Study of the Need for Solar Panel Coverglass for CubeSat Missions

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1. Abstract:

The focus of this study was to determine if TASC cells could match the power produced by UTJ cells without expensive coverglass. If a configuration could be found that provides similar power to UTJ cells, it would greatly lower the cost of solar panels while adding flexibility to CubeSat missions with their superior packing factor. In order to develop a coherent model of how the cells degrade over time, three major possible solar panel damage vectors were identified: Atomic Oxygen and Ozone exposure, UV/Photon Radiation, and High Energy Particle Radiation. A literature review and additional analysis was conducted citing data from a number of sources, charting the drop in cell performance from a variety of factors over a number of timescales. Then regression analysis was performed and models were produced for each type of decay, the details of which follow. Power drops were calculated first for each vector and then as a whole based on initial values for each configuration and, unless otherwise listed, were calculated after 2 years on orbit.

The results of this analysis show that only 3 mils of encapsulate are required to effectively shield the cells for a period of 2 years and produce similar power requirements. The encapsulate chosen for study in this analysis was Dow Corning DC93-500. It is a space grade encapsulate that meets or exceeds all openly available outgassing standards data on UV browning (7).

2. Background:

Small satellites, particularly CubeSats, demand a high degree of optimization for their solar panel arrays due to their size. Usually Spectrolab UTJ CICs are used, but these large cells have an inefficient packing factor, and when combined with various external components, may present unacceptably low power outputs.

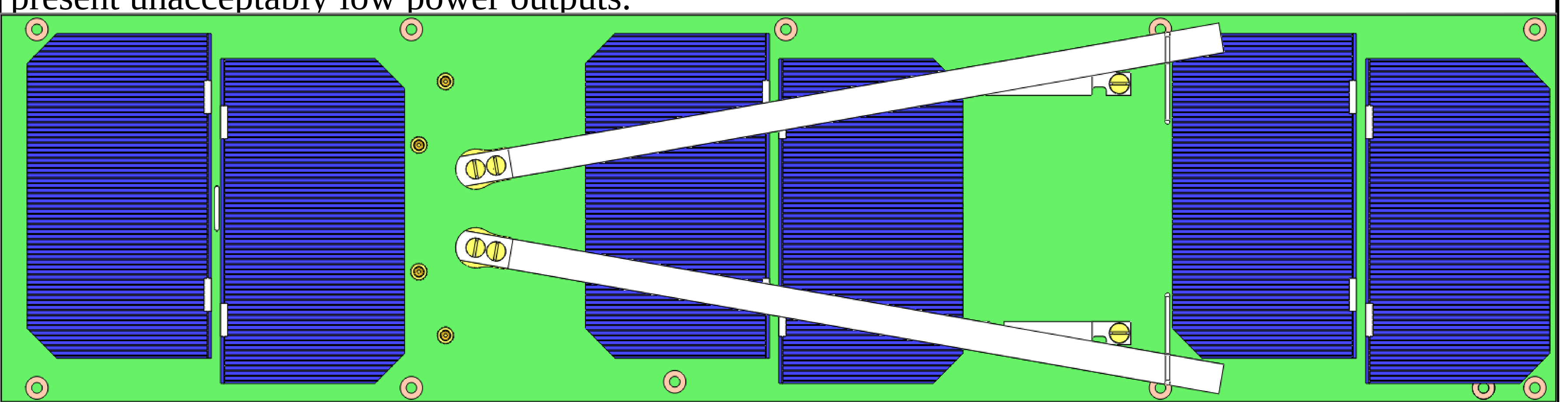


Figure 1:
3U panel, with exterior deployable antennas that potentially reduce available area for solar panels, shown with UTJ cells.
Source: IGPP

The use of Spectrolab TASC cells can be beneficial since they can be fitted around exterior components, however they lack integrated cover glass and are more susceptible to damage from space than the robust UTJs. TASC cells may be able provide similar power to UTJs while being more flexible and more forgiving to external components if properly shielded.

