapshot: http://www.pcsat2.info/PCSat2Web/RealTime.jsp
Live Telemetry 7 day trends: http://www.findu.com/cgi-bin/pcsat-tele2.cgi
Live USER packet page: http://www.findu.com/cgi-bin/pcsat2.cgi

FIRST ON-ORBIT MEASURED DATA

As described in the Data Acquisition section, the FTSCE electronics measure the sun angle sensors and the array of temperature sensors distributed thought out the PEC. This is done every ten minutes to create an orbital profile of temperature and illumination across the PEC. The approximate locations of the temperature sensors attached to the solar cell experiments are shown in Figure 11. Temperature data measured throughout September 23 are shown as an example in Figure 10 for the aSi on stainless steel and the Emcore experiment panels along with the experiment deck temperature. The ISS orbit places the PEC in the sun for about 60 minutes and in shadow for about 30 minutes, and this orbital cycling can be seen in the thermal profile. No FTSCE data packets containing data measured between about 2:00 and 7:30 were captured, so there is a lack of data apparent in that time frame. Each of the solar cell coupons is thermally isolated from the experiment deck, which is evidenced in the rather large excursions in the solar cell experiment temperatures compared to the experiment deck temperature. The TFSC experiments have much less thermal mass than the other experiments, and as such, the aSi on stainless steel coupon temperatures are seen to cover a wider range than the Emcore panel. A graph of the data from these three temperature sensors over the first approximately six weeks of orbit are shown in Figure 12, which gives an indication of the overall thermal cycling environment that the FTSCE will experience.

As the experiment is experiencing the thermal cycling, it is also experiencing illumination cycling as shown in Figure 13. These are short circuit current data measured on two different solar cells onboard FTSCE, namely a 2x2 cm^2 GaAs/Si cell and one of the 2x2cm^2 3J solar cells mounted beneath the silicone material experiment. These data show how the solar cells cycle from full illumination to eclipse through the ISS orbit. These data combined with the thermal data serve to quantify the cycling environment that the FTSCE is experiencing on orbit.

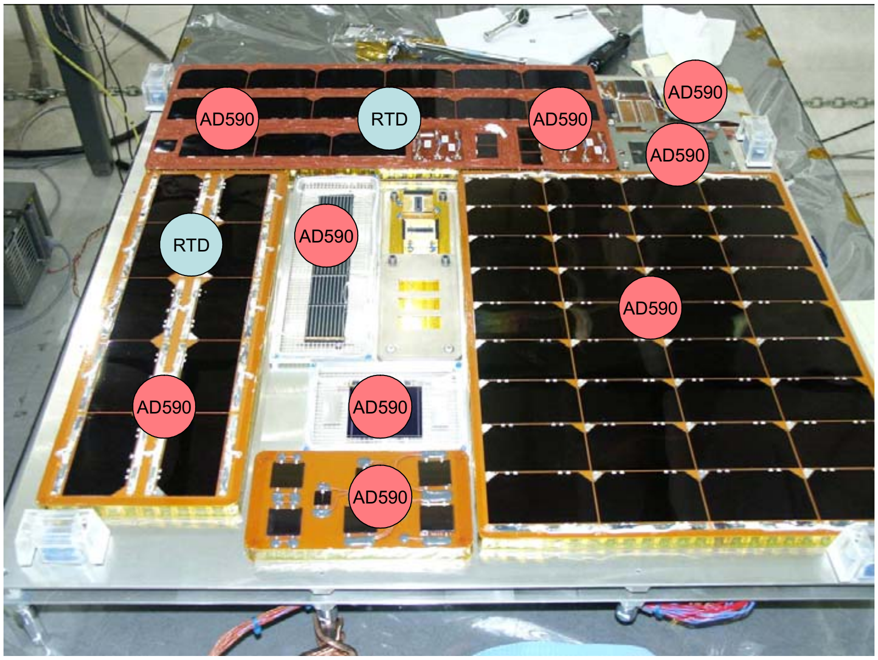

Figure 11: The label indicate the approximate locations of the temperature sensors mounted on the FTSCE panels.

