Qualification, Production, and Program Status of SolAero's Inverted Metamorphic and Upright Ge Solar Cells

Space Power Workshop 2022

John Hart, Dan Aiken, Zac Bittner, Ben Cho, Brad Clevenger, Daniel Derkacs, Andrew Espenlaub, Navid Fatemi, Frank Fencl, John Hart, Jeremy Leshin, Ahmad Mansoori, Nate Miller, Jeremy Moore, Pravin Patel, Albert Perry, Hans Schoon, Janine Walker

This work was supported in part by AFRL:

Contracts FA9453-14-C-0370 , FA8650-20-2-5527, FA9453-22-C-0044 and FA8650-13-C-5501

Outline

1. SolAero Overview
2. SolAero Solar Cells – Higher Power Under Real Operating Conditions
3. Solar Cell Mass Reduction
4. Summary

SolAero Overview

- **World's only vertically integrated supplier of space solar array panels to the global aerospace market**
  - **Established in 1998**
  - **Acquired by Rocket Lab January 2022**
  - **420 Employees**

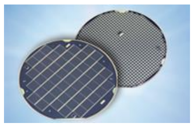
- **Supplier to the US Government and all civil space and commercial primes worldwide**

Space Solar Cells

Space Solar CICs

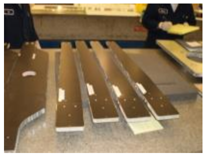
Space Solar Panels

Optoelectronics

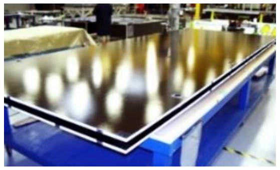


Sponsored Research & Development Services

Structural Components



Panel Substrates

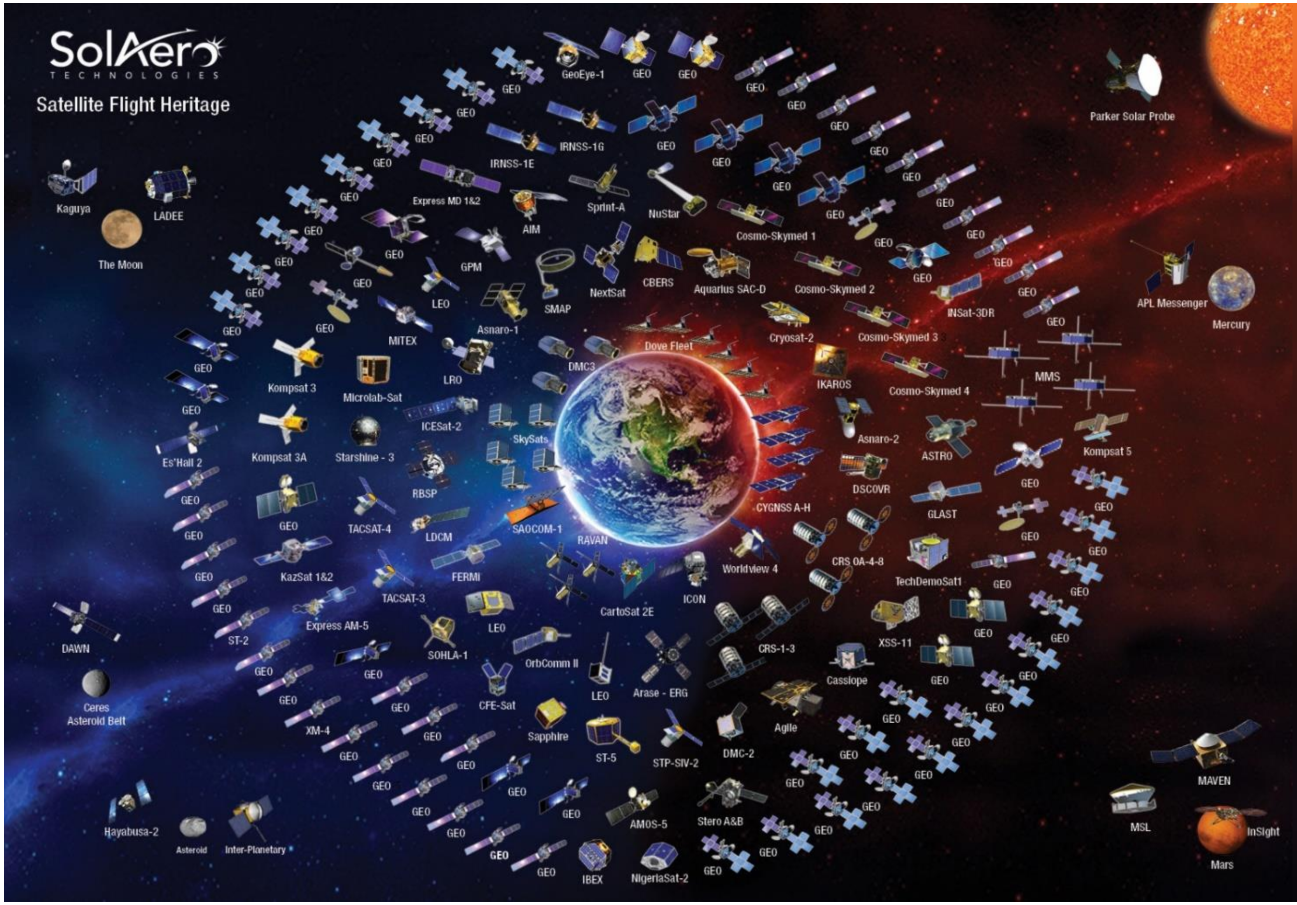


Markets & Customers We Serve

- US & Global Governments & Space Agencies
  - Defense Intelligence, Surveillance & Communication
  - Civil Space, Earth Observation, Interplanetary Exploration
- GEO Telecom Satellites for Commercial & US Government
  - Broadband, TV/Radio, Phone, Aviation, Military Telecommunications, Missile Tracking