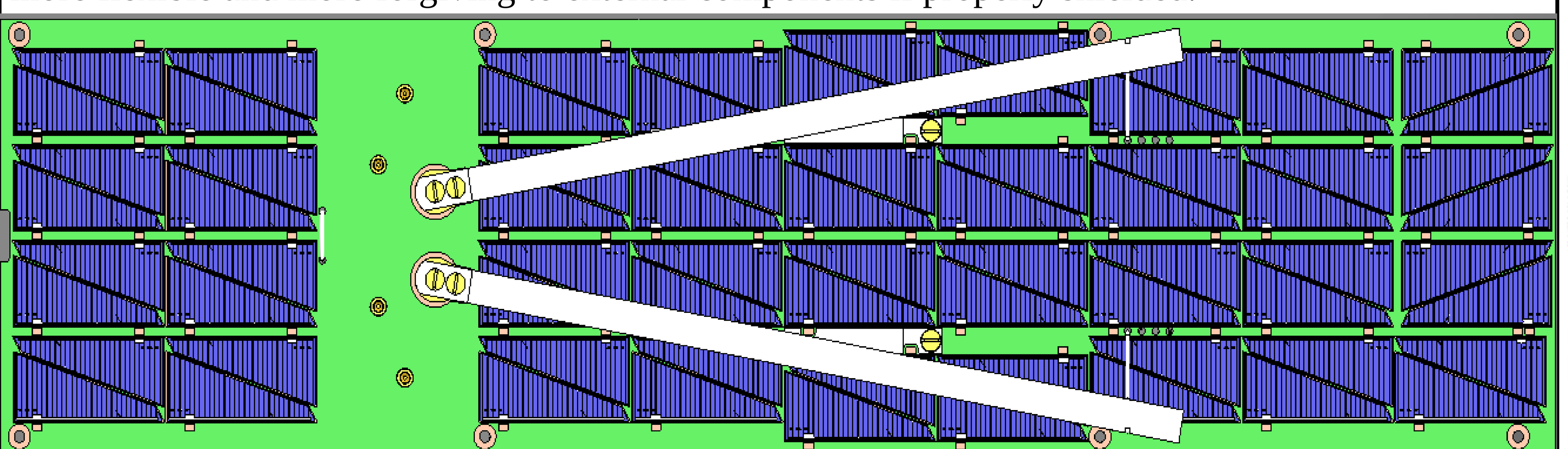


Figure 2:
3U panel, with the same exterior components with TASC cells. Source: IGPP

Adding aftermarket cover glass to cells with RTV encapsulate is possible but difficult:
- geometry of cell makes application difficult due to solder tabs
- glass is fragile; challenging to cut and work with
- bubbles can form in the encapsulate unless pressed down heavily
- absent laminators; large sheets are problematic due to thermal stresses

Configuration Data		
	TASC	UTJ
Cells	72	6
Efficiency	27%	28.3%
Peak Power	5.5W	5.1W*

*Note that power system limitations on the cell strings, and current loop cancellation for magnetic cleanliness, favor the implementation of TASC cells in certain circumstances.

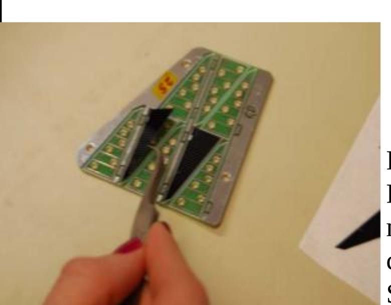


Figure 3:
Potential application method for TASC solar cells.
Source: DANDE (4)

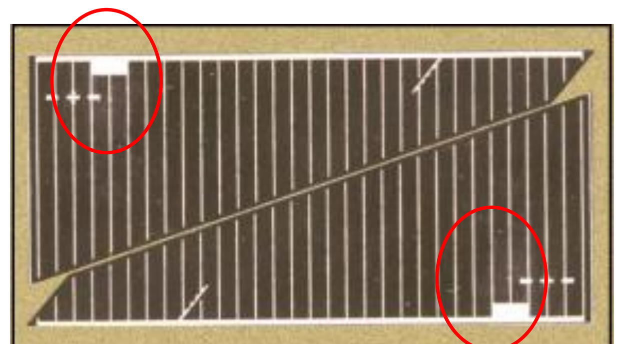


Figure 4: TASC cell pair. Note solder interconnects that make application of coverglass difficult (6)

3.1 Atomic Oxygen / Ozone:

DC93-500 is a high heritage defense against atomic oxygen and ozone damage (2):
- solar cells themselves (especially metal interconnects) are very vulnerable to oxygen
- prevents interior components from taking damage
- should be shielded completely by the encapsulate

The power loss of a covered cell due to oxygen is approximated to be less than 1%.

Figure 5: Kapton, exposed to Atomic Oxygen/Ozone 2.5mm scale (2)

Figure 6: Kapton, shielded by DC93500 from AO/O3 (2)

3.2 High Energy Particle Radiation:

Spectrolab's published data sheets show that their TASC cells hold up well to particle radiation.