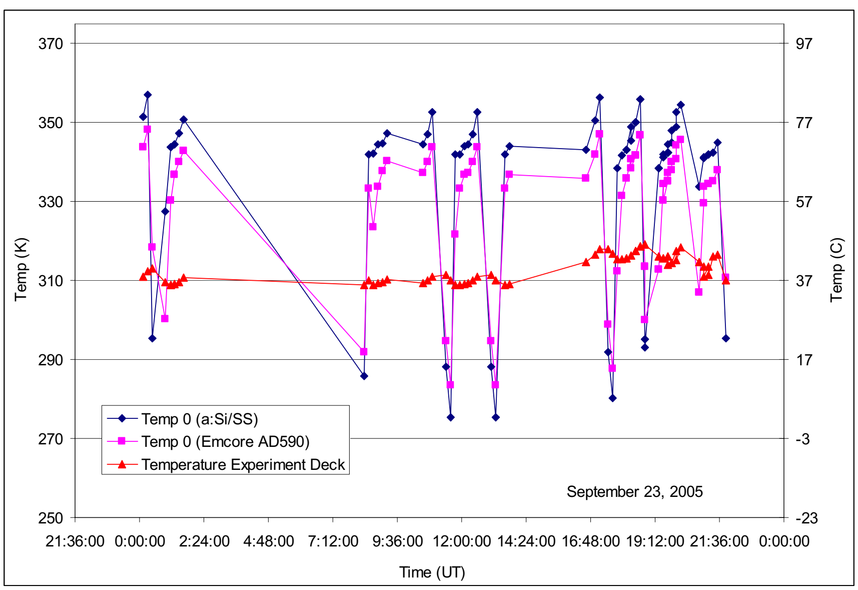

Figure 10: An example of the thermal profile data measured on two of the FTSCE experiments: aSi on stainless steel (a:Si/SS) and Emcore (the AD590 temperature senor on that panel along with the experiment deck temperature.

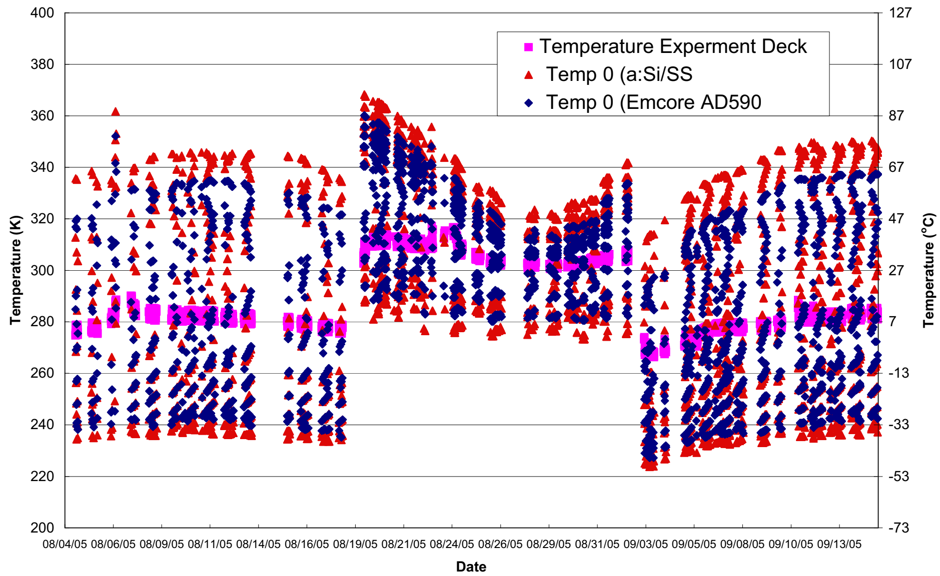

Figure 12: Temperature data measured onboard MISSE5 during the first six weeks of orbit. The data labeled Temperature Experiment Deck refer to the temperatures sensor mounted to the deck holding the solar cell experiments. The data labeled a:Si/SS refer to the temperature sensor mounted on the aSi on stainless steel experiment. The data labeled Emcore AD590 refer to the AD 590 temperature sensor mounted on the Emcore experiment panel.

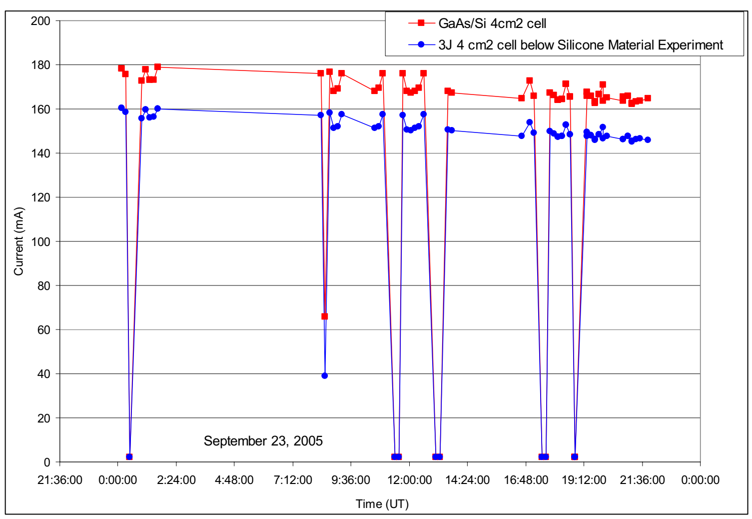

Figure 13: Short circuit current data measured on two of the FTSCE samples showing the illumination cycling experienced by FTSCE over the ISS orbit.

