
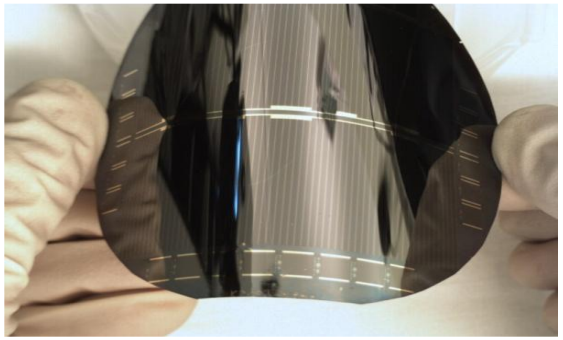
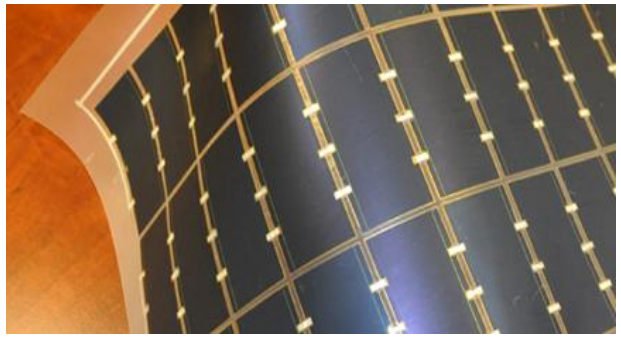

SOaRS 2025

April 25, 2025

# *Advancements in Solar Arrays*


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MicroLink Devices, Inc.

# Outline

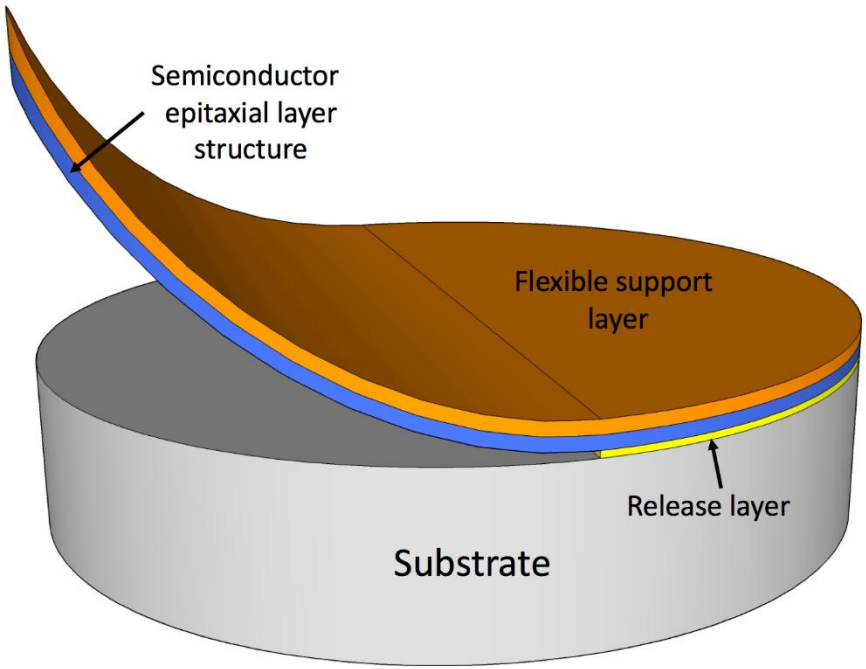
- Textured Solar Arrays → Zephyr Platform
- Laser Power Converters → BAE PHASA-8
- Space Solar Cells → Airbus Sparkwing → Maxar Bus → SDA



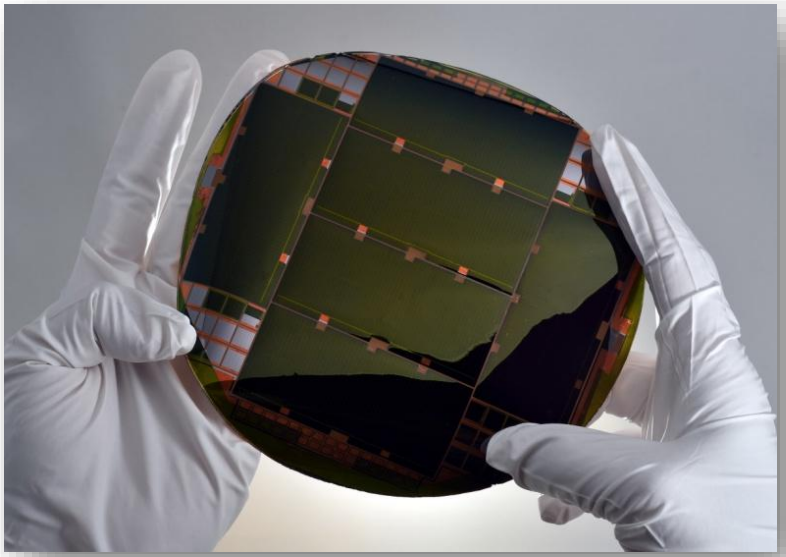


# Epitaxial Lift-off (ELO) Process Technology

- ELO uses highly selective wet chemical etching to dissolve a release layer and "peel" III-V epi-layers from their original growth substrate
- Lifted-off semiconductor material supported by metal layer
- GaAs substrate reused for cost reduction