SPENVIS Test Orbit:
- 650km, 97 degree inclination
- radiation dose: 8e11 MeV/cm^2/day
- Spectrolab UTJ CIC drops that to 9e9 MeV/cm^2/day (3)

Using mass per unit area as first order approximation of effectiveness for radiation shielding, only 3 mils of encapsulate are required to effectively shield the cells for the mission length.

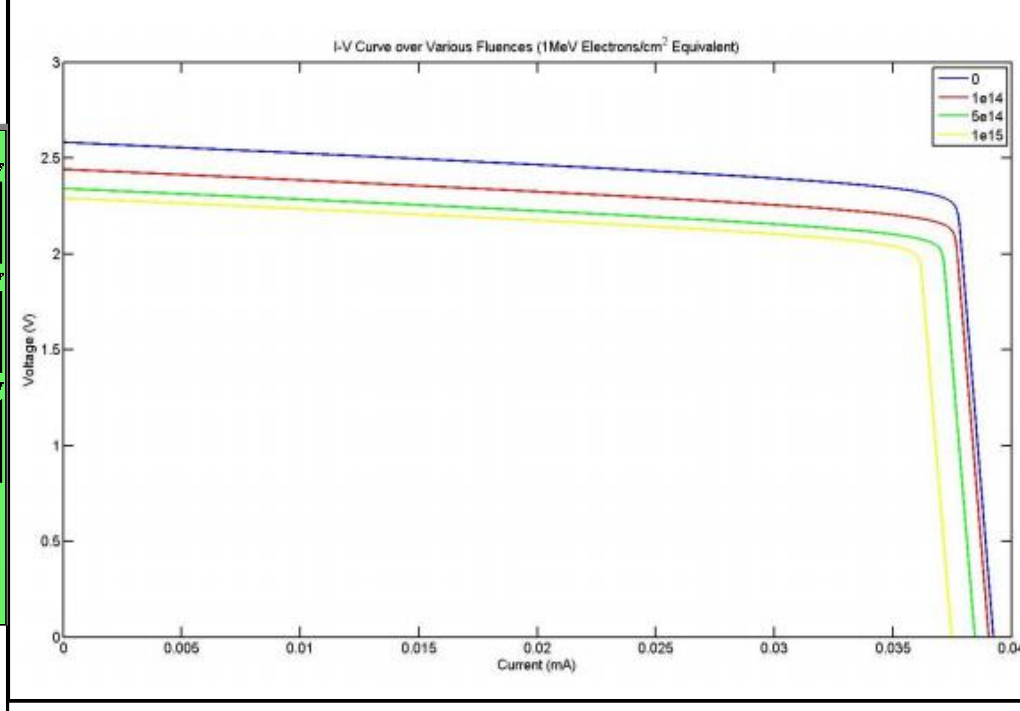


Figure 8: I-V data for TASC cells after various radiation buildups (MeV/cm^2) (3)

Radiation Degradation
(Fluence 1MeV Electrons/cm²)

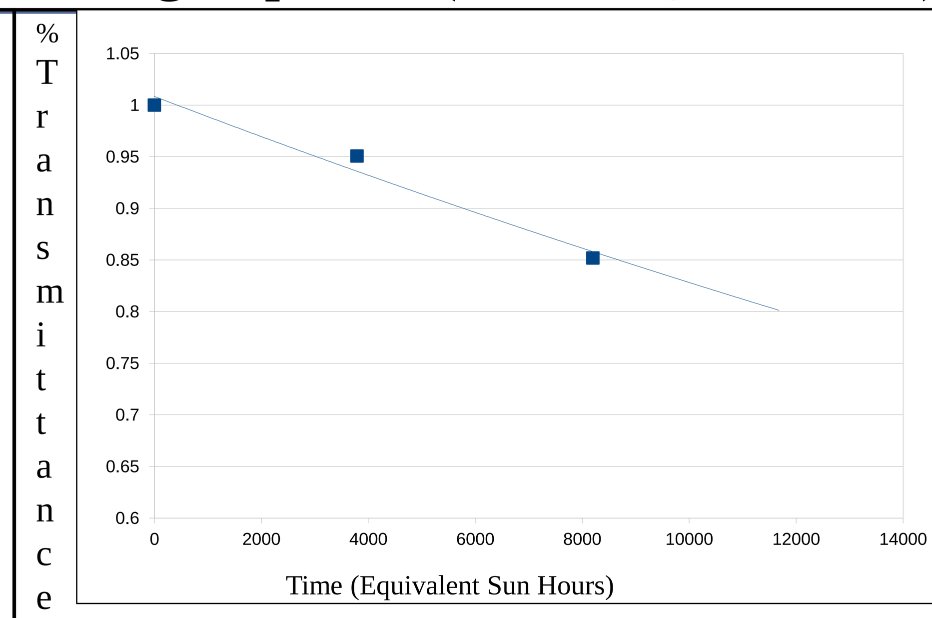
Parameters	$1x10^{14}$	$5x10^{14}$	$1x10^{15}$
Imp/Imp_0	1.00	0.98	0.96
Vmp/Vmp_0	0.94	0.90	0.88
Pmp/Pmp_0	0.94	0.88	0.84

