Spacecraft Plasma Interaction experiments SPIX performed in India

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Problem Definition

- To carry more transponders satellite bus voltage has to be increased from the present 42V to 100V.
- This level of power is likely to grow further upwards, which further requires an increased bus voltage.
- Increased satellite bus voltage leads to arcing on solar arrays which is a serious threat to the spacecraft.
- Mitigation techniques like grouting become questionable at the end of life conditions.
- A further complexity is caused due to the introduction of newer cells and cover glasses by manufacturers.

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Need for ground test

- Solar arrays arcing can not be studied in space, it has to be performed at ground.
- Therefore we have to design simulation chambers in the laboratories, where we can create the space like conditions/environment.
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Introduction

- **To initiate spacecraft plasma interaction activity an experimental facility has been commissioned at FCIPT.**
- **This is a collaborative project with ISRO. In this project arcing on solar arrays has been studied [for Low Earth Orbit (LEO) like plasma environment].**

SPIX Project

1. **To develop the basic understanding of space plasma environment and formation of arcs in LEO environment.**
2. **To develop a data base for a variety of coupon configurations.**
3. **To develop *preliminary models* of charging and arcing.**

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Development at FCIPT

i. Design and fabrication of experimental chamber

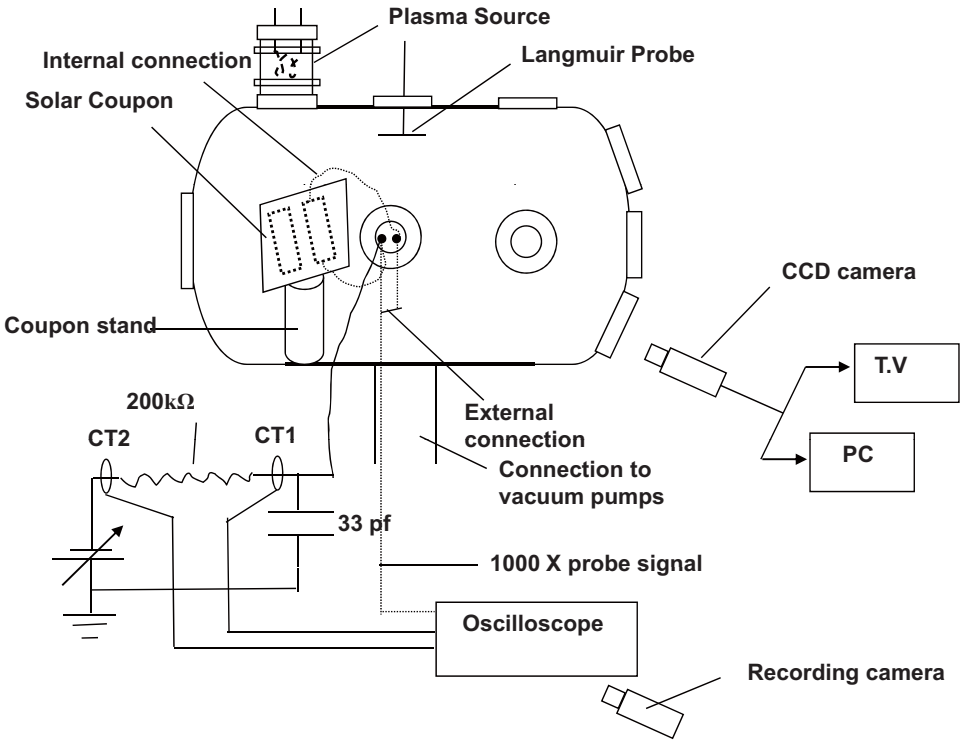
ii. Plasma source (Source + high voltage power supplies)