An example of measured IV curves are shown in Figure 16. These data were measured in a 3J InGaP/GaAs/Ge solar cell, one from each of the two vendors. Measurements at different solar angles and temperatures are shown, and the data have not been corrected to any standard measurement condition. These data highlight the high quality of data being received. Note that the best IV curve was the most recently measured one with the smallest solar illumination angle. These data indicate that the 3J cells are performing very well with no indication of degradation.

An example of IV curves measured in a GaAs/Si solar cell is shown in Figure 16, and an example of the IV curves measured in the aSi on kapton module is shown in Figure 16. Again, these data show these cell technologies to be performing quite well with no indication of degradation.

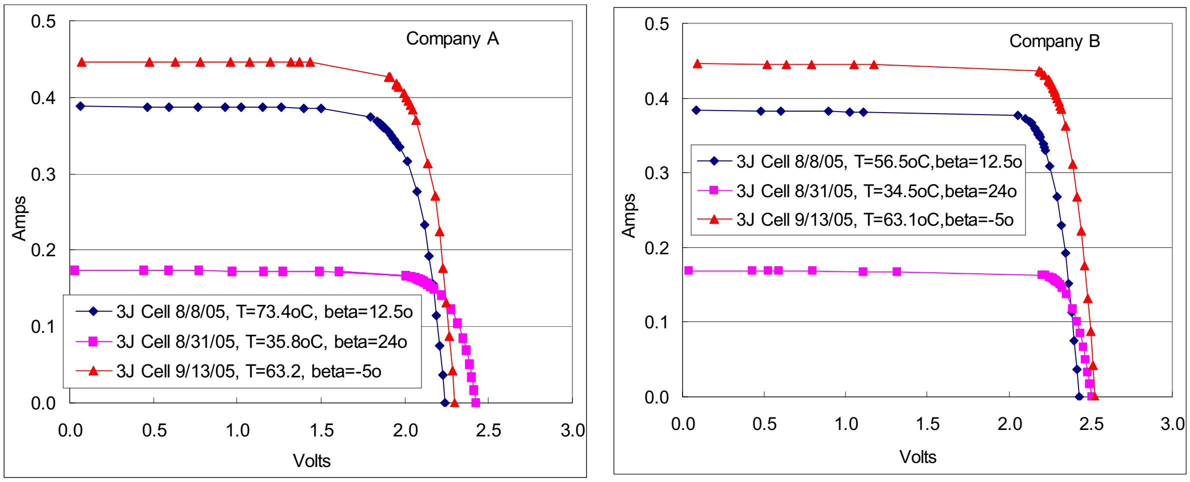

Figure 16: Representative IV curves measured on 3J InGaP/GaAs/Ge solar cells onboard MISSE5. The measurement temperature and solar illumination angle (beta) are shown in the legend.

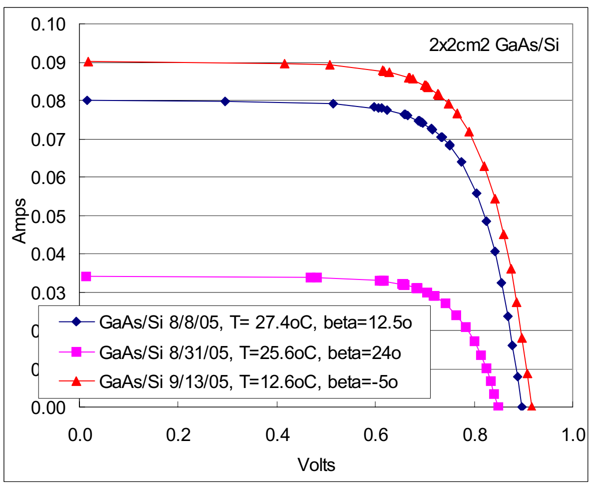

Figure 16: Example IV curves measured in a GaAs/Si solar cell onboard FTSCE. The measurement temperature and solar illumination angle (beta) are shown in the legend.