6-inch processed ELO foil –
25-µm thick, flexible and lightweight



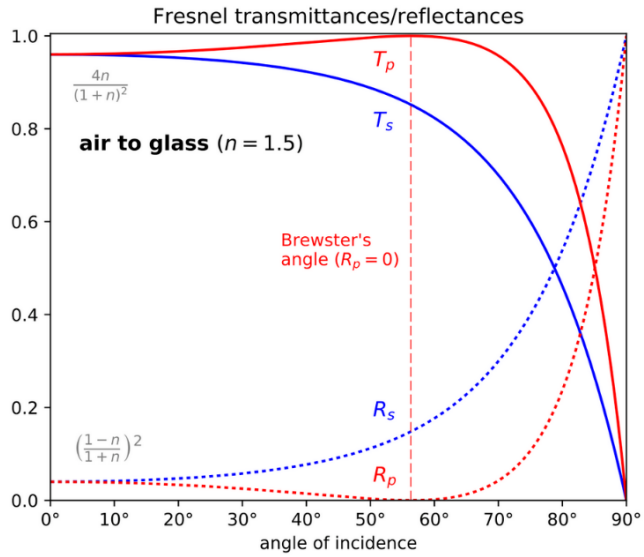
# Textured Top Sheet

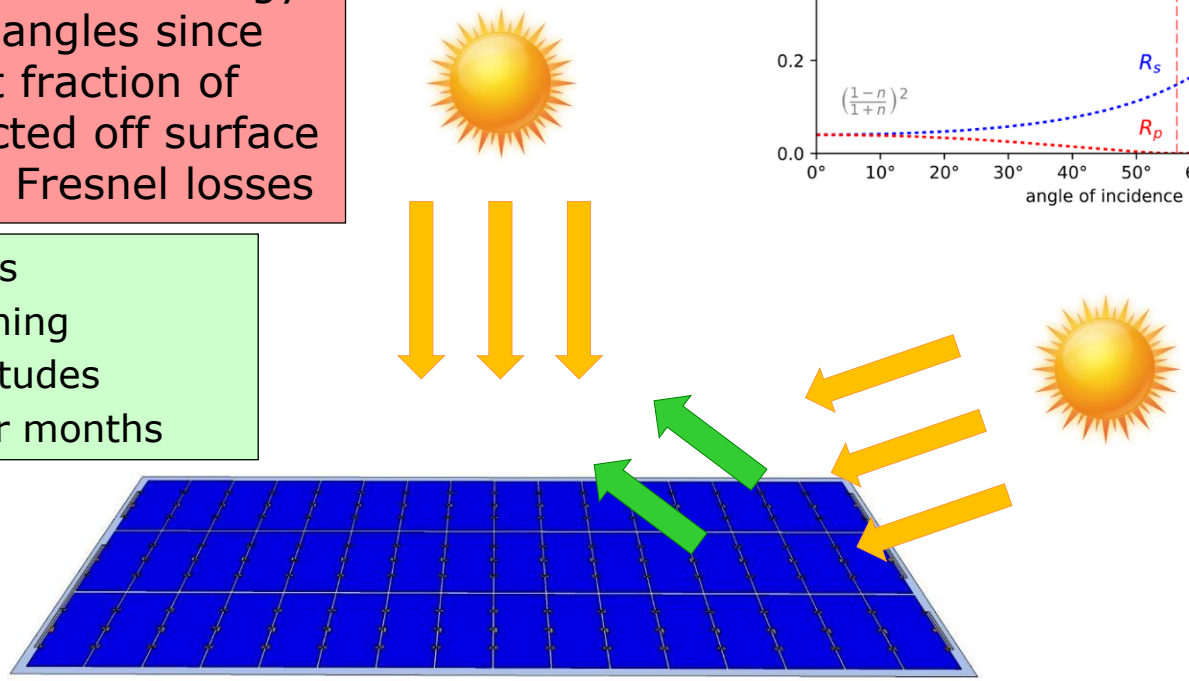
Solar array performance reduced at lower sun elevation angles

Less available solar energy at low sun angles since significant fraction of sunlight reflected off surface of film due to Fresnel losses