iii. Plasma diagnostics

iv. Vacuum compatible feedthroughs

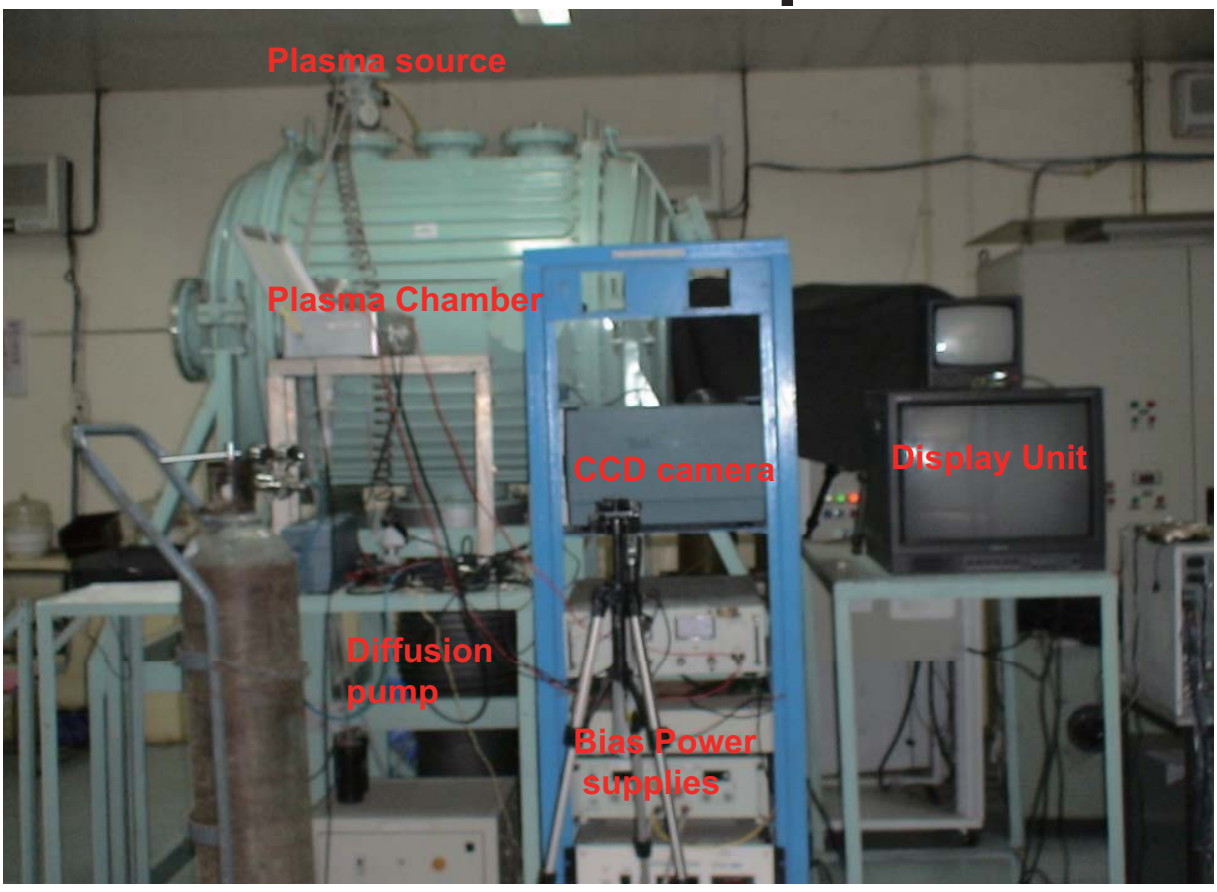
v. Installation and testing of various components.