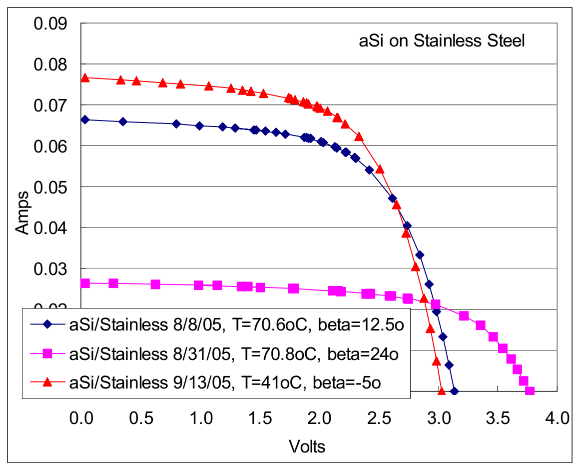

Figure 16: Example IV curves measured in an aSi on stainless steel solar cell onboard FTSCE. The measurement temperature and solar illumination angle (beta) are shown in the legend.

SUMMARY

This paper has given an overview and a quick look at initial data from the FTSCE onboard MISSE5. The data retrieval and analysis continue. NRL is in the process of establishing a webpage that will display near real-time data from the experiment along with general spacecraft telemetry information. This will document the daily performance of the experiment while on orbit. MISSE5 is scheduled to be on orbit for one year. After one year, the PEC will be retrieved and returned to Earth. The PEC will be returned to NRL for de-integration. All of the solar cell technologies will be fully characterized. Continuous reports of the MISSE5 status will be made in the upcoming PV conferences.

REFERENCES

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[2] M. Gonzalez, C. L. Andre, R. J. Walters, and S. A. Ringel, "Grown-in and Radiation-Induced Deep Levels in High-Performance GaAs Solar Cells on SiGe/Si", Paper 8AV.3.39, Paris, France June (2004).

Table 2: Thin-film materials samples flown on MISSE-5. The Sections refers to the location of the material on the experiment blanket (Figure 3)

Sections	Material ID #	Organization	Material	Area
A-1	C301	MSFC	Aluminized beta cloth	0.75" x 1.5"
A-2	C302	MSFC	Aluminized beta cloth	0.75" x 1.5"
A-3	C303	MSFC	Super beta cloth	0.75" x 1.5"
A-4	C310	MSFC	Black Beta Cloth	0.75" x 1.5"
B-01	C421	Team	PTFE	0.75" x 2.5"
B-02	C422	Team	0.1 mil Kapton over PTFE	0.75" x 2.5"
B-03	C423	Team	0.3 mil Kapton over PTFE	0.75" x 2.5"
B-04	C424	Team	FEP	0.75" x 2.5"
B-05	C426	Team	0.3 mil Kapton over FEP	0.75" x 2.5"
B-06	C429	Team	0.3 mil Kapton over THV	0.75" x 2.5"
B-07	C430	Team	Tedlar	0.75" x 2.5"
B-08	C433	Team	Tefzel	0.75" x 2.5"
B-09	C435	Team	PFA	0.75" x 2.5"
B-10	C436	Team	THV	0.75" x 2.5"
B-11	C438	Team	Halar	0.75" x 2.5"
B-12	C439	Team	PVDF	0.75" x 2.5"
B-13	C440	Team	TEFLON AF 1600	0.75" x 2.5"
B-14	C444	Team	Kapton environment witness sample - 5 mil	0.75" x 2.5"
B-15	C446	Team	0.3 mil Kapton over PVDF	0.75" x 2.5"
B-16	C447	Team	polyethylene (low oxygen) - Kapton H - Y966	0.75" x 2.5"
B-17	C448	Team	Polypropylene	0.75" x 2.5"
B-18	C432	Team	0.3 mil Kapton over Tedlar	0.75" x 2.5"
B-19	C434	Team	Aclar	0.75" x 2.5"
B-20	C442	Team	Ag Teflon	0.75" x 2.5"
B-21	C471	LaRC	4CN Piezo	3/8" x 2.5"
C-1	C503	Boeing-PW	1.0% doped uralane 5753	0.5" x 1.5"
C-2	C504	Boeing-PW	1.2% doped uralane 5753	0.5" x 1.5"
C-3	C505	Boeing-PW	Nichrome on 2.0 mil PET	0.5" x 1.5"
C-4	C506	Boeing-PW	Ti on NiCr on 2.0 mil PET	0.5" x 1.5"
C-5	C507	Boeing-PW	Chrome on 5.0 mil Teflon	0.5" x 1.5"
C-6	C510	Boeing-PW	Goldizing on 3.0 mil Kapton	0.5" x 1.5"
D-1	C225	LaRC	CP2 Coated w/ SWNT (top)	3/8" x 1.5"
E-01	C033		MLBT -12	0.5 " x 1.5"
E-02	C034		MLBT-11	0.5 " x 1.5"
E-03	C484		Estane 5714, neat	0.5" x 1.5"
E-04	C485		Estane 5714, PR-24-HT (5vol%)	0.5" x 1.5"
E-05	C486		Estane 5714, PR-19-HT (15vol%)	0.5" x 1.5"
E-07	C488		Phosphine oxide arylene ether ketone based on cyclohexane	0.5" x 1.5"
E-08	C489		Phosphine oxide arylene ether ketone based on diamantine	0.5" x 1.5"
E-09	C490		Nylon 6 film, Capron 8209, base resin	0.5" x 1.5"
E-10	C491		2wt% LS in nylon 6 film, in-situ polymerized (Ube)	0.5" x 1.5"
E-11	C492		5wt% LS in nylon 6 film, in-situ polymerized (Ube)	0.5" x 1.5"
E-12	C493		5wt% LS in nylon 6 film, 30B	0.5" x 1.5"
E-13	C494		5wt% LS (30B) in nylon 6, melt processed, blown film	0.5" x 1.5"
E-14	C495		5wt% LS (93A) in nylon 6, melt processed, blown	0.5" x 1.5"