- Non-GEO (NGSO) Satellites & Constellations
  - USG & Commercial in LEO and MEO
  - Broadband, Missile Tracking, Earth Observation

Flight Heritage

- SolAero has powered over 1000 satellites on-orbit over the past 20 years
  - Zero on-orbit anomalies reported to date



SolAero boasts a **perfect on-orbit reliability record**, highlighting unparalleled expertise and superb execution

1000+ successful
space missions

>100 GEO
missions on orbit

>800 LEO / Polar
missions launched

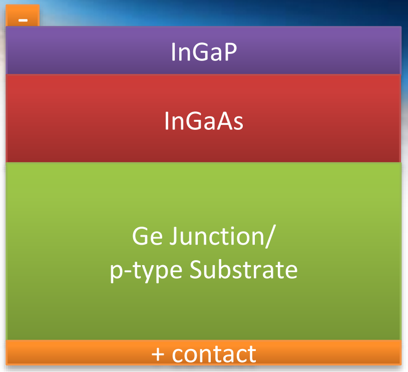
15 Interplanetary & Lunar *missions launched*

>500 satellites
scheduled to be launched

SolAero Solar Cells – Higher Power Under Real Operating Conditions

SolAero Cell Technologies & Nomenclature

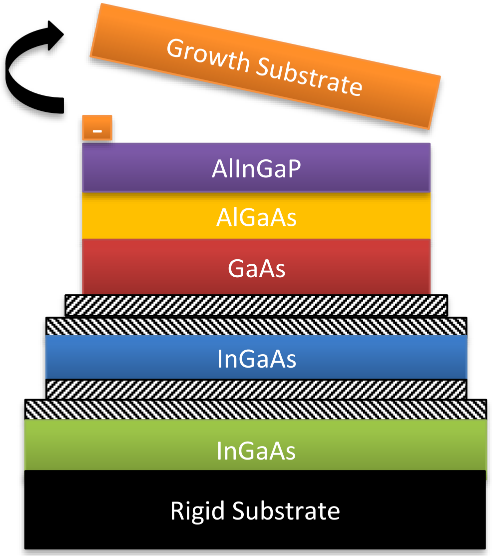
- ***Triple Junction Solar Cells on Germanium***
  - **ZTJ : 4th generation 3-junction solar cell**
  - **ZTJ+ : 5th generation 3J with higher radiation hardness**
  - **ZTJ-Ω : 6th generation 3J for low rad, proton dominated environments**



Example 3J

- ***Quadruple Junction Solar Cells on Germanium***
  - **Z4J : 1st generation 4J with high radiation hardness**
  - **Z4J+ : 2nd generation 4J with high radiation hardness**
    - **Delta qualification planned for mid 2022**

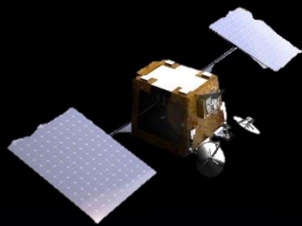
- ***Inverted Metamorphic Solar Cells - IMM***
  - **IMM cells are 42% lighter than 140-µm thick Ge-based cells**
  - **IMM-α : 1st generation radiation hard 5J IMM**
  - **IMM-β : 2nd generation radiation hard 5J IMM**
    - **Delta qualification started**