Figure 7: Peak power data for TASC cells after various radiation buildups (MeV/cm^2) (6)

3.3 UV / Photon Radiation:

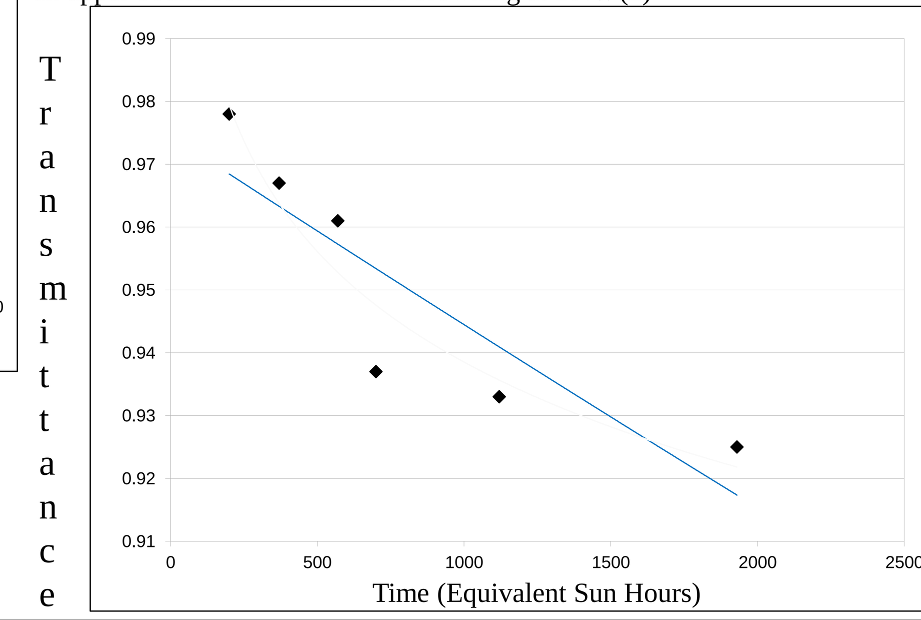
Damage to the encapsulate is the primary cause of power loss:
- all RTV encapsulates brown with exposure to UV
- usually shielded by coverglass; breakdown is slow
- uncovered: primary means by which cell efficiency is lowered
- data in figures 9, 10, and 11 track drop in transmittance of DC93-500, but suffers from limitations.

With coverglass in place, cells operate at lower temperatures:
- reflect edges of spectrum, mostly unusable
- gains efficiency due to lower temperature; counterbalances lost power
- 1.5% more higher output
- encapsulate-only plan does not receive these benefits



Data Set 2:
Browning of unshielded DC93500 from the Kleiman study. While it contained almost twice the data points, none of the tests exceeded 2000 ESH making extrapolation questionable. In addition the data is not self consistent, as different test durations were conducted at different intensities. This was treated as a lower bound, at 13%. (2)

Data Set 1:
Browning of unshielded DC93500 from a JAXA study for a mercury bound mission, had very few data points with which to extrapolate from. Additionally, the tests were conducted at a very high temperature (230C) , and may have led to secondary and accelerated decomposition. This was taken as an upper bound for the amount of browning at 20%. (1)



4. Conclusions:

Taking into account the decrease in solar cell performance from all three sources, the projected End of Life wattage of a TASC equipped satellite is well within acceptable mission parameters. Given this data (see table), a relatively thin layer of encapsulant is all that is necessary to preserve TASC cells in LEO for a period of approximately 2 years.