			film	
E-15	C496		Polypropylene (PP) base resin (Dow)	0.5" x 1.5"
E-16	C497		Polypropylene - LS nanocomposite (proprietary), insitu polymerized	0.5" x 1.5"
E-17	C498		Low-Density Polyethylene (LDPE) base resin (Dow)	0.5" x 1.5"
E-18	C499		LDPE-LS nanocomposite (proprietary), insitu polymerized (Dow)	0.5" x 1.5"
E-19	C512		MLBT-4	0.5" x 1.5"
E-20	C511		MLBT-6	0.5" x 1.5"
F-1	C501	LaRC	Irradiated Pd Polyimide	5/8" x 1.5"
F-2	C242	LaRC	Irradiated Polyimide Control	5/8" x 1.5"
G-1	C489A	LaRC	Ultem with 1% nanoal	3/8 " X 1.5 "
H-01	C224	LaRC	CP2 neat	3/8 " X 3 "
H-02	C227	LaRC	TOR-NC neat	3/8 " X 3 "
H-03	C228	LaRC	TOR - NC coated w/SWNT,top	3/8 " X 3 "
H-04	C229	LaRC	TOR - NC coated w/SWNT,bottom	3/8 " X 3 "
H-05	C230	LaRC	Alkoxysilane-CP2 neat	3/8 " X 3 "
H-06	C231	LaRC	Alkoxysilane-CP2 w/0.05%SWNT	3/8 " X 3 "
H-07	C232	LaRC	Alkoxysilane-CP2 coated w/SWNT,top	3/8 " X 3 "
H-08	C233	LaRC	Alkoxysilane-CP2 coated w/SWNT,bottom	3/8 " X 3 "
H-09	C234	LaRC	CP2 Control Polyimide	3/8 " X 3 "
H-10	C236	LaRC	Azo benzene polyimide 2	3/8 " X 3 "
H-11	C237	LaRC	Azo benzene polyimide 3	3/8 " X 3 "
H-12	C238	LaRC	Shape memory polyimide 1	3/8 " X 3 "
H-13	C239	LaRC	Shape memory polyimide 1	3/8 " X 3 "
H-14	C240	LaRC	Irradiated Pt polyimide	3/8 " X 3 "
H-15	C241	LaRC	Pd polyimide "terlayer (HI)	3/8 " X 3 "
H-17	C247	LaRC	Pure Ultem	3/8 " X 3 "
H-18	C248	LaRC	Ultem with 5% nanoal	3/8 " X 3 "
H-19	C252	LaRC	Ln-conta""g polyimide film	3/8 " X 3 "
H-20	C253	LaRC	Au Self-metalliz"g film, N2 cure	3/8 " X 3 "
H-21	C254	LaRC	Au Irrad. Self-metalliz"g film	3/8 " X 3 "
H-22	C255	LaRC	Azobenzene CP polyimide film 1	3/8 " X 3 "
H-23	C256	LaRC	Azobenzene CP polyimide film 1	3/8 " X 3 "
H-24	C257	LaRC	Self-metalliz"g polyimide film 4	3/8 " X 3 "
H-25	C270	LaRC	uncoated polymer film	3/8 " X 3 "
H-26	C271	LaRC	coated polymer film 1	3/8 " X 3 "
H-27	C272	LaRC	coated polymer film 2	3/8 " X 3 "
H-28	C273	LaRC	Kapton with 15% Alacac	3/8 " x 3 "
H-29	C463	LaRC	002ASPiezo	3/8 " X 3 "
H-30	C464	LaRC	01ASPiezo	3/8 " X 3 "
H-31	C465	LaRC	05ASPiezo	3/8 " X 3 "
H-32	C466	LaRC	1ASPiezo	3/8 " X 3 "
H-33	C467	LaRC	5ASPiezo	3/8 " X 3 "
H-34	C469	LaRC	1CNPiezo	3/8 " X 3 "
H-35	C470	LaRC	1CNCLPiezo	3/8 " X 3 "
H-36	C500	LaRC	Pure Kapton	3/8 " X 3 "
H-37	C502	LaRC	Pd polyimide "terlater (LI)	3/8 " X 3 "
H-38	C246	LaRC	Kapton with 10% Alacac	3/8 " X 3 "
H-39	C245	LaRC	Kapton with 5% Alacac	3/8 " X 3 "
H-40	C468	LaRC	0103Piezo	3/8 " X 3 "
H-41	C469	LaRC	1 CNPiezo	3/8 " X 3 "