Example IMM

Typical Solar Array Operating Conditions

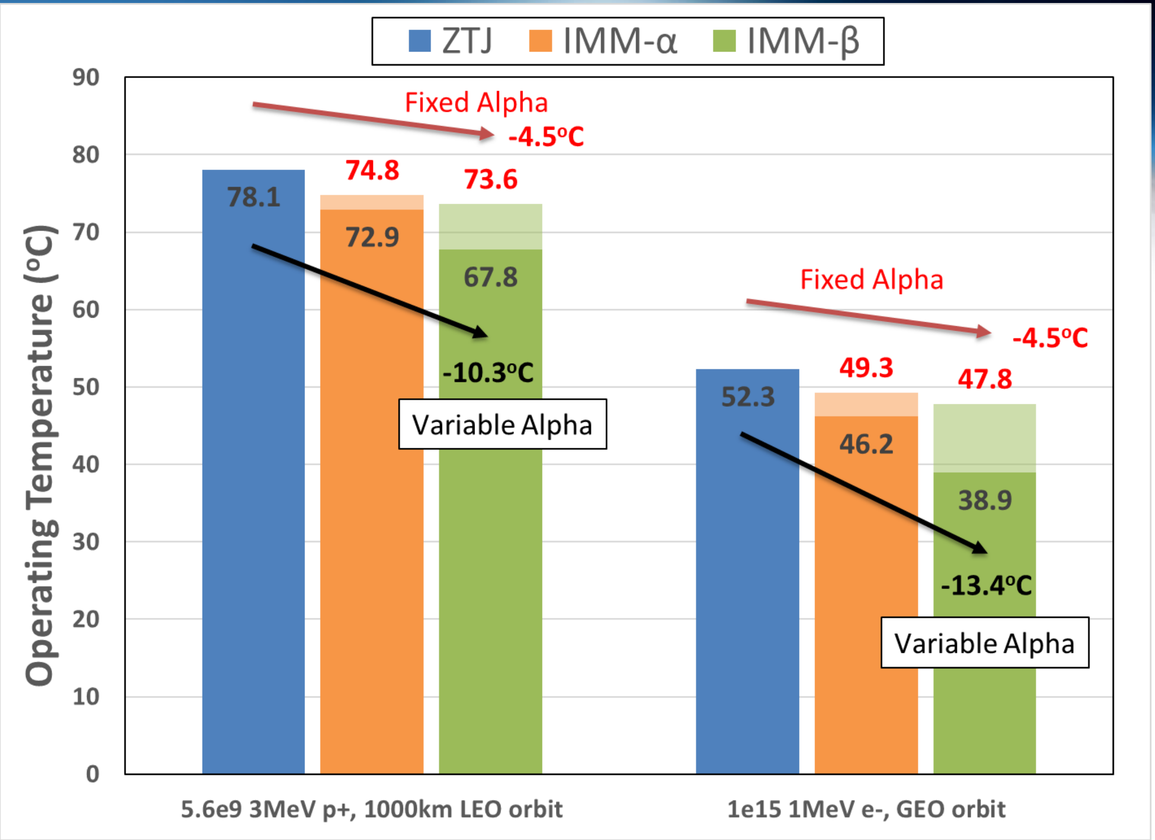
- *GEO*
- *15 year mission duration*
- *Higher radiation environment*



- *LEO*
- *3-5 year mission duration*
- *Lower radiation environment*
- *Typically hotter due to the proximity of the earth*

- *SolAero targets its solar cells for peak performance in real mission conditions*
- *Different orbits and panel configurations will have different operating temperatures*
- *Both cell efficiency and absorption (alpha) determine actual operating temperature*