Challenge occurs

- Morning/evening
- At higher latitudes
- During winter months

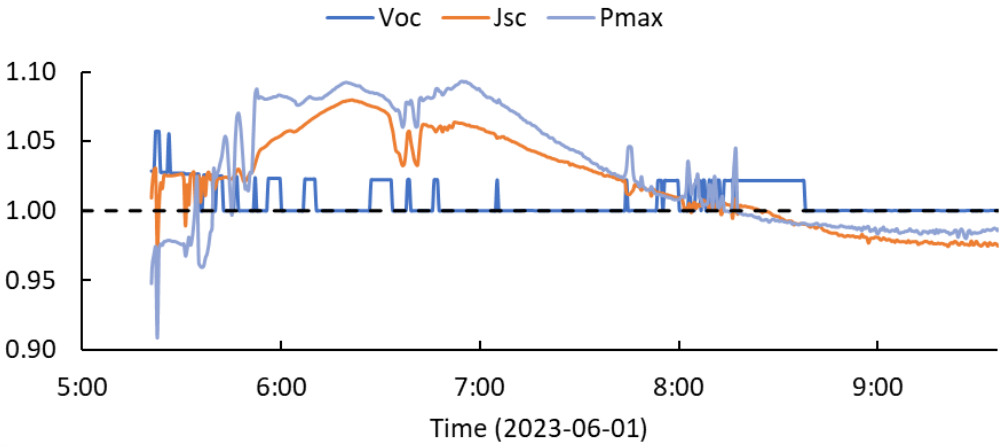


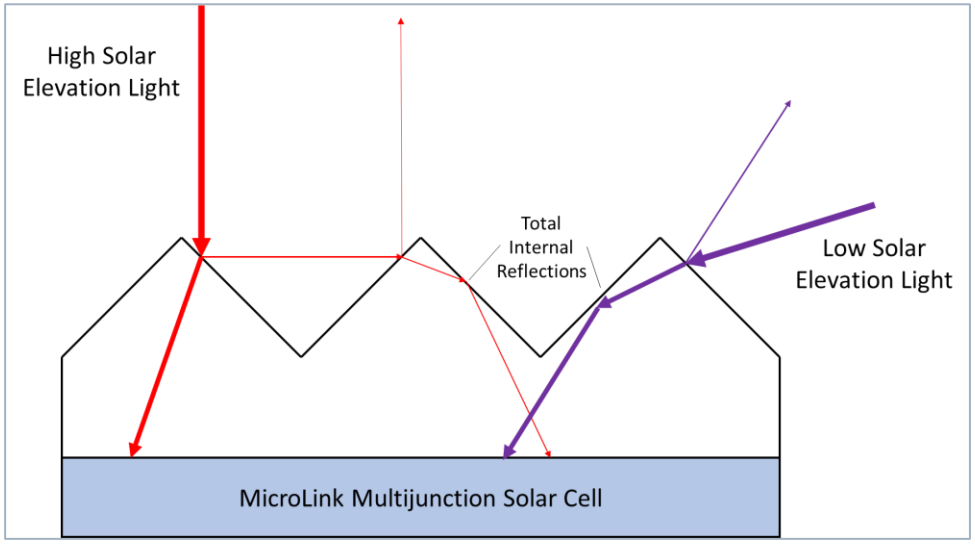
# Rooftop Textured Array Demonstration

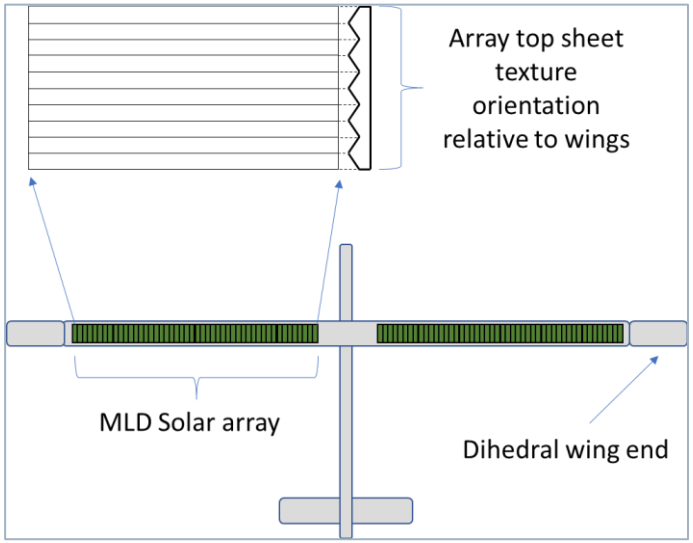
- Textured arrays delivered up to 10% more power during early morning hours

Ratio of Textured vs Planar Array
$J_{sc}$ and $P_{max}$

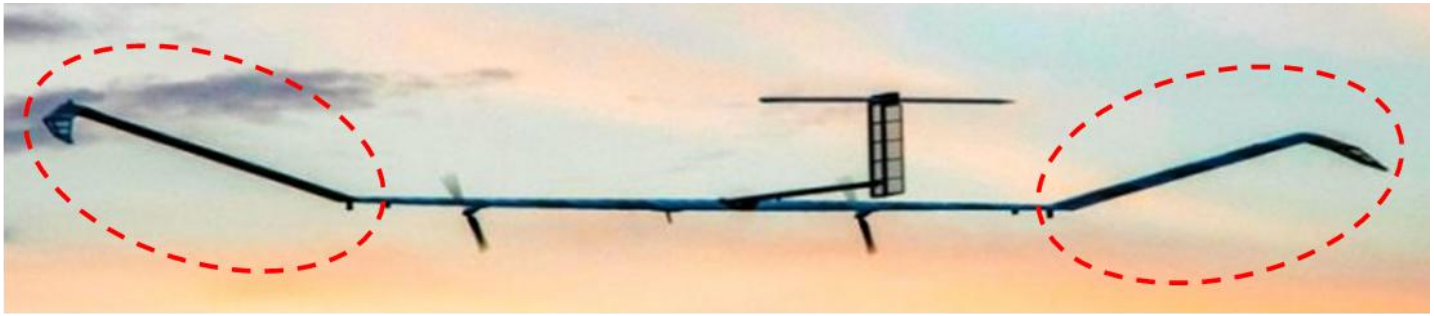


# Textured Top Sheet

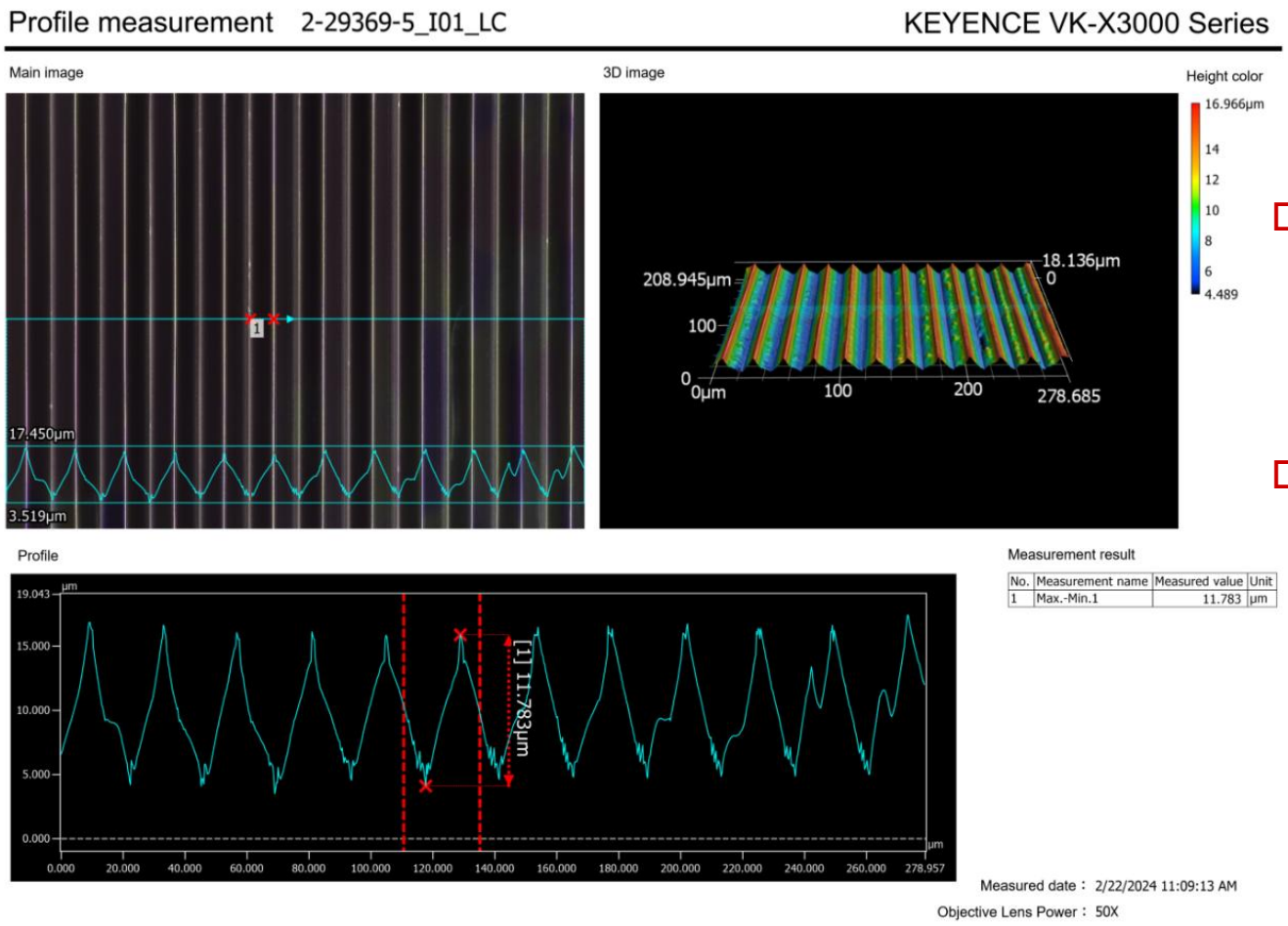



Airbus Zephyr



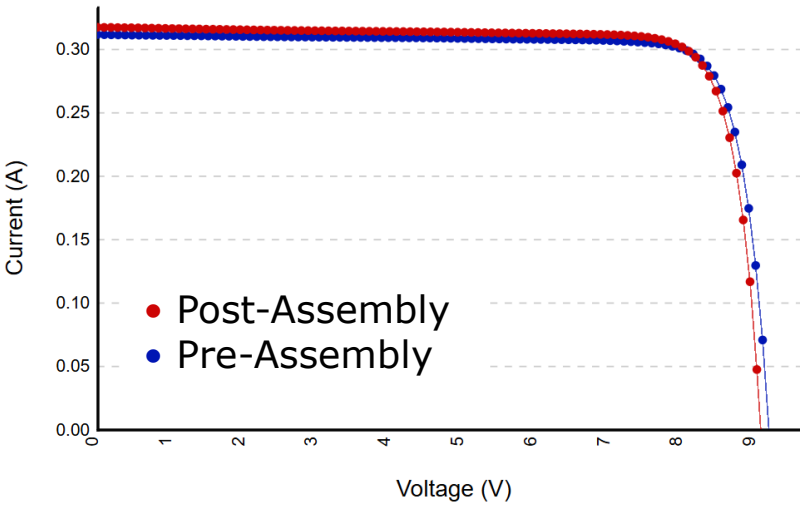
# Prism Quality

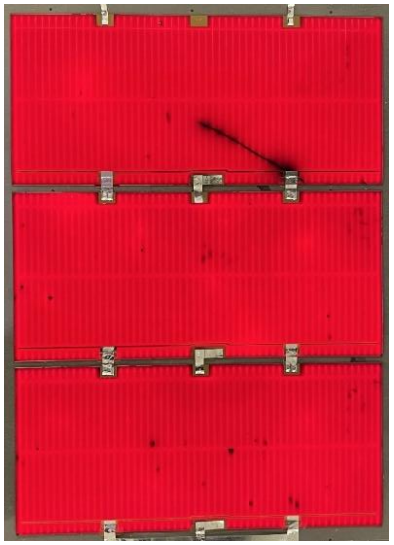



- Laser confocal microscopy showed high quality of linear prisms
- No damage to prisms after lamination to solar cells

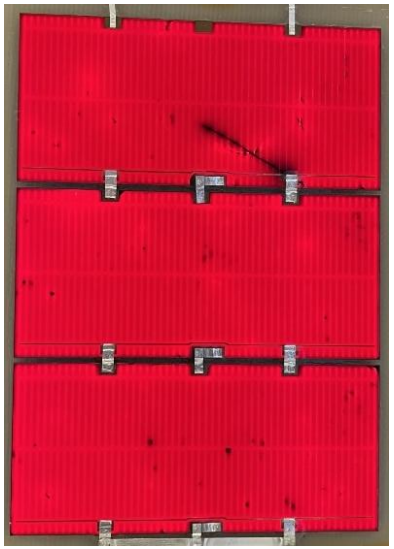
# Laminated Performance

- Slight expected drop in $J_{SC}$
- No significant changes in efficiency
- Pending angular performance measurements



**Pre-Assembly**

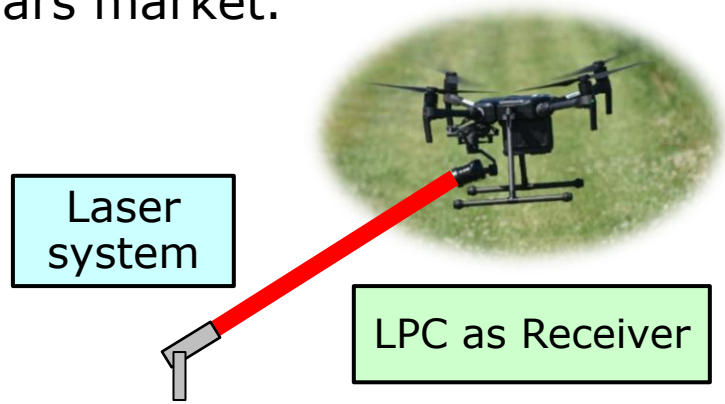


**Post-Assembly**

| | $V_{OC}$ (V) | $J_{SC}$ (mA/cm$^2$) | Fill Factor (%) | Efficiency (%) |
|---|---|---|---|---|
| Post-assembly | 9.207 | 15.6 | 83.95 | 29.44 |
| Pre-assembly | 9.034 | 15.9 | 84.02 | 29.43 |

# Laser Power Beaming Technology

- Wireless and long-range power transmission using laser light
- The market is predicted to have CAGR of 20% for the next 5-years into a tens of billions dollars market.
- Potential applications:
  - Autonomous vehicles
  - Space power supply
  - Telecommunications
  - Disaster relief
  - Power grid transmission
  - Commercial satellites

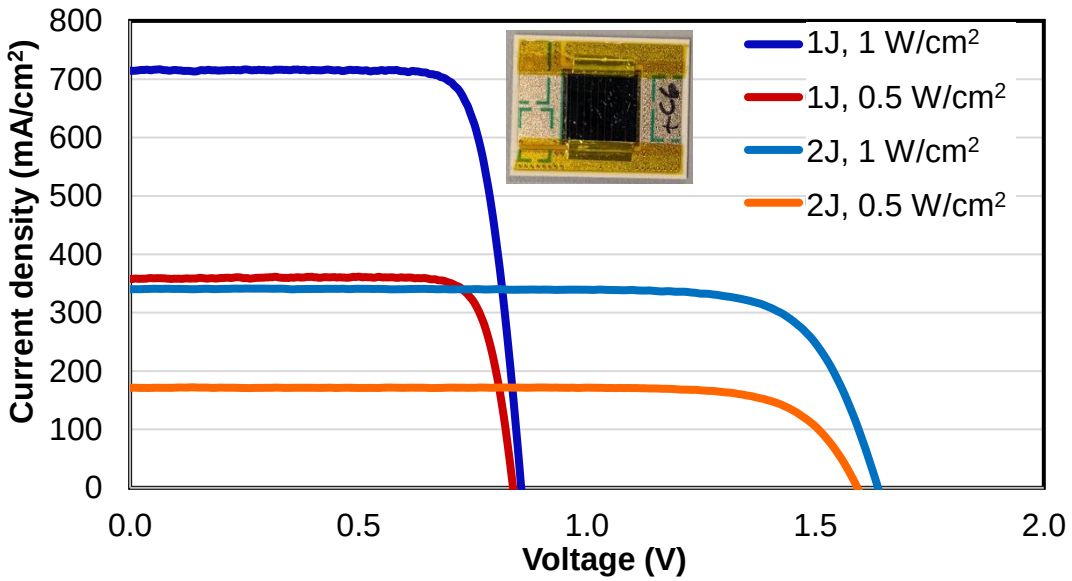



- The megawatt market size for laser power converter (LPC) applications is expected to be equivalent to hundreds of millions of dollars by 2030, with one laser source and multiple LPC receiver systems.

# MLD Laser Power Converter

- Lattice matched (1.11 eV) AlGaInAs
- 1 junction cell shows 50±2% efficiency with improvements to 60% expected soon
- Higher number of junctions in cells reduce sensitivity to varying laser intensities and improved $I^2R$ losses
- Multijunction cell development: Phase I funded project for each new version of MJ cell design

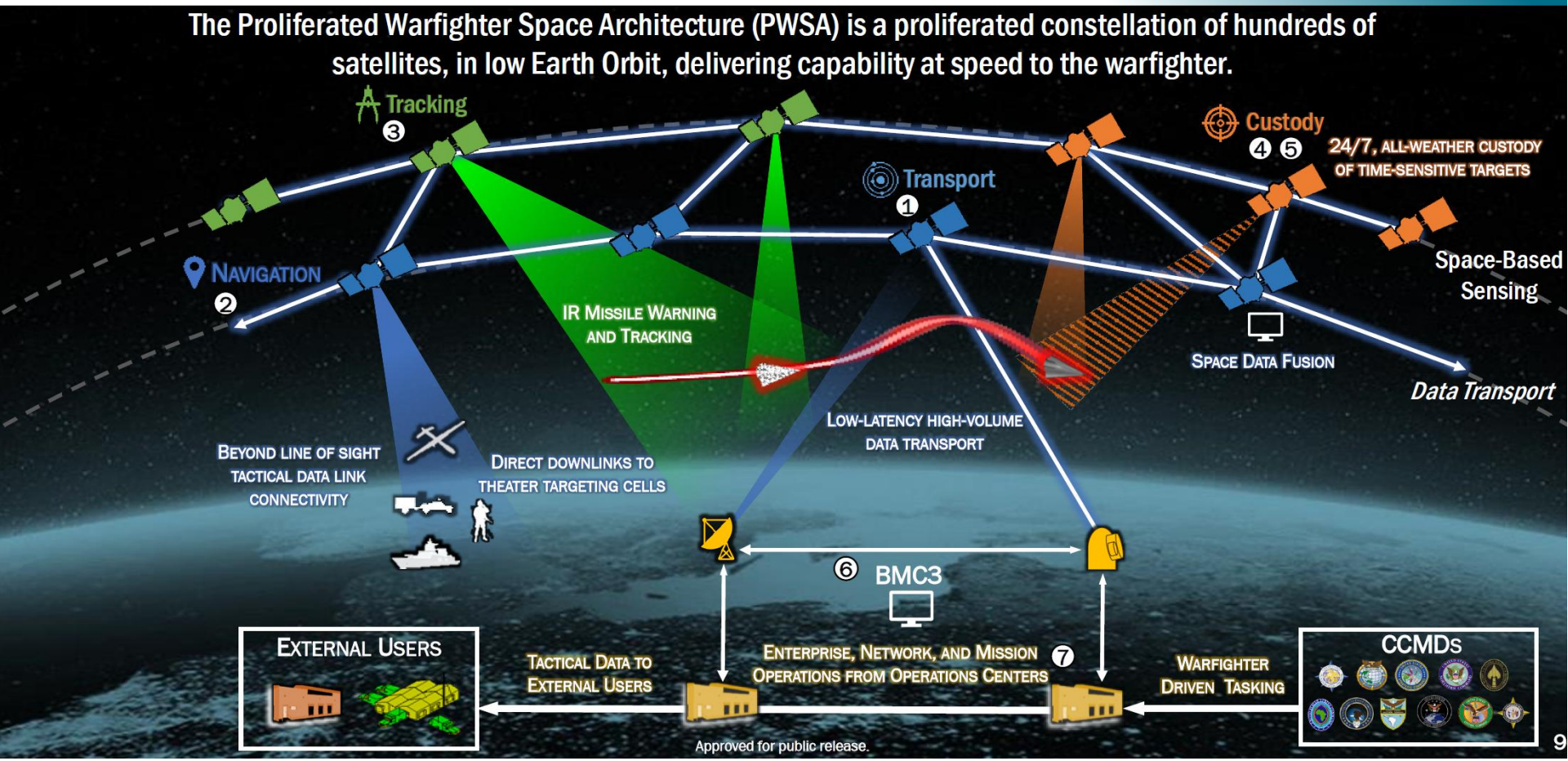
| | Power Density ($W/cm^2$) | $V_{OC}$ (V) | $J_{SC}$ ($mA/cm^2$) | Fill Factor (%) | Efficiency (%) |
|---|---|---|---|---|---|
| 1-Junction | 1 | 0.86 | 715 | 80.07 | 49.04 |
| | 0.5 | 0.84 | 358 | 82.58 | 49.60 |
| 2-Junctions | 1 | 1.64 | 340 | 77.97 | 43.52 |
| | 0.5 | 1.60 | 171 | 78.41 | 42.86 |



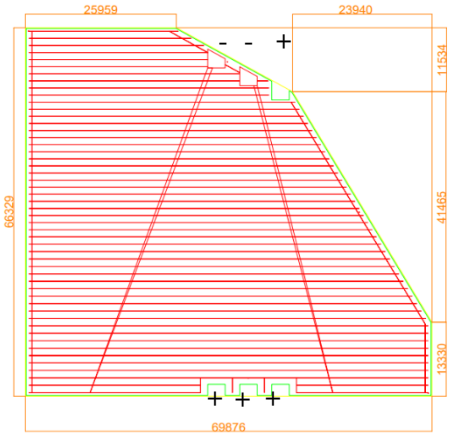
# Roadmap of LPC Cell Development

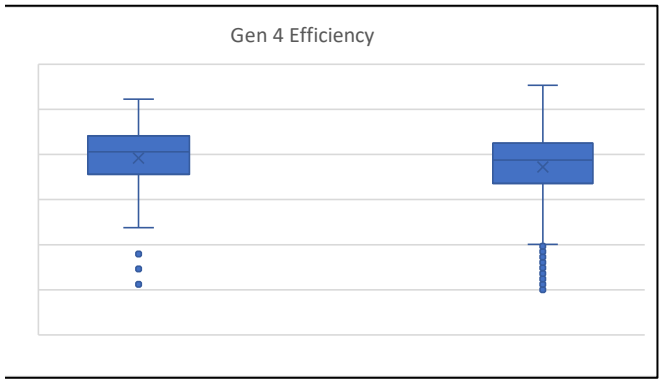
- LPC Cell Development Path:
  - Multi-junction 2J, 3J, and 4J cell development ongoing.
  - Tunnel diodes with reduced parasitic absorption.
  - Ultimately want to maximize the practical number of junctions
- Develop Module:
  - Cell layout for optimized module manufacturing that minimizes packing losses and maximizes power conversion.
  - Grid metal designs that reduce shading and resistance losses.
  - Thermal mitigation strategies to spread the heat of the module.
- Develop better backside reflectance for enhanced cell performance:
  - Use a dielectric for enhanced back-side reflectance.

# PWSA Joint Force Integration



# MTJ-1 Space Cell Preliminary Performance




## MTJ-1 Space Cell Design

- Quartex cell geometry
- Epitaxial layer structure optimized for low fluence (1e14 $cm^{-2}$ electron)
- Back metal design for space
- applications (thermal stability)
- Industry-leading low mass (24 $mg/cm^2$) 3x below Ge

## BOL Bare Solar Cell Performance

| Parameters | Value @ +25˚C |
|---|---|
| Cell Area (Quartex Cell) | 37 $cm^2$ |
| AM0 Efficiency BOL (%) | 29.8 |
| $V_{OC}$ (V) | 3.05 |
| $I_{SC}$ (mA) | 600 |
| $V_{mp}$ (V) | 2.65 |
| $I_{mp}$ (mA) | 570 |
| Max Power BOL (W) | 1.506 |

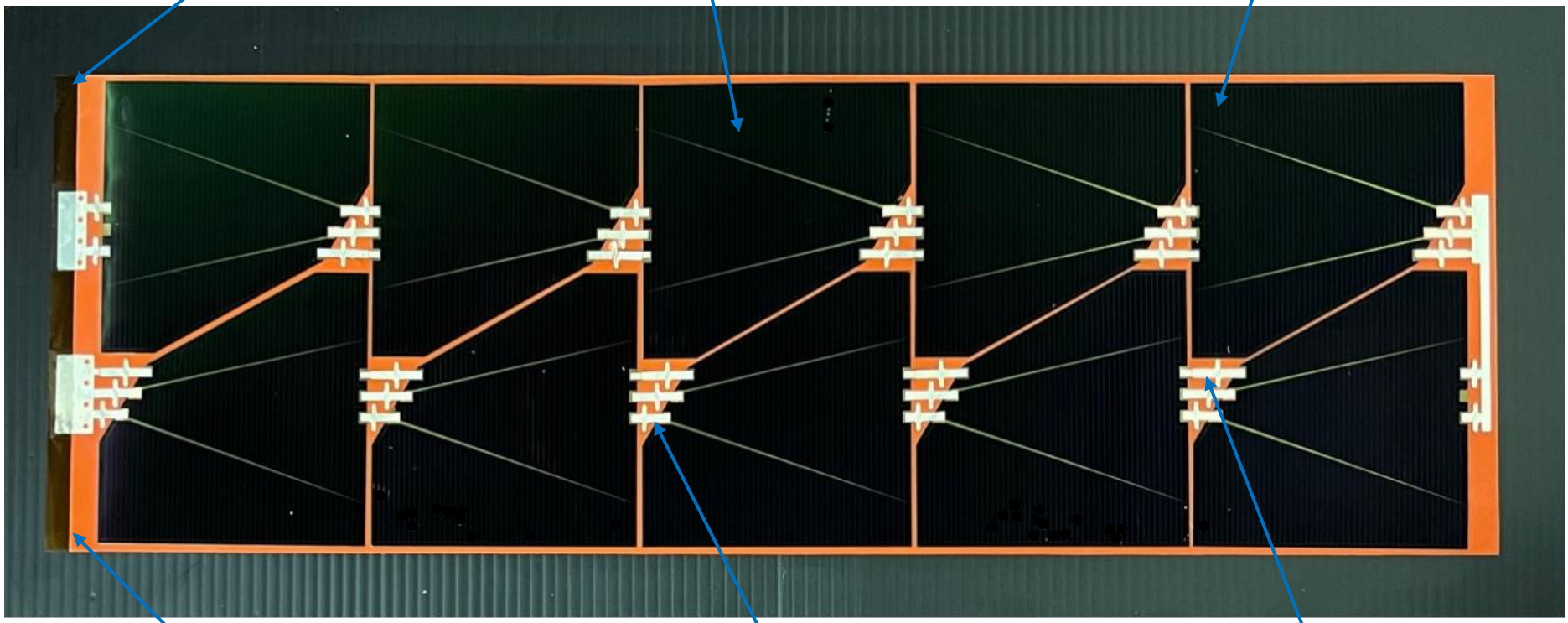
## EOL Remaining Factors (electron exposure)

| | | Post 1MeV Exposure Retention | | | | |
|---|---|---|---|---|---|---|
| Energy (MeV) | Fluence (cm-2) | Voc | Isc | Vmp | Imp | Pmp |
| 1 | 1.00E+14 | 0.955 | 0.951 | 0.968 | 0.949 | 0.918 |
| 1 | 5.00E+14 | 0.92 | 0.84 | 0.928 | 0.834 | 0.772 |

## Temperature Coefficients

| Energy (MeV) | Fluence | Voc (mV/°C) | Jsc (uA/cm2/°C) | Vmp (mV/°C) | Jmp (uA/cm2/°C) | Eff (%/°C) |
|---|---|---|---|---|---|---|
| | BoL | -6.08 | 11.68 | -6.38 | 7.91 | -0.0562 |
| 1 | 1.00E+14 | -7.06 | 9.66 | -7.42 | 7.4 | -0.0658 |
| 1 | 5.00E+14 | -7.03 | 14.36 | -7.1 | 11.05 | -0.0479 |

# Solar Power Module (SPM) – Design



# Microlink SPM

| Equipment (unit) | Supplier | Cat. | Heritage | QM | Qualification Status | Remark |
|---|---|---|---|---|---|---|
| TJ InGaP/GaAs/InGaAs solar cell | Microlink Devices | A | - Hale aircraft (Zephyr) | X | Open | Qualification planned in accordance to AIAA-S111/112, see development schedule |
| Solar Power Module | Microlink Devices | A | none | X | Open | Qualification planned in accordance to AIAA-S111/112, see development schedule |
| Bonded SPM on substrate | AirbusNL | A | none | X | Open | Various breadboard tests performed including >3,000 thermal cycles |

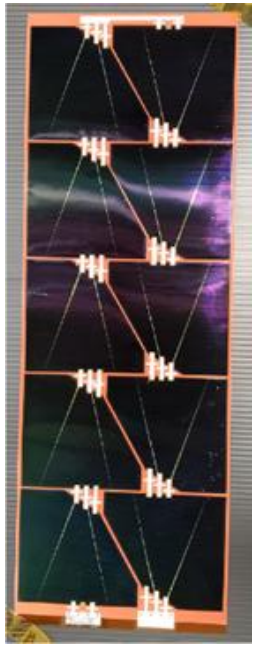
**Solar cell / Solar power module**

- Qualification ongoing in accordance to AIAA-S111/112
- Including 20,000 thermal cycles on Sparkwing panel substrate

**SPM bonding & welding on Sparkwing substrate**

- EM coupon test in October 2024
- 10x TVAC + 1,000 ambient pressure thermal cycles
- Life thermal cycling on DVT coupon as part of the contract

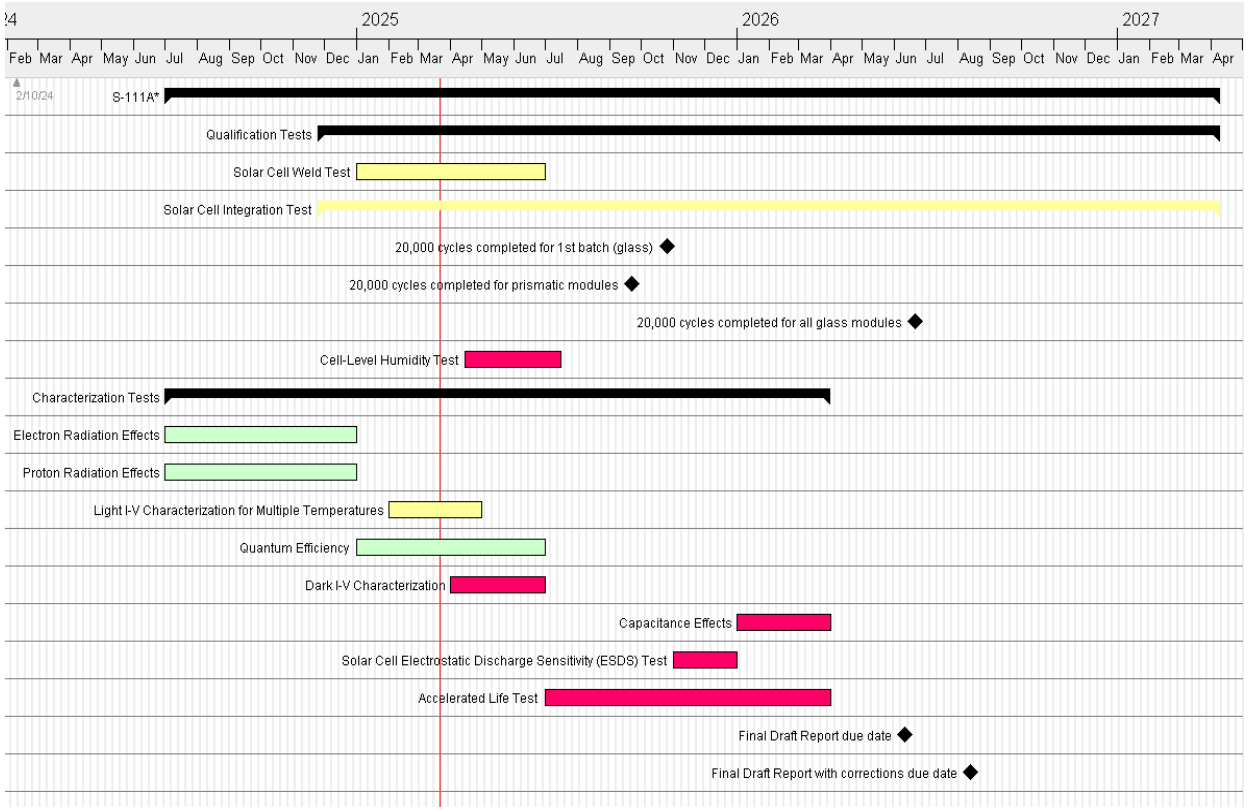
*Test conditions, results and references will be presented at EQSR.*



# Technology Derisking Prior to S-111A Qualification

| Technology area | Pre-qual test/derisking |
|---|---|
| Cell design | ✅ 1E14/cm$^2$ 1MeV e$^-$<br>✅ Grid metal tape test<br>✅ Damp heat exposure (45°C, 95% RH)<br>✅ Thermal runaway evaluation |
| Interconnect<br>(Ag-Kovar w/racetrack strain relief) | ✅ FEA analysis<br>✅ 2,000,000 cycle mechanical fatigue test<br>✅ 7000 thermal cycles (-120 – +120°C)<br>✅ Weld pull force |
| Encapsulation<br>(Prismatic silicone with UVR coating) | ✅ 2000 ESH vacuum UV<br>✅ 7-year LEO ATOX<br>✅ 1E15/cm$^2$ 1MeV e$^-$<br>✅ 800km low-energy p+<br>✅ Combined effects (proton/thermal cycle)<br>☐ Extended vacuum UV (10,000 ESH, Q2 2025) |
| Bypass diodes (Si Schottky) | ✅ Life test<br>✅ Weld pull force |

# S-111A Qualification Gantt



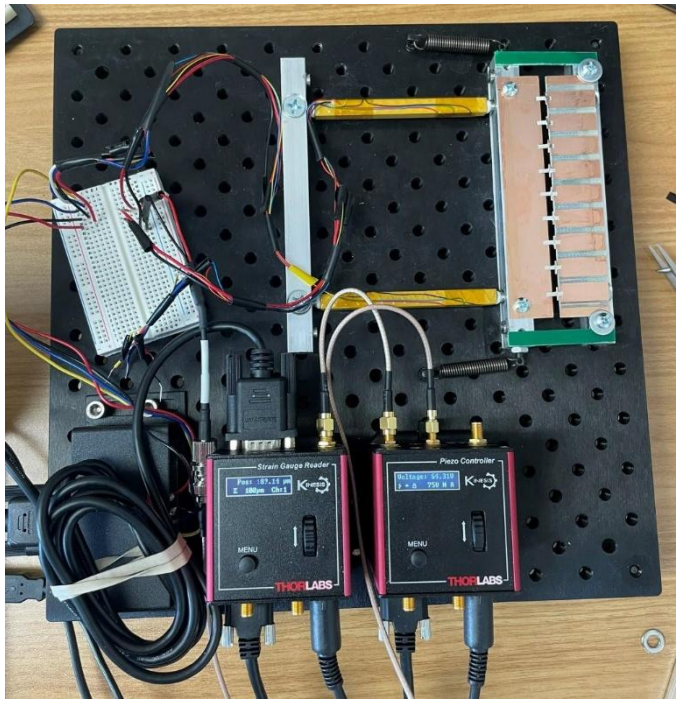

- Qual started Q3/2024
- Radiation testing complete
- Initial thermal cycling to complete end Q3/2025
- AIAA S-111A qual to complete Q2/2026

* The S-111A Solar Cell Integration Test concludes at 20,000 cycles. Continued cycling is to satisfy mission-specific requirements.

# Technology Derisking

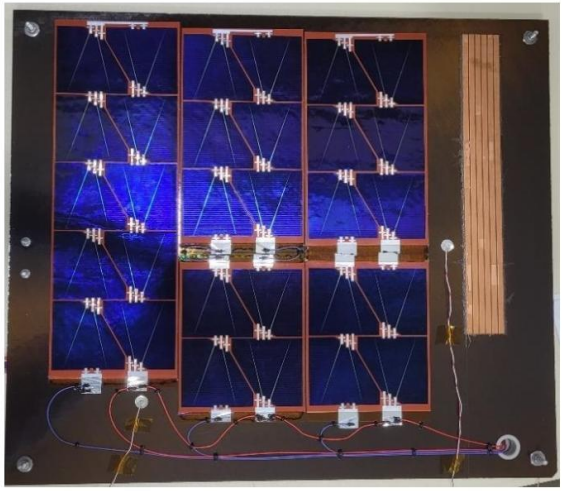
## Mechanical fatigue testing of planar interconnects

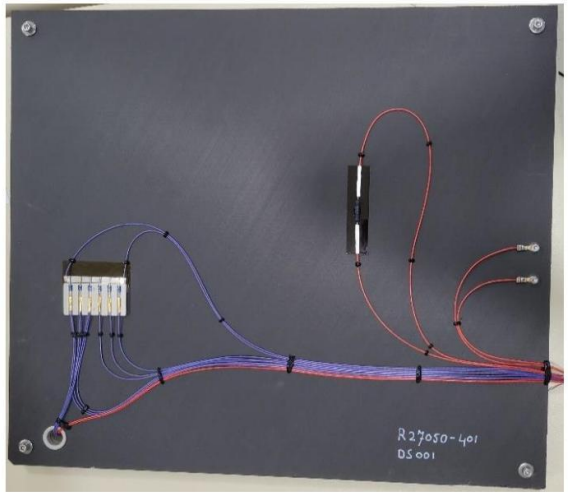
- "Racetrack" planar Ag-Kovar interconnect design
- Piezoelectric mechanical fatigue tester used to cycle interconnects over 2M cycles (100-micron displacement for LEO thermal range).



# MicroLink - Airbus/Sparkwing Demonstration Coupon

- MicroLink has had a multi-year joint development with Airbus Leiden to integrate MicroLink SPMs into Airbus Sparkwing arrays.
- Currently proposing