On Possible Arc Inception on Low Voltage Solar Array

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OUTLINE

- Detrimental effects of electrostatic discharges
- Characteristics of arcs
- Dependence of threshold voltage on environment
- Ground simulations
- Physical processes and explanation
- Conclusions

Cause of Power-Related Spacecraft Failures, 1993-2013

Failure Code	Cause	# of incidents	Loss ($ M)
PLD	Plasma Discharge	13	**$2,200**
SAM	Array Mechanical Failure	6	$1,622
DEP	Array Deployment failure	7	$425
DRI	Array Drive/gimbal failure	14	$399
ARY	Array failures (other)	16	$1,224
DAR	Darkening of glass or reflectors	15	$1,145
WIR	Wiring / interconnects	14	$676
BAT	Battery Failure	22	$356
CIR	Circuit failures	22	$341
CEL	Solar cell failures	9	$23
COM	Attitude or computer failure	8	$87
IMP	Impact	5	$54
UNK	Unknown or not specified	7	$376
Total		158	$8,928

Landis, 2013

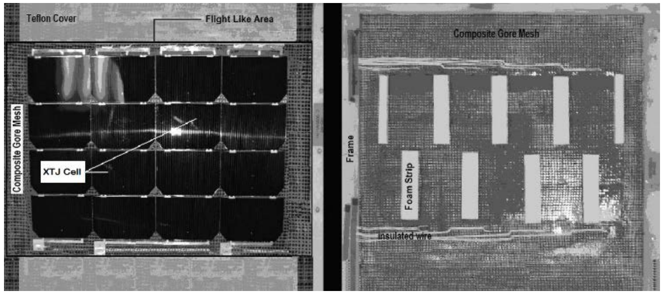
LEO Simulations

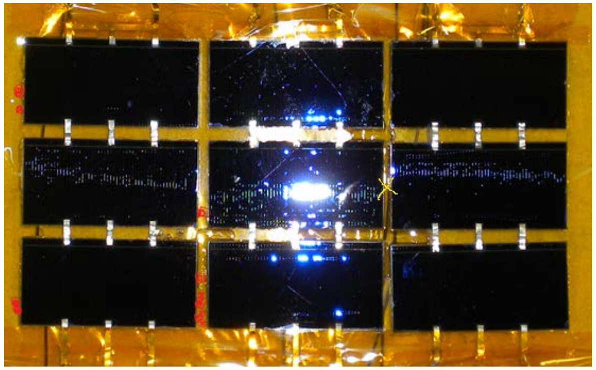
Table 1. List of solar array samples tested in two large chambers.

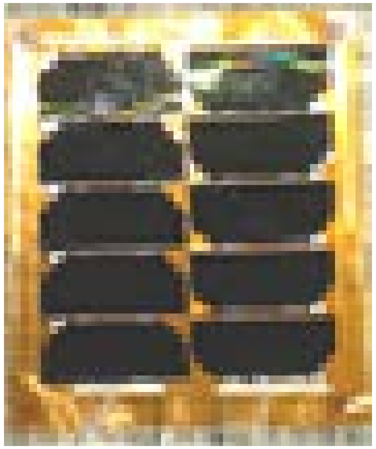
Sample No.(Type)	Coverglass Thickness (µm):	Material	Overhang (µm)	Cell size (cm)	Interconnect
1(Si)	300	UVR	0	4x6	exposed
2(Si)	150	UVR	0	4x6	exposed
3(Si)	150	CMX UVR	0	4x6	exposed
4(Si)	150	UVR	250	4x6	exposed
5(Si)	150	UVR	0	8x8	wraptrough
6(TJ)	150	UVR	0	4x6	exposed
7(TJ)	150	UVR	0	4x6	exposed
8(TJ)	75	CMX	0	4x8	exposed
9(TJ)	75	CMX	0	4x8	exposed
10(TJ)	100	CMX	0	4x8	exposed

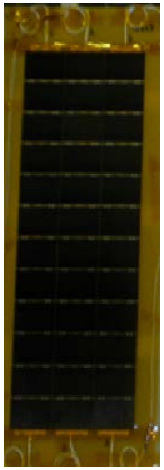
Table 2. Arc inception parameters.