Steady State Temperature Modeling On- Orbit

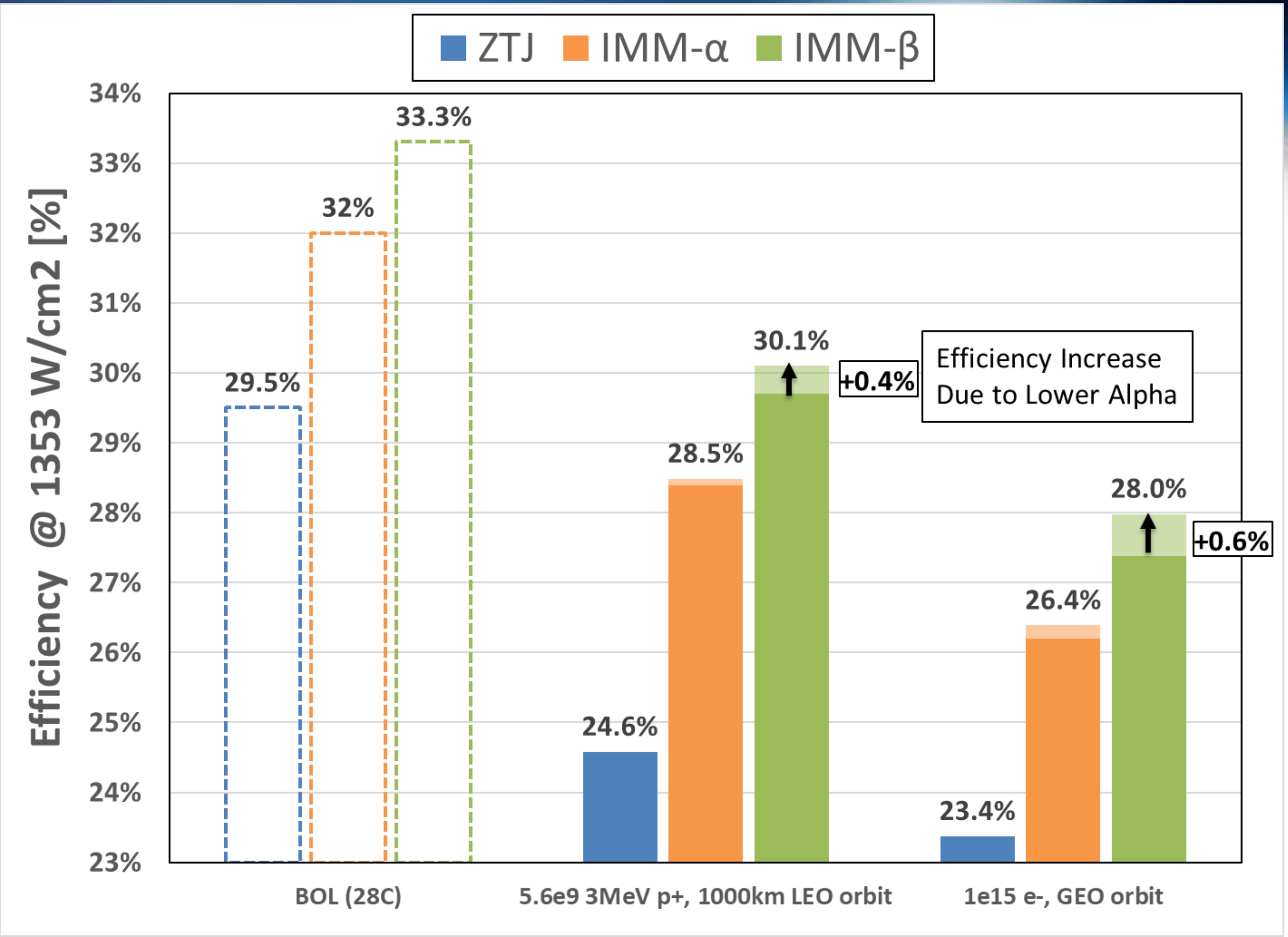


Steady-State Model Details

- *36,000km for GEO*
- *1000km for LEO*
- *The panel substrate is CFRP*
- *The packing factor is 85%*
- *35% Earth Albedo*
- *0° beta angle*
- *Cell performance is based on irradiation fluence shown*

- ***If a cell is more efficient, the array operates cooler***
- ***Rejecting un-used light (reducing alpha) also reduces the array operating temperature***
- ***Modeling these effects together gives the most accurate picture of on-orbit temp***
- ***The alpha reduction and higher efficiency of the IMM platform enables operating temperatures up to 13°C cooler than Ge based solar cells***