I-1	C129	Boeing-PW/AZ Tech.	AZ70WIZT White Coat"g	0.75" x 1.5"
I-2	C128	Boeing-PW/AZ Tech.	AZ2000IECW Semi-conductive White Coat"g	0.75" x 1.5"
I-3	C130	Boeing-PW/AZ Tech.	AZ2100IECW White Electrically Dissipative Coat"g	0.75" x 1.5"
I-4	C131	Boeing-PW/AZ Tech.	AZ1000ECB Semi-conductive Black Coat"g	0.75" x 1.5"
I-5	C 226	LaRC	CP2 Coated w/ S WNT (bottom)	3/8" x 1.5"
J-01	C315	MURI-C	Kapton H	0.5" x 1.5"
J-02	C318	MURI-C	polyethene oxide	3/8" x 1.5"
J-03	C319	MURI-C	polyacrylic acid	3/8" x 1.5"
J-04	C320	MURI-C	polyv"ylmethyl ketone	3/8" x 1.5"
J-05	C321	MURI-C	polyv"yl acetate	3/8" x 1.5"
J-06	C336	MURI-C	POSS polyimide control (0 wt%)	3/8" x 1.5"
J-07	C337	MURI-C	POSS polyimide (5 wt%)	3/8" x 1.5"
J-08	C338	MURI-C	POSS polyimide (10 wt%)	3/8" x 1.5"
J-09	C339	MURI-C	POSS polyimide (15 wt%)	3/8" x 1.5"
J-10	C340	MURI-C	POSS polyimide (20 wt%)	3/8" x 1.5"
J-11	C344	MURI-C	POSS polyv"ylidene fluoride control (0 wt%)	3/8" x 1.5"
J-12	C345	MURI-C	POSS PVDF (2.5 wt%)	3/8" x 1.5"
J-13	C346	MURI-C	POSS PVDF (5 wt%	3/8" x 1.5"
K-01	C179	GRC	Teflon FEP	3/8" x 3"
K-02	C180	GRC	Teflon FEP	3/8" x 3"
K-03	C181	GRC	Teflon FEP	3/8" x 3"
K-04	C182	GRC	Teflon FEP with SiOx-PTFE coat"g	3/8" x 3"
K-05	C183	GRC	Teflon FEP with SiOx-PTFE coat"g	3/8" x 3"
K-06	C184	GRC	Teflon FEP with SiOx-PTFE coat"g	3/8" x 3"
K-07	C185	GRC	Polyimide Upilex W with SiOx coat"g	3/8" x 3"
K-08	C186	GRC	Polyimide Upilex W with SiOx coat"g	3/8" x 3"
K-09	C187	GRC	Polyimide Upilex W with SiOx coat"g	3/8" x 3"
K-10	C188	GRC	Fluor"ated CP1 with SiOx-PTFE coat"g	3/8" x 3"
K-11	C189	GRC	CP1 with SiOx-PTFE coat"g	3/8" x 3"
K-12	C190	GRC	CP1 with SiOx-PTFE coat"g	3/8" x 3"
K-13	C191	GRC	Polyimide Kapton E	3/8" x 3"
K-14	C192	GRC	Polyimide Kapton E	3/8" x 3"
K-15	C193	GRC	Polyimide Kapton E	3/8" x 3"
K-16	C194	GRC	Alum"ized Kapton E with SiOx-PTFE coat"g	3/8" x 3"
K-17	C195	GRC	Alum"ized Kapton E with SiOx-PTFE coat"g	3/8" x 3"
K-18	C196	GRC	Alum"ized Kapton E with SiOx-PTFE coat"g	3/8" x 3"
K-19	C197	GRC	PTFE	3/8" x 3"
K-20	C198	GRC	PTFE	3/8" x 3"
K-21	C199	GRC	PTFE	3/8" x 3"
K-22	C200	GRC	PTFE WITH SiOx coat"g	3/8" x 3"
K-23	C201	GRC	PTFE WITH SiOx coat"g	3/8" x 3"
K-24	C202	GRC	PTFE WITH SiOx coat"g	3/8" x 3"
K-25	C209	GRC	Polyimide Kapton HN	3/8" x 3"
K-26	C210	GRC	Polyimide Kapton HN	3/8" x 3"
K-27	C211	GRC	Polyimide Kapton HN	3/8" x 3"
K-28	C212	GRC	Kapton HN with SiOx-PTFE coat"g	3/8" x 3"
K-29	C213	GRC	Kapton HN with SiOx-PTFE coat"g	3/8" x 3"
K-30	C214	GRC	Kapton HN with SiOx-PTFE coat"g	3/8" x 3"
K-31	C215	GRC	Polyarylene ether benzimidazole, TOR LM	3/8" x 3"
K-32	C216	GRC	Polyarylene ether benzimidazole, TOR LM	3/8" x 3"
L-1	C037	LaRC	Environment monitor-A0- Kapton film	3/8 " X 1.5 "