Schematic of System at FCIPT



Experimental chamber

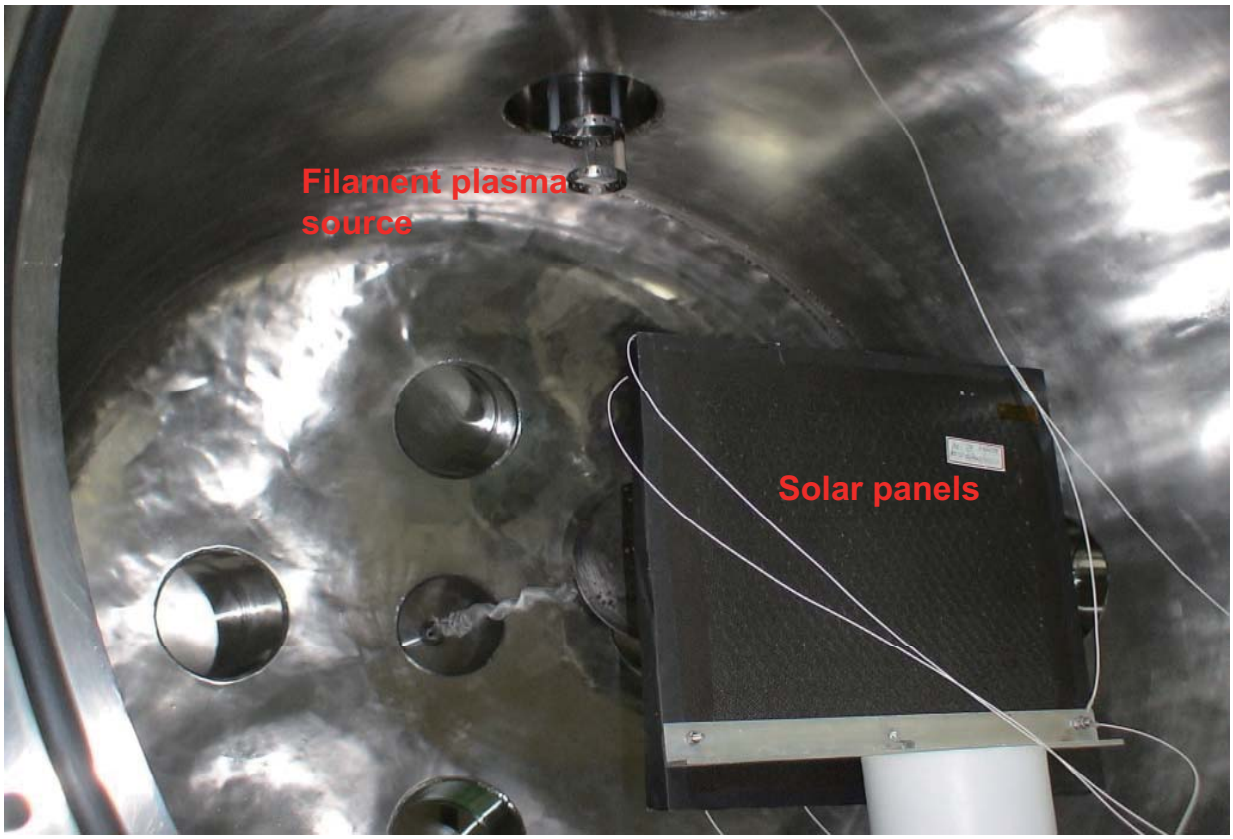
SPIX Setup



SPIX Setup

HV Power supply and Pumping unit

Plasma source



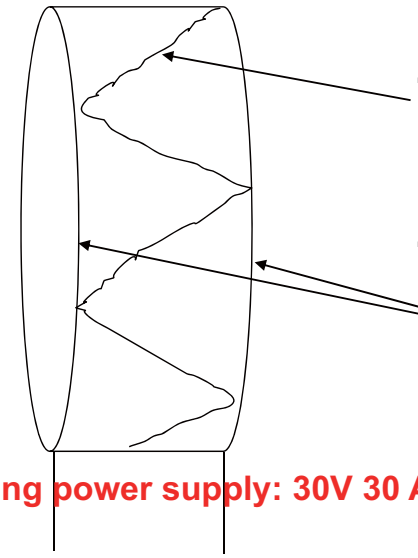
Diagnostic setup

Langmuir Probe Unit

Plasma Generation Scheme

Plasma was produced by impact ionization of Ar gas by energetic electrons emitted by thermionic emission from heated tungsten filaments.

- **The filaments are biased negative w.r.t. an anode to emit electrons.**
- **Emission of electrons from the filament can vary the plasma density.**



Thoriated Tungsten wire=0.5 mm

Two SS electrode (To hold filaments)

Plasma Densities: 10^{-5} - 10^{-7} cc^{-3}

Heating power supply: 30V 30 A

Plasma Generation Scheme

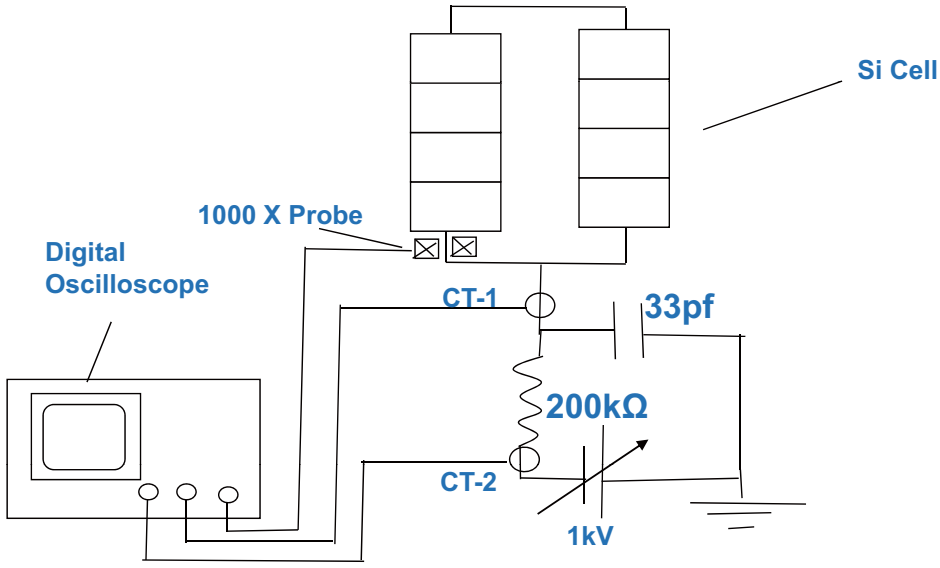
- Once the plasma density achieved and remains sable for 15 minutes external biasing to the solar coupon was applied. Initially voltage is increased. After applying this voltage, system is left for 30 minutes for curing.