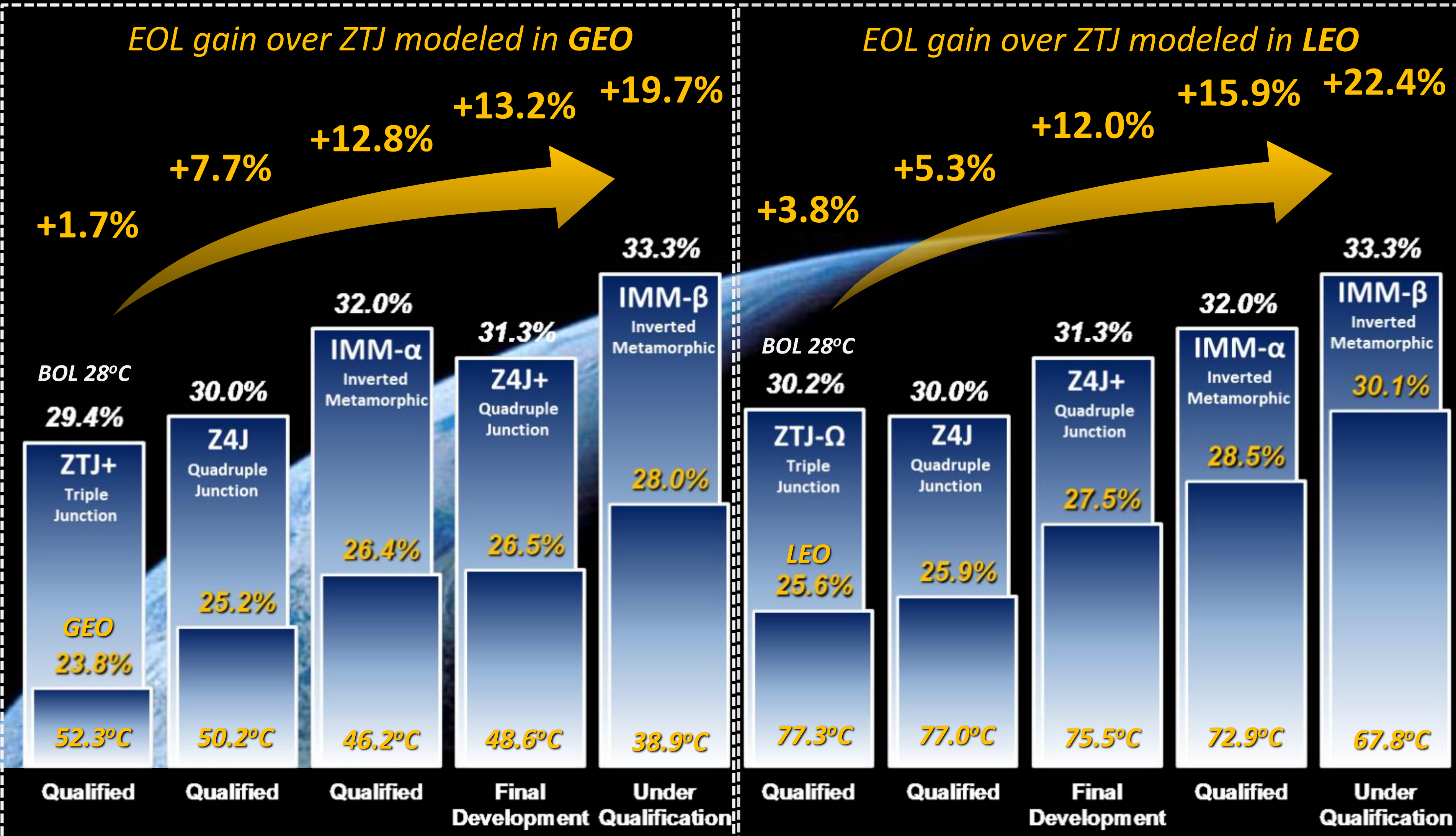
Efficiency Modeling On- Orbit



- ***Modeling cell efficiency at a fixed temperature is an unrealistic approach***
- ***The best way to model on-orbit performance is to correctly take into account the differences in temperature due to efficiency and alpha***

Cell Technology Roadmap – 1353W/m²

IMM and Z4J products provide a pathway to higher performance under real operating conditions



GEO: 1E15 1MeV e-/cm2, @ Modeled Temp

LEO: 5.6e9 3MeV p+/cm2, @ Modeled Temp

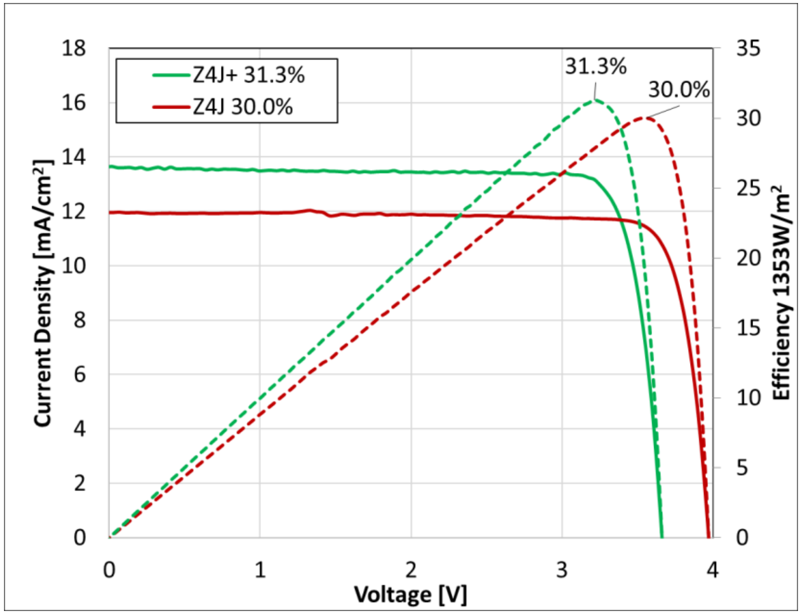
Next Generation Ge-Based Solar Cells

ROCKETLAB SolAero TECHNOLOGIES

- ***Z4J : 30% radiation-hardened 4J cell***
  - **Superior electron & proton radiation hardness**
    - **90% PRF after exposure to 1E15 1-MeV e-/cm²**
  - **Fully qualified to AIAA-S111-2014 Standard**

Z4J Electrical Performance	
	1353 W/m²
η, 28°C	30.0%
V_{oc} volts	3.95
J_{sc} mA/cm²	12.0
V_{mp} volts	3.54
J_{mp} mA/cm²	11.45

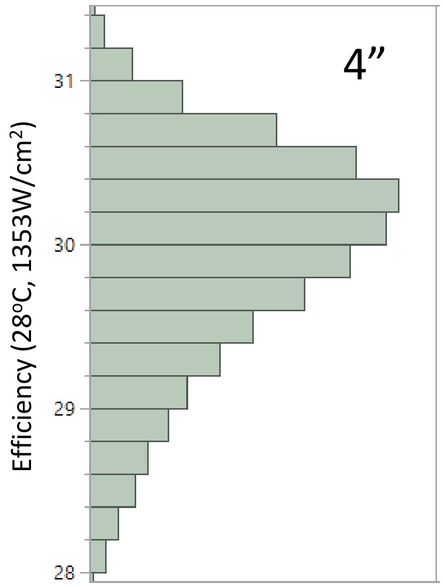
- ***Z4J+ : 31.3% radiation-hardened 4J cell***
  - **90% PRF after 1E15 1-MeV e-/cm²**
  - **Equivalent to 32% efficiency with 87% PRF**
  - **Structure is expected to be locked by Q2**
    - **Delta qualification planned mid 2022**