L-2	C038	LaRC	Environment monitor-A0- Kapton film	3/8 “ X 1.5 “
L-3	C039	LaRC	Environment monitor-A0- Kapton film	3/8 “ X 1.5 “
L-4	C249	LaRC	Ultem with10% borane TMA	3/8 “ X 1.5 “
L-5	C250	LaRC	Ultem with15% borane TMA	3/8 “ X 1.5 “
L-6	C251	LaRC	Ultem with 20% borane TMA	3/8 “ X 1.5 “
L-7	C258	LaRC	laser reduced metal/polyimide film 1	3/8 “ X 1.5 “
L-8	C259	LaRC	laser reduced metal/polyimide film 2	3/8 “ X 1.5 “
L-9	C260	LaRC	laser reduced metal/polyimide film 3	3/8 “ X 1.5 “
L-10	C261	LaRC	laser reduced metal/polyimide film 4	3/8 “ X 1.5 “
M-02	C136	GRC	Cellulose acetate	0.5" x 1.5"
M-03	C137	GRC	Polybutylene terephthalate	0.5" x 1.5"
M-04	C138	GRC	Polychlorotrifluoroethylene	0.5" x 1.5"
M-05	C139	GRC	Crystall”e polyv”ylfluoride w/white pigment (white Tedlar)	0.5" x 1.5"
M-06	C141	GRC	Epoxy (Hysol EA 956) - Kapton H - Y966	0.5" x 1.5"
M-07	C142	GRC	Perfluoroalkoxy (Teflon PFA)	0.5" x 1.5"
M-08	C143	GRC	Tetrafluorethylene-ethylene copolymer (Tefzel)	0.5" x 1.5"
M-09	C144	GRC	PEO - Kapton HN - Y966	0.5" x 1.5"
M-10	C145	GRC	PMR 15 - Kapton H - Y966	0.5" x 1.5"
M-11	C146	GRC	Fluor”ated ethylene propylene (Teflon FEP)	0.5" x 1.5"
M-12	C147	GRC	PG, HOPG, G - Kapton H - Y966	0.5" x 1.5"
M-13	C148	GRC	Ethylene-chlorotrifluoroethylene (Halar)	0.5" x 1.5"
M-14	C149	GRC	Polyimide BPDA (Upilex S)	0.5" x 1.5"
M-15	C152	GRC	Poly-(p-phenylene terephthalamide) (Kevlar)	0.5" x 1.5"
M-16	C153	GRC	Polyamide 6 (Nylon 6)	0.5" x 1.5"
M-17	C154	GRC	Polyamide 66 (Nylon 66)	0.5" x 1.5"
M-18	C155	GRC	Polyacrylonitrile (Barex)	0.5" x 1.5"
M-19	C156	GRC	Polybenzimidazole	0.5" x 1.5"
M-20	C157	GRC	Polycarbonate - Kapton HN - Y966	0.5" x 1.5"
M-21	C158	GRC	Poly(p-phenylene-2 6-benzobisoxazole)	0.5" x 1.5"
M-22	C159	GRC	Polyethylene (low oxygen) - Kapton HN - Y966	0.5" x 1.5"
M-23	C160	GRC	Polyetheretherketone	0.5" x 1.5"
M-24	C161	GRC	Polyethylene terephthalate (Mylar)	0.5" x 1.5"
M-25	C162	GRC	Polyimide (CP1)	0.5" x 1.5"
N-1	C304	MSFC	Super beta cloth	0.75" x 1.5"
N-2	C305	MSFC	AZ93 on Kapton	0.75" x 1.5"
N-3	C307	MSFC	SiO/ Kapton E/ VDA	0.75" x 1.5"
N-4	C309	MSFC	Black Beta Cloth	0.75" x 1.5"
N-5	C519	MSFC	SiO CPI/ VDA	0.75" x 1.5"
O-1	C386	MURI-P	99.99% Al foil	1.5" x 1.5"
P-1	C347	MURI-C	POSS PVDF (10 wt%)	3/8" x 1.5"
P-2	C351	MURI-C	POSS Perfluoralkoxide control	3/8" x 1.5"
P-3	C352	MURI-C	POSS PFA (2.5 wt.%)	3/8" x 1.5"
P-4	C353	MURI-C	POSS PFA (10 wt.%)	3/8" x 1.5"
P-5	C360	MURI-C	al/Kapton lithographically etched	3/8" x 1.5"
P-6	C361	MURI-C	al/Kapton lithographically etched	3/8" x 1.5"
Q-1	C174	GRC	Polyphenylene isophthalate (Nomex)	0.5" x 1.5"
Q-2	CE5	GRC	Tetrafluoroethylene-ethylene copolymer (ETFE) Tefzel 500 LZ	0.5" x 1.5"
R-1	C095	Boe”g-PW	Germanium on black Kapton	0.75" x 1.5"