Experimental parameter (LEO condition)

- Base pressure = $1x10^{-5}$ mbar
- Pressure during experiment = $5x10^{-5}$ mbar
- Gas used = Ar
- Filament power supply = 10.3 V / 23.1 A
- Biasing power supply = 63.0 V / 0.02 A
- Plasma Density = ~10^6 /cm^3
- Temperature = 1-2 eV

Experiment Schematics

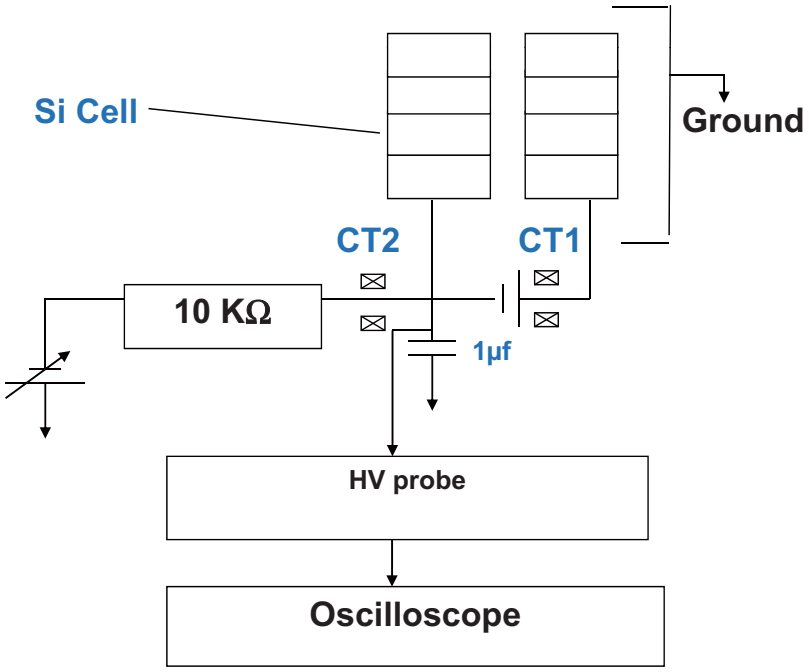
I- Cho's Configuration



Both terminals of solar coupons are shorted and negatively biased .
Minor arcs are observed.

Experiment Schematics

II - NASA Configuration

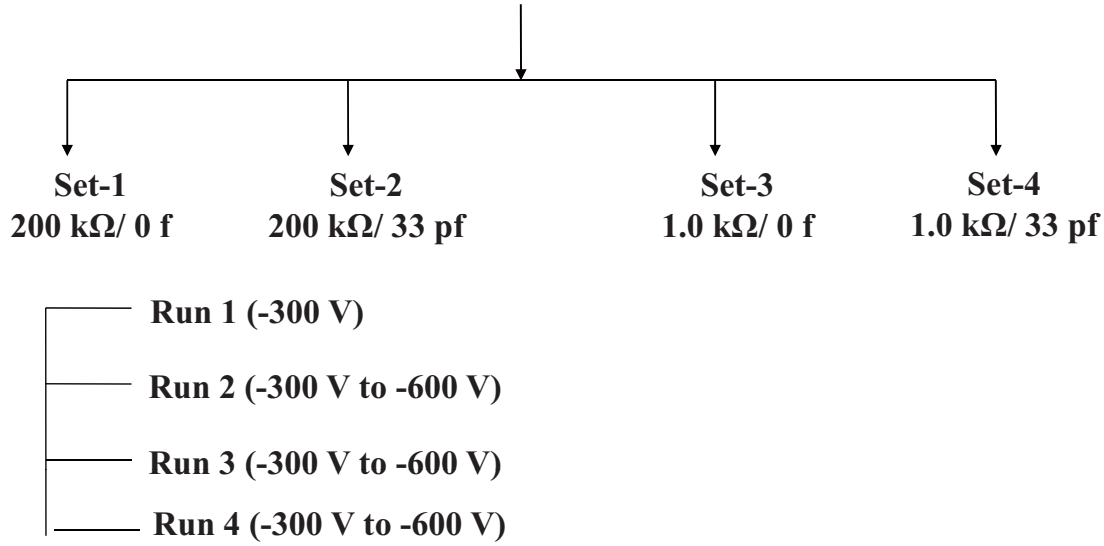


A potential is applied between to solar cell to simulate actual conditions.
Major arc take place at the triple junction

Experiments performed

Coupons given by ISAC : Si-Cell without grouting , Si-Cell with grouting , GaAs Cells, ATJ cells

Sets of experiment performed on each coupon



Curing Experiment

OBJECTIVES:

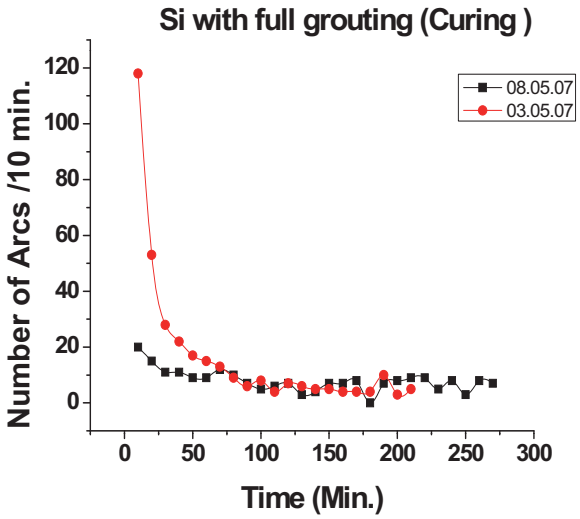
- To study the effect of curing on arc rate for Cho configuration with out grouting and partial or full grouting Si and ATJ solar arrays.