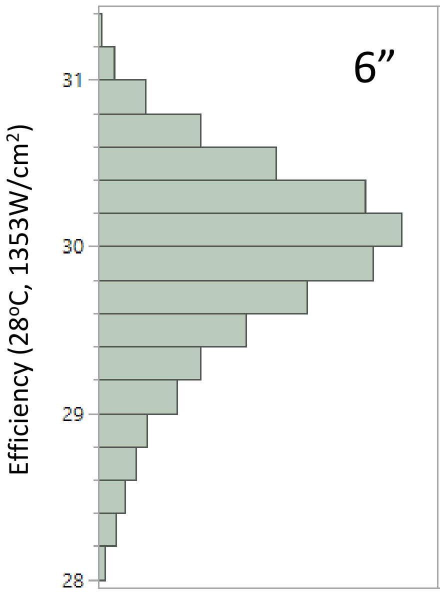


Z4J Production

- *Example Z4J Builds*
  - 4” 1-pers
    - 33,000 cells > 65-cm^2
    - 30% median efficiency
  - 6” 2-pers
    - 27,000 cells > 80-cm^2
    - 30% median efficiency

Z4J Electrical Performance	
	1353 W/m^2
η, 28°C	30.0%
V_{oc} volts	3.95
J_{sc} mA/cm^2	12.0
V_{mp} volts	3.54
J_{mp} mA/cm^2	11.45



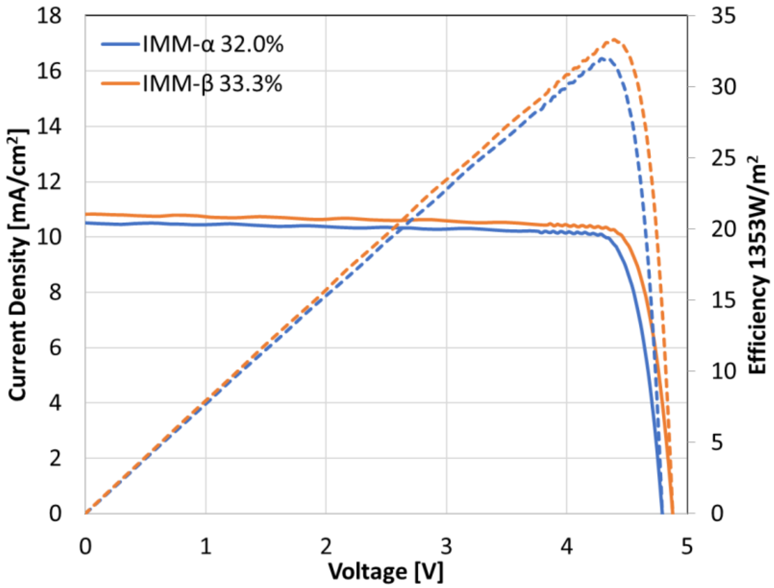


Inverted Metamorphic Solar Cell Technologies

- ***IMM-α : For all mission environments***
  - 32% BOL efficiency
    - Exceptional performance in GEO and LEO
    - 87% PRF after 1E15 1-MeV e-/cm^2
  - Fully qualified to AIAA-S111-2014 Standard

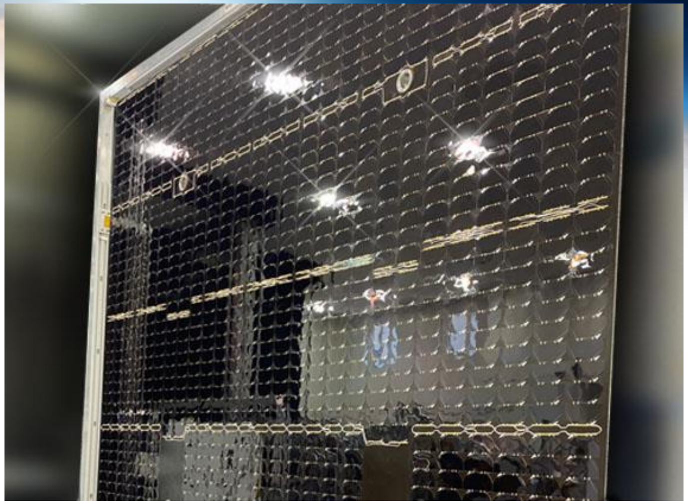
1353 W/m² Electrical Performance		
	IMM-α	IMM-β
η, 28°C	32.0%	33.3%
V_{oc} volts	4.78	4.87
J_{sc} mA/cm^2	10.66	10.81
V_{mp} volts	4.28	4.38
J_{mp} mA/cm^2	10.12	10.30