R-2	C098	Boe”g-PW	Germanium on Kapton	0.75" x 1.5"
S-1	C218	GRC	DC 93-500 Silicone	1" x 1.5"
S-2	C219	GRC	CV 1144 Silicone	1" x 1.5"
T-1	C163	GRC	Polymethyl methacrylate (Plexiglas)	0.5" x 1.5"
T-2	C164	GRC	Polypropylene - Kapton HN - Y966	0.5" x 1.5"
T-3	C165	GRC	POM - Kapton HN - Y966	0.5" x 1.5"
T-4	C167	GRC	Polysulphone	0.5" x 1.5"
T-5	C169	GRC	Polyeurethane	0.5" x 1.5"
T-6	C170	GRC	Polyv”ylidene fluoride (Kynar)	0.5" x 1.5"
T-7	C171	GRC	Polyv”yl fluoride (clear Tedlar)	0.5" x 1.5"
U-1	C172	GRC	Polyetherimide	0.5" x 1.5"
U-2	C173	GRC	Amorphous Fluoropolymer (Teflon AF)	0.5" x 1.5"
U-3	C175	GRC	Polyimide PMDA (Kapton E)	0.5" x 1.5"
U-4	C176	GRC	Polyamide-imide (Torlon) - Kapton HN - Y966	0.5" x 1.5"
U-5	C177	GRC	Ultra High Molecular Weight Polyethylene	0.5" x 1.5"
U-6	C220	GRC	MD944 Silicone adhesive tape	0.5" x 1.5"
U-7	C474	GRC	Polyv”yl chloride	0.5" x 1.5"
V-1	C475	GRC	Tetrafluoroethylene hexafluoropropylene v”ylidene fluoride	0.5" x 1.5"
V-2	C477	GRC	Expanded polytetrafluoroetylene (Gore-Tex)	0.5" x 1.5"
V-3	C478	GRC	Polytetrafluoroethylene (Teflon PTFE)	0.5" x 1.5"
V-4	C479	GRC	Polyimide PMDA (Kapton 100 CB)	0.5" x 1.5"
V-5	C480	GRC	Poly Arylene Benzimidazole (TOR)	0.5" x 1.5"
V-6	C481	GRC	Poly Arylene Benzimidazole (clear COR)	0.5" x 1.5"
V-7	C483	GRC	Polysulfone	0.5" x 1.5"
W-1	C133	Boeing-PW-AZ Tech.	AZW/LA-11 Low Alpha White Coat”g	0.75" x 1.5"
X - 1	CE-1	GRC	Polyethersulfone (PES)	0.5" x 1.5"
X - 2	CE-2	GRC	Polymethylpentent (PMP)	0.5" x 1.5"
Y - 1	C235	LaRC	Azo benzene polyimide 1	3/8" x 2.25"
Y - 2	C601	LaRC	Ultem with 1/2% nanoAl+	3/8" x 2.25"
Z-1	C217	GRC	Polyarylene ether benzimidazole, TOR LM	3/8" x 1.5"
Z-2	C315	MURI-C	Kapton H	0.5" x 1.5
Z-3	C135	GRC	Acrylonitrile butadiene styrene	0.5" x 1.5"