- To study the effect of density variation on arc rate for Cho's configuration with out grouting and partial or full grouting Si and ATJ solar arrays.

Base pressure : ~1.7 x 10^{-5} mbar
Operating pressure : 5 x 10^{-5} mbar
Cell biasing voltage : -600 V
Resistance (R1) : 200KΩ
Capacitance (C2) : 33pF

No.	Discharge Current (Amp)	Plasma Density (/cm^3)
1	0.02	0.65 x 10^6
2	0.03	1.85 x 10^6
3	0.04	2.28 x 10^6

Curing Experiment Results



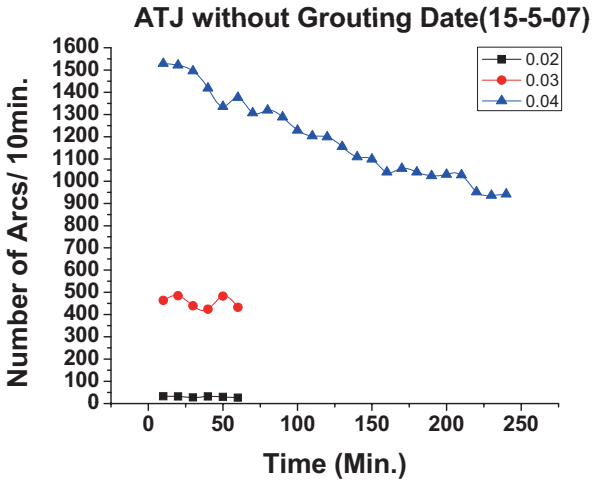
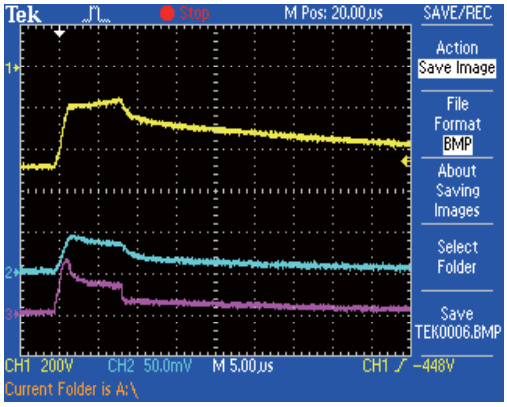


Figure of Curing data for Si with full grouting on 3rd may and then again repeated it on 8th may. It shows very good effect of curing.

Figure of density variation results for ATJ without grouting coupon on 15th may 2007. It clearly shows that arc rate increases with increase in density.

Typical Data of Recoded Set

Oscilloscope trace



- **10 minutes of oscilloscope waveform movie was recorded for each biasing voltage.**
- **Using a CCD camera, solar coupon movie clips was recorded for different run and sets for all coupons.**