- ***IMM-β : For all mission environments***
  - 33.3% BOL efficiency (1353 W/m^2)
    - 87% PRF after 1E15 1-MeV e-/cm^2
    - α reduced by 4 points, ~10-13°C lower op than ZTJ
  - Delta qualification underway

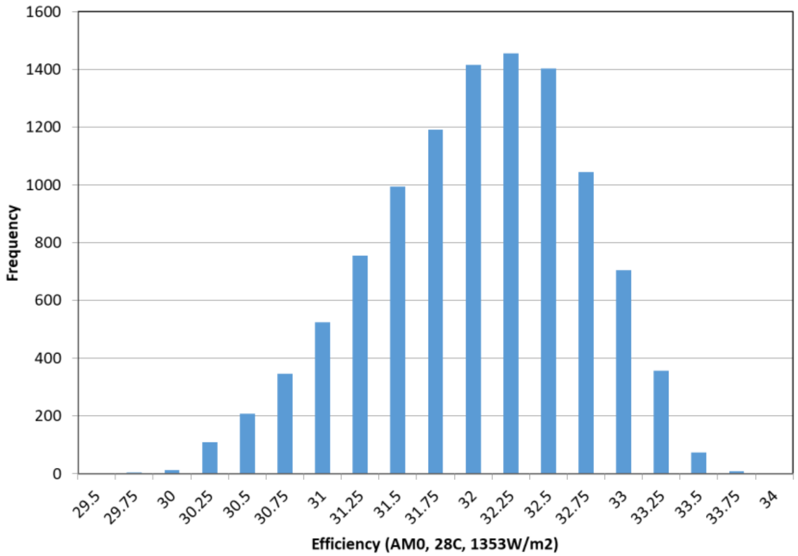


IMM-α Production

- ***IMM-α Powering a multitude of flight programs***
- ***IMM-α BOL Efficiency Distribution of a representative multi-satellite mission***
  - 30.78 cm^2 cell area
  - 32.0% median efficiency
  - 33.8% highest efficiency