De-rating due to (after 2 years):	Bare TASC Cells	3 mils	10 mils	Full CIC (UTJ)
High Energy Particle Radiation	-15%	-7%	-1%	-1%
Atomic Oxygen/Ozone	Unknown assume (-20%)	-1%	-1%	-1%
UV Radiation	≈ -1%	-16.5% +/- 3.5%	-16.5% +/- 3.5%	-7%
Temperature (Constant)	-1.5%	-1.5%	-1.5%	0
Total Power at EOL (of initial)	**66%**	**77% +/- 3.5%**	**83% +/- 3.5%**	**91%**

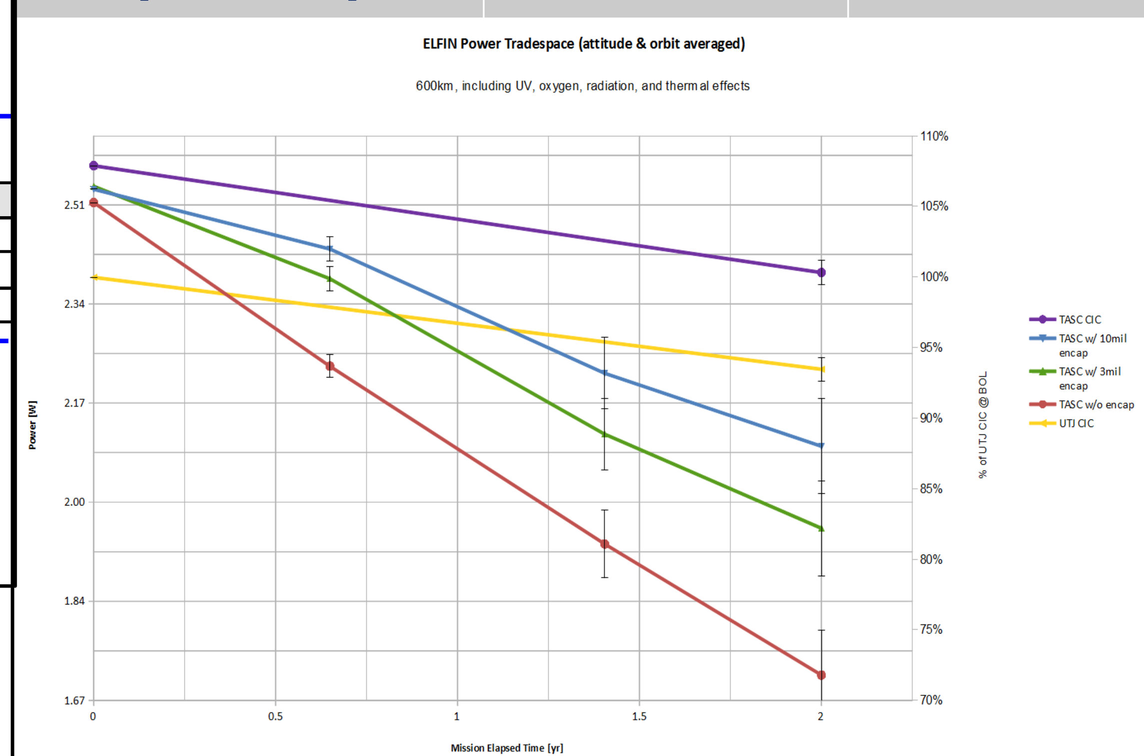


Figure 10: This graph shows the decrease of EOL power for a number of encapsulant schemes, graphed against the performance that could be expected from a UTJ. This shows that a TASC configuration would produce approximately 94% the power that a UTJ configuration would after the same time in space.

4.1 Future Work:

The error bars on the rate at which TV breaks down under UV are still large due to the necessary extrapolation. Additional test information for longer durations and lower temperatures would greatly improve the characterization of this material. As well, additional testing is needed to confirm the radiation blocking properties of RTV encapsulant.

5. References:
-1- "Durability Evaluation Of Ingap/Gaas/Ge Triple-junction Solar Cells In HIHT Environments For Mercury Exploration Mission" Shimada, T.
-2- Protection of Materials and Structures from the Space Environment, By Kleiman, J
-3- "EVALUATING THE EFFECTIVENESS OF PEAK POWER TRACKING TECHNOLOGIES FOR SOLAR ARRAYS ON SMALL SPACECRAFT " Daniel Martin Erb
-4- DANDE Program Lessons Learned Capture Document
-5- "Application of infrared reflecting (IRR) coverglass on multijunction III-V solar cells" Hojun Yoon
-6- Spectrolab Triangular Advanced Solar Cells (TASC) Product Datasheet
-7- Dow Corning Datasheet, DC93-500 Product Information

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