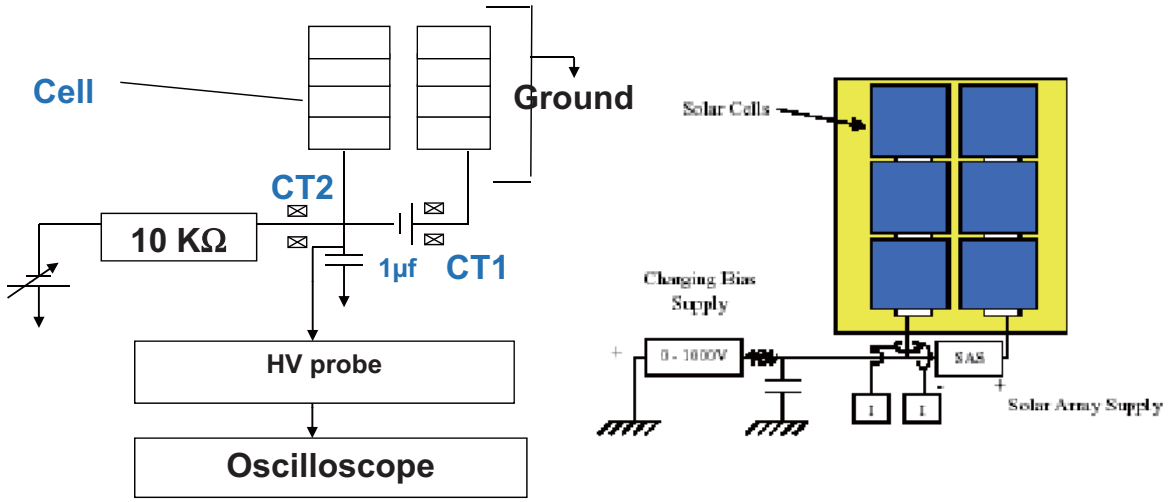
Discussion

- Initially in first few minutes the number of arcs were large in number and then it started decreasing with time and gets stabilized. This period was different for various coupons.
- During the next set of experiments, it again starts with the stabilized value of arcs, even when experiment was repeated after few days.
- Number of arcs increases with increase in plasma density.
- Arc rate is less in case of coupons with grouting whether partial or full grouting.
- In both Si and ATJ solar arrays with full or partial grouting after curing number of arcs reduces to 0 or 1 arc/10 min.

Conclusions

- For a given biasing voltage GaAs has minimum number of arcs per unit area.
- Si-Cell with grouting have less number of arcs.
- Number of arcs increases when an external capacitance (33 pf) is added to the circuit.
- More number of arcs occurs in coupling mode (1 kΩ resistance in circuit) compared to de-coupling mode (200 kΩ resistance in circuit).
- The results further indicate that for most of the cases the minimum number of arcs are obtained for GaAs, followed by Si-with grouting, Si-without grouting and ATJ cells comes after them.

NASA Type experiment in test setup



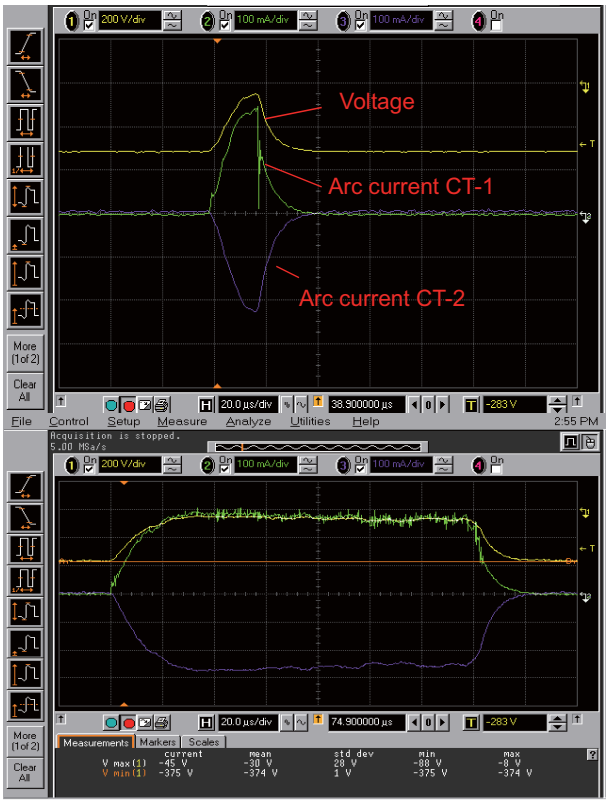
Comparison table of FCIPT/IPR and NASA Arc Experiments

Experimental Parameters	NASA	SPIX test setup
Operating Pressure	2 x 10^{-5} mbar	2.7 x 10^{-5} mbar
Gas Used	Xenon	Argon
Plasma Density	3-5x10^{6} cm^{-3}	1 x 10^{6} cm^{-3}
Solar Array Simulator	Used SAS voltage = 80V	Applied 80V
Bias Voltage	-200 V to -400 V	-200 V to -900V
Arc Site	Triple junction	Triple Junction
Capacitor Used	1µf	1 µf
Resistance	10 kΩ	10 kΩ
Peak Current During Arc	1-3 A	313 mA

Parameter & Obtained Results

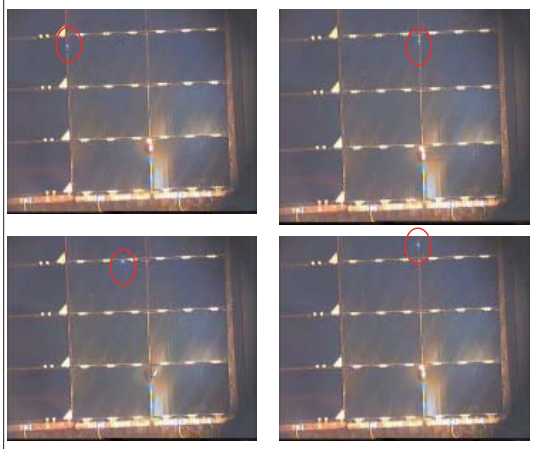
Experimental Parameters	SPIX setup
Operating Pressure	2.7 x 10^{-5} mbar
Gas Used	Argon
Plasma Density	1 x 10^{6} cm^{-3}
Solar Array Simulator	Applied 80V
Bias Voltage	-200 V to -900V
Arc Site	Triple Junction
Capacitor Used	1 µf
Resistance	10 kΩ
Peak Current During Arc	313 mA