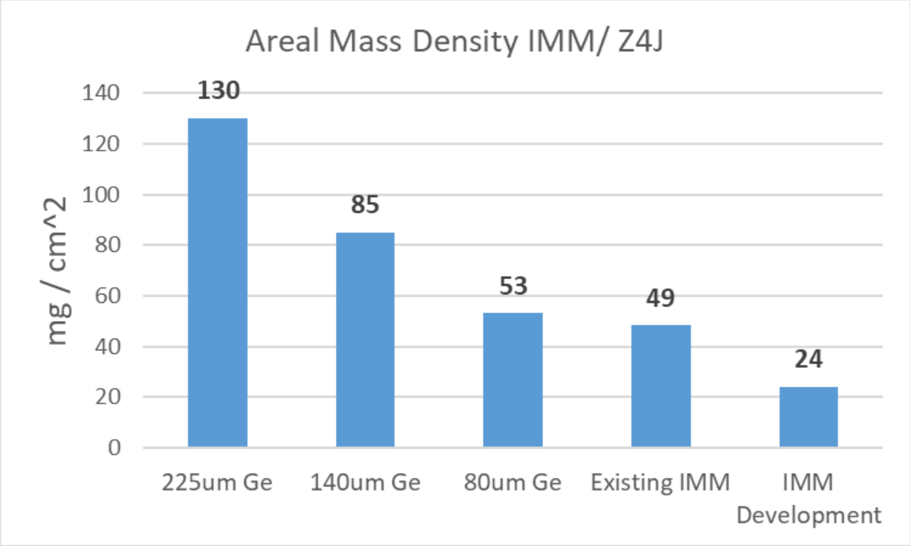
IMM-α Flight Panel



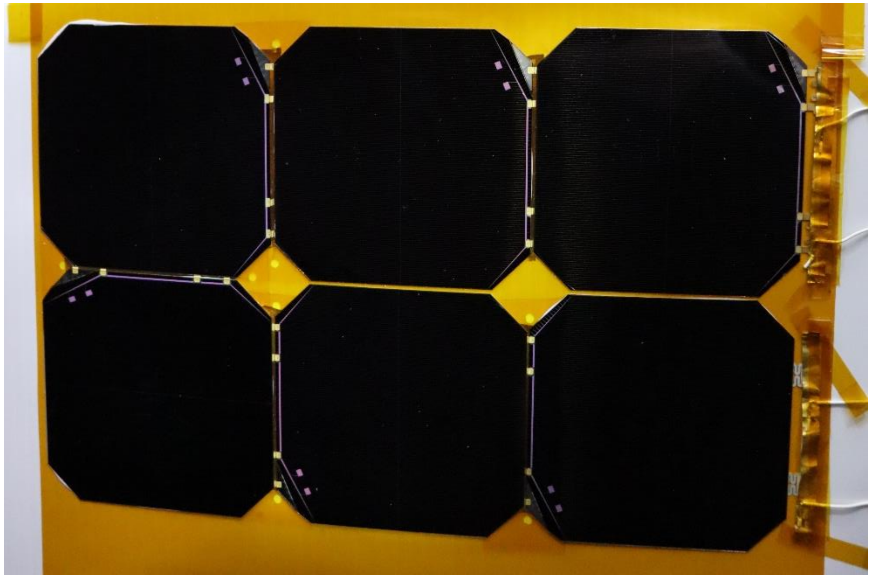
Cell Mass Reduction

Mass Production of Mass-Reduction

- ***500kW + produced ~80cm² cells at 225um thickness***
- ***53kW produced Z4J cells >80cm² at 175um thickness***
- ***44kW produced Z4J cells >80cm² at 140um thickness***
- ***80um thick development***
  - **6” 2-pers >80cm² with 80um Ge thickness done in pilot volumes**
  - **4” 1-per coupons with 2-mil cover glass**

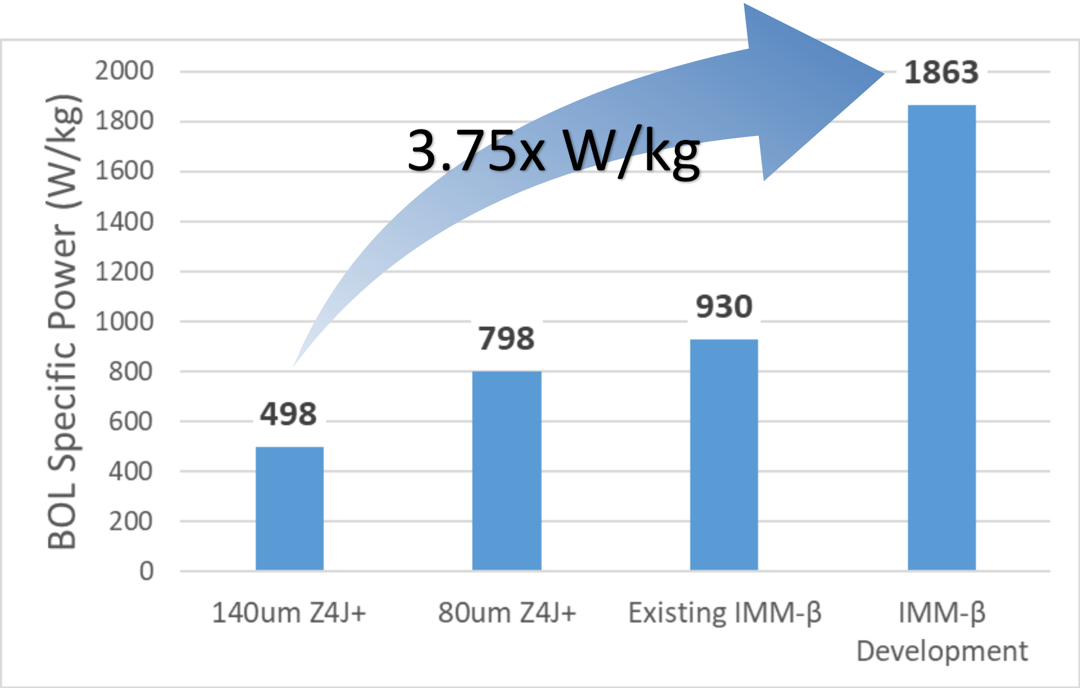


80um Z4J SPM Coupon

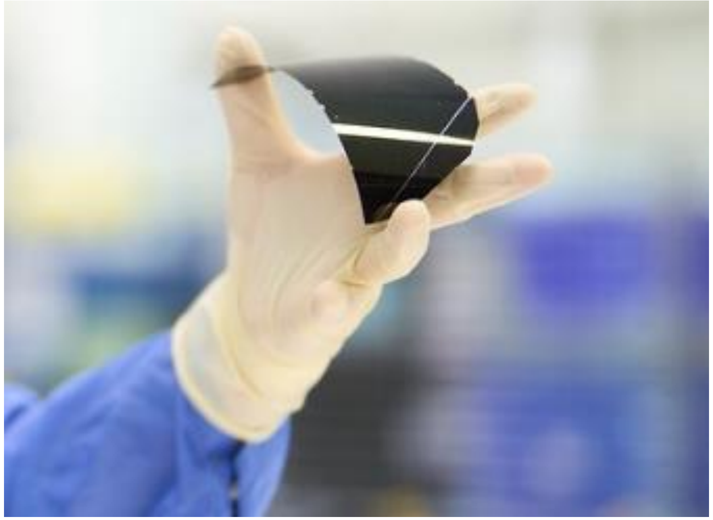


IMM Product Mass Reduction

- ***IMM provides 42% mass reduction compared to 140um Ge based cells***
- ***Thinner IMM solar cells in pilot production are 2x the specific power of existing IMM and 3.75x higher specific power of 140um Ge***



81cm^2, IMM-β, 1863 W/kg



Acknowledgements

SolAero gratefully acknowledges the support of our partners!

- *AFRL*
- *Aerospace*
- *NREL*

Thank You