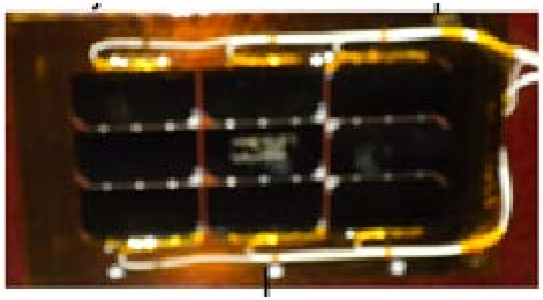
Sample No.	Primary Arc Inception(V)	Sustained Arc Inception V	Sustained Arc Inception A
1	250	60	2.0
2	265	80	1.6
3	280		
4	340		
5	300(530)	>120	>4
6	170	80	2.25
7	200	50	2.0
		50	2.6
8	260		
9	>240		
10	220	100	>1.6

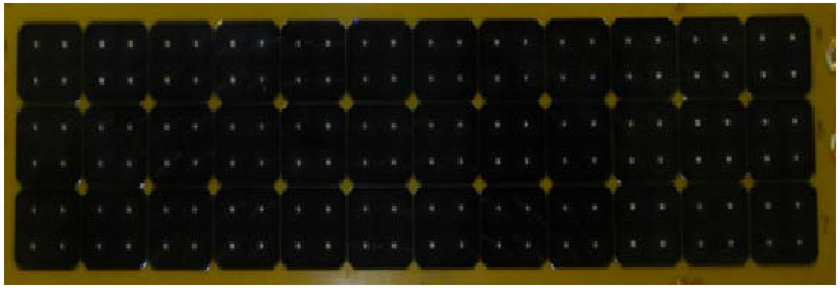

Teflon Cover
Flight Like Area
Composite Gore Mesh
XTJ Cell
Frame
Foam Strip
Composite Gore Mesh
Insulated wire

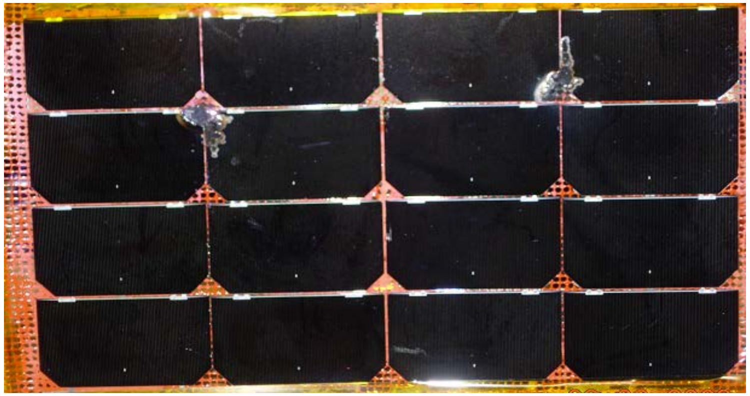


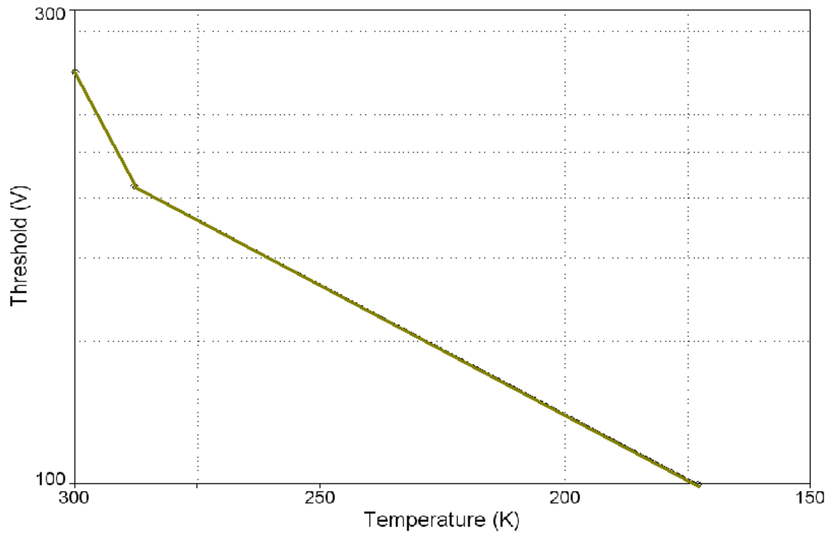




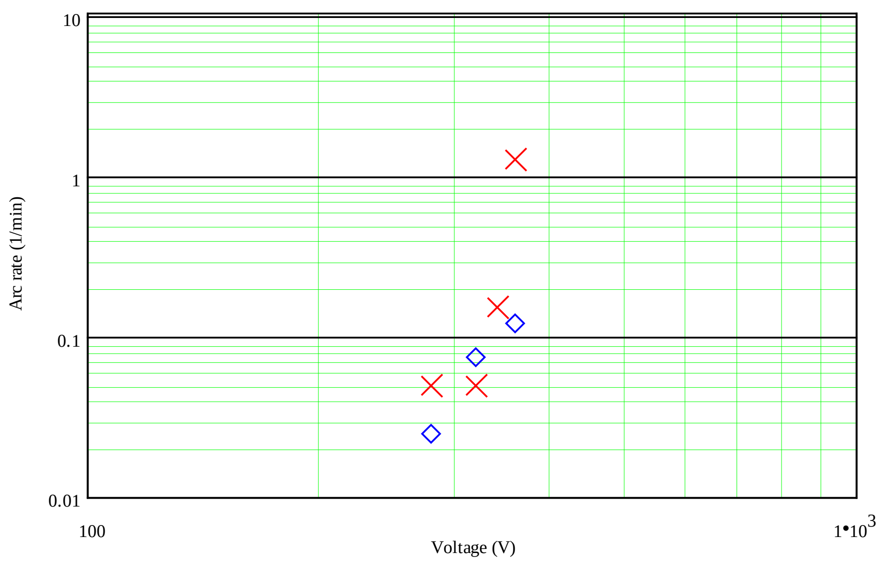








One example of decreasing arc threshold with temperature ***(Vayner&Galofaro, 2010)***



Arc rates were measured for two different water vapor partial pressures at 300 K: 0.26 µTorr (red) and 0.023 µTorr (blue) ***(Vayner, 2014)***

Cavern in adhesive

The potential difference between coverglass and underlying (semi)conductor is

$$U = E_1 d_1 + E_2 d_2 \qquad (1)$$

Where E_1 and E_2 are electric field strengths in adhesive and coverglass respectively; d_1 and d_2 are thicknesses of respective layers.

Border condition on adhesive/coverglass plane is

$$\varepsilon_1 E_1 = \varepsilon_2 E_2 \qquad (2)$$

Thus, electric field strength on the surface of (semi)conductor is

$$E_1 = \frac{\varepsilon_2}{\varepsilon_2 d_1 + \varepsilon_1 d_2} U \qquad (3)$$

Dielectric constant of adhesive material (DC93500) is equal to ε_1=3. Dielectric constant of coverglass depends on glass type but can be adopted as ε_2=5 for purposes of crude estimates. If there would be a small cavern in adhesive layer then the dielectric constant of vacuum (ε_c=1) should be substituted in Eq.3 for the calculation of electric field strength on (semi)conductor surface. For example, if d_1=50 μm and d_2=150 μm the field enhancement factor would be

$$\beta = \frac{E_{1c}}{E_1} = 1.75 \qquad (4)$$

For more contemporary arrays with thicknesses of respective layers of 25 μm and 125 μm the enhancement factor will reach β=2.

GEO Simulations

Spacecraft body (exposed conductive surface) in eclipse acquires the potential that is determined by the balance of electron and ion currents:

$$\Phi_{sc} = -\frac{T_e}{2} \ln\left(\frac{m_p}{m_e} \frac{T_e}{T_i} \right) \approx 3T_e \qquad (5)$$

The duration of charging process can be estimated as

$$\tau_{sc} = \frac{C_{sc} \cdot \Phi_{sc}}{j_e \cdot A} \qquad (6)$$

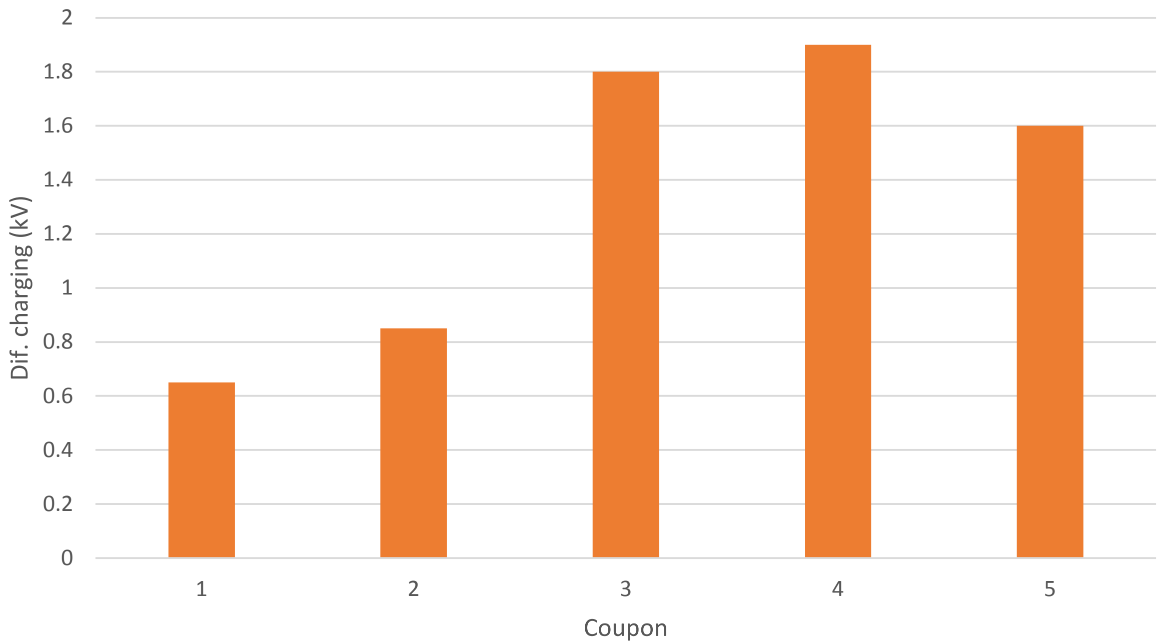
τ=0.25-0.3 s; C_a=0.25 μF/sq.m → τ_a=30-300 s (1 kV)

Monoenergetic electron beam:

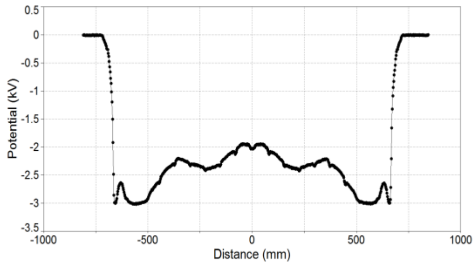
$$U = U_{bias} - \Phi_{cg} = U_{bias} - W_b + W_{sc} \qquad (7)$$

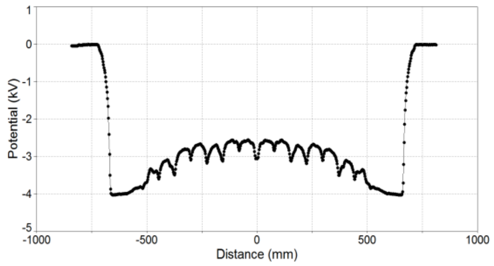
$$U = W_{sc} - 0.8(kV)$$

(8)



Differential charging is shown for samples from Table 1



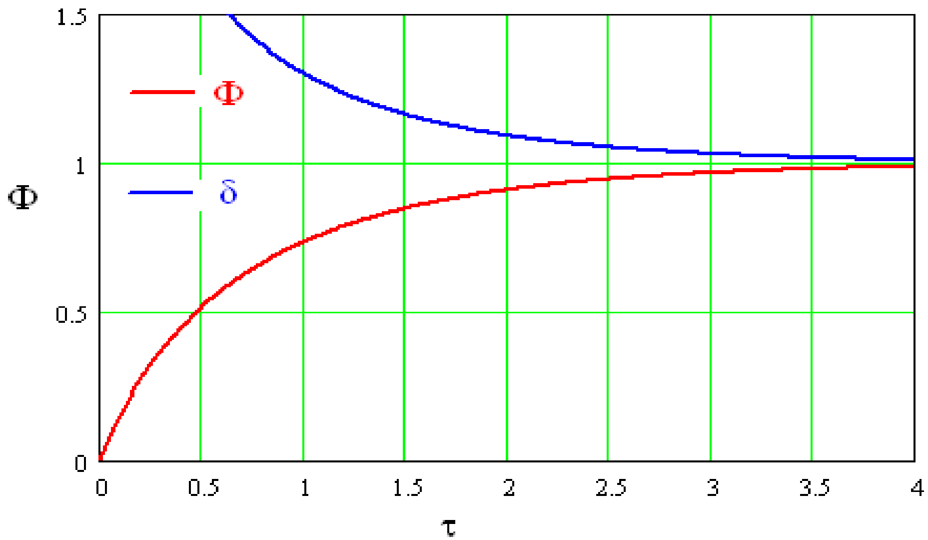


$$C_a \frac{dU}{dt} = j_b \left(1 - \delta\left(W_b - U_{cg}\right)\right)$$

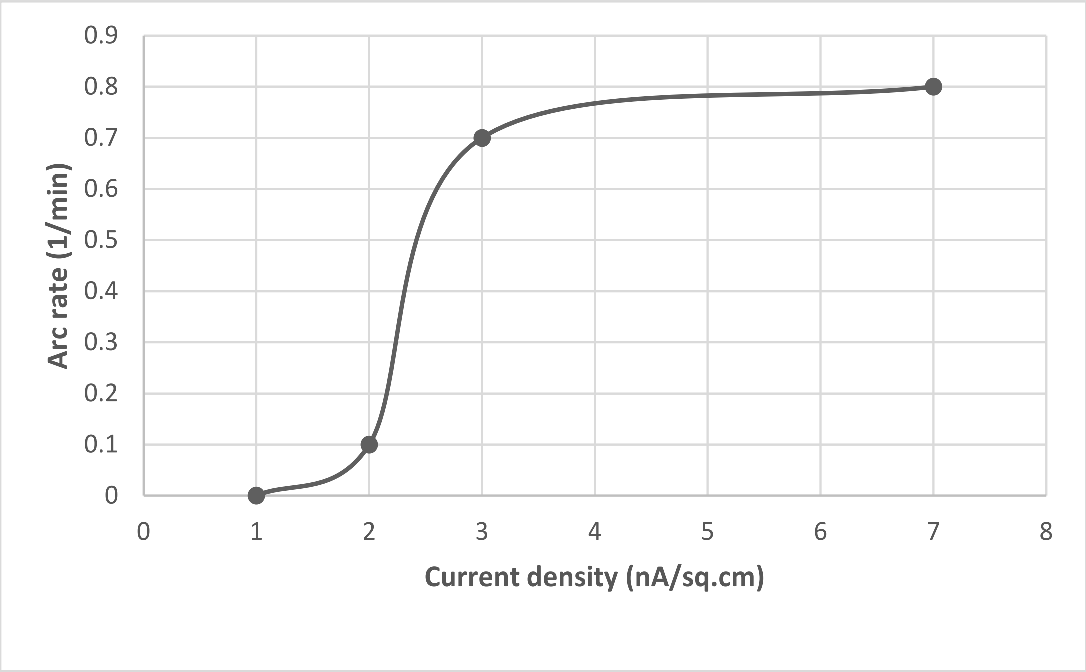
$$\tau_{;} = \frac{j_b}{C_a W_{sc}} t$$

$$\delta(W) = \delta_m \exp\left(-\frac{W}{W_{sc}}\right)$$

$$\Phi = \frac{W_b - U_{cg}}{W_{sc}}$$



Steady state voltage can be reached for a time span about *τ=4*.



typical beam of 1 nA/cm^2 provides coverglass charging time a little more than 120 s. If second crossover energy is 2.0 kV [23], bias voltage is -2.5 kV, and beam energy is 3.3 kV then surface potential at steady state is U_{cg}= -1.3 kV, and differential charging reaches U= 1.2 kV. Measurements demonstrated a strongly nonlinear dependence of arc rate on electron beam current density

The reasons for these discrepancy between measurements and theory are not clear now.

$$j_c = \sigma \frac{U}{d_c}$$

1.Coverglass conductivity?

2. Field enhancement caused by charging of side surfaces of dielectrics?

No RIC consequences were taken into account in experiments and theoretical estimates

It is difficult to estimate the contribution of this current to the duration of charging process. For a typical glass conductivity of 10^{-13} S/m the conductive current density is below 0.06-0.1 nA/cm^2 under differential potential of 1 kV, and the contribution of conductive current to charging process can be disregarded.

Conclusions

Electrostatic discharges on solar array surface can be initiated even on arrays with comparatively low operational voltages (around 100 V). RTV grouting the gaps between strings and interconnectors results in increasing thresholds but cannot guarantee absolute preventions of arcs. The most effective method for prevention of differential charging in GEO environment is ITO layer over coverglass but this method has such disadvantages as higher solar array cost and weight. Moreover, if spacecraft is supposed to fly through LEO and GEO then the deployment of ITO causes a sharp increase in current collection from ionosphere plasma and decrease in array efficiency. The is no unique technique in preventing arcs: components of spacecraft power system must be undergone comprehensive tests in simulated environments corresponding to the spacecraft trajectory.