Biasing voltage	No of arc /min.	Time duration
-310 V	6	30 µs
-375 V	7	160 µs
-425 V	12	240 µs
-450 V	18	310 µs

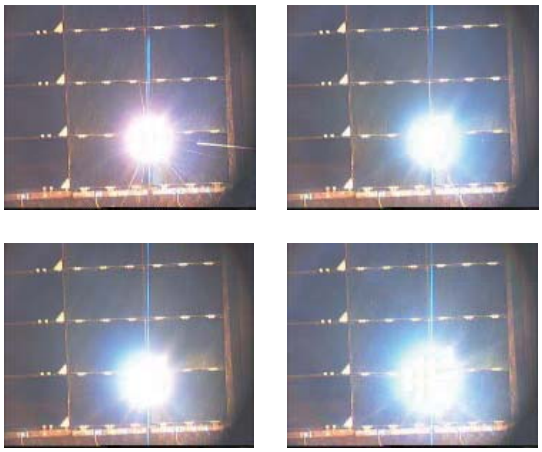


Trace of arc current at – 310 V & -375V applied voltage

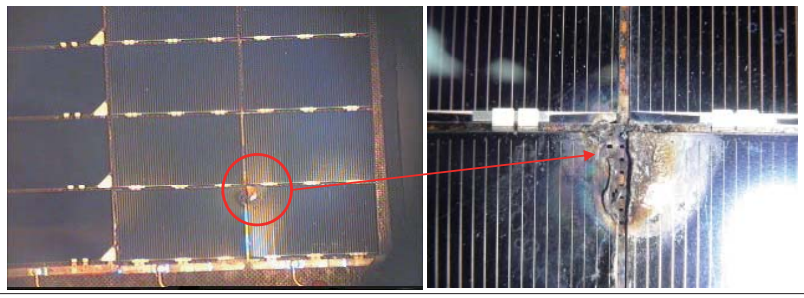
Captured Images at the time of Arcing



Minor Arcs shown at different locations between inter connectors.

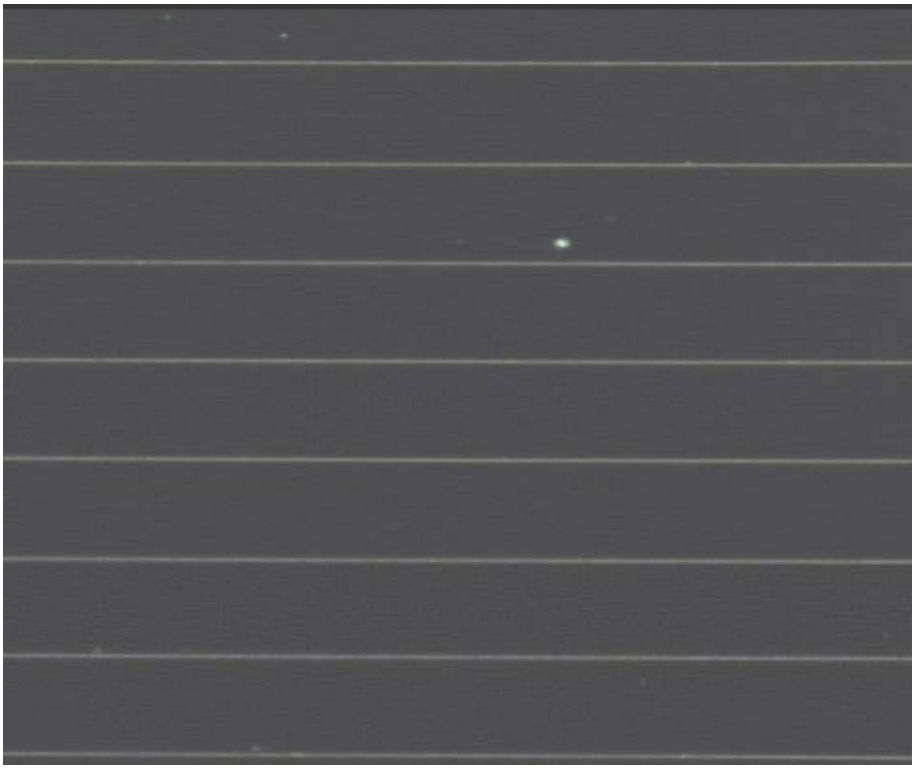


Evolution of the major Arc (SAS = 80 V, Bias = -407 V) with time (in seconds)

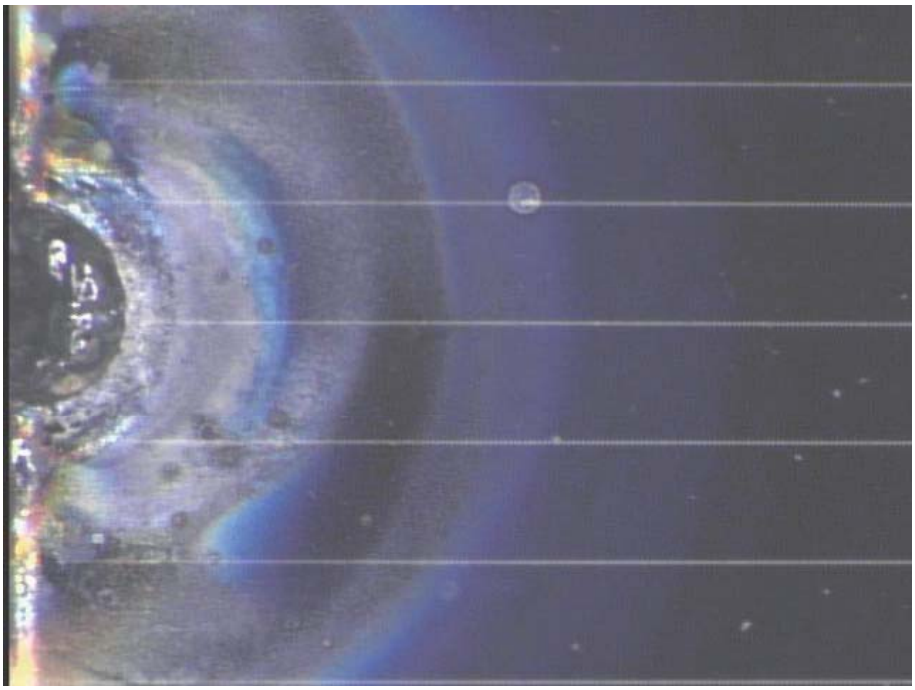


Damaged Solar Panel

PICTURE OF A PART OF A SOLAR CELL BEFORE PSA



PICTURE OF A PART OF THE SAME SOLAR CELL AFTER PSA



Conclusions

- In the absence of background plasma there is no arcing.
- If the pressure and/or plasma density increases arcing frequency and intensity increases.
- In this configuration, more than SAS, the overall bias contributes and control the arc properties.
- Once an sustained arc happens at some location all subsequent major (sustained) arcs have a tendency to initiate there.

SPIXFP & SPIXARC code

- Two codes have been developed:

1. SPIXFP – Spacecraft Plasma Interaction Experiment Floating Potential finder (Calculation of charging on a spherical body and body with tiny patch of different material on it). (Excellent agreement with EQUIPOT code by SPENVIS)

2. SPIXARC - Spacecraft Plasma Interaction Experiment Arcing estimation (Estimates the arcing characteristics from the arc experimental circuit/parameter). (Good match with our experiment)

Future work

- With suitable modification in existing LEO test facility we would like to upgrade it for GEO conditions.
- Therefore we are waiting for finalization of ISO document.
- The upgraded facility shall lead to saving of valuable time, money and use of existing facility in for both test purpose (LEO and GEO both).

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Methodology

Plasma + Irradiation studies

- Up-gradation and modification of the existing test facility to ISO standard which requires new design finalization, specification generation, procurement and integration of subsystems including electron gun and track probe. Development of necessary data acquisition software. Selection of sophisticated hardware to acquire the data. Integration/Installation of the instruments, subsystems and interfacing with data acquisition systems to prepare test facility for LEO and GEO combined.

- Primary and secondary arc experiments and data analysis for test facility.

RECOMMENDATIONS

- To minimize Charging

- Aluminum should not expose to the environment directly.

- Major difference in potential comes during transition from eclipse to sunlit. To avoid this one can use some external circuit so that temporarily it can't draw any power.

- To minimize Arcing

1. Prevention of minor arcs
   - All external circuit connector should be as small as possible.
   - Long duration curing before using cell to generate power.
   - Grouting of the solar panel coupon

2. Prevention of major arcs
   - All external circuit connector should be as small as possible.
   - Putting a current limiting device such as resistor or some active device
   - Increasing the string gap
   - Grouting of the solar panel coupon

POSSIBLE FUTURE ACTIVITIES

- To generate data base for simulation repetition of experiments performed at various labs.
- Some flight experiment should also be included (to find the surface potential and arc rate). The data base from flight experiment may give some clues for simulation.
- Effect of curing for longer period should be studied.
- Transparent film should be developed which can physically blocks ions from charging the cover glass surface.
- Plasma thruster interactions studies is required. (ex. interaction of thruster plume with solar panel).
- To improve our understanding about material properties detailed SEM and AFM microscopy study should be considered for analysis of damage coupons.

Thanks for your kind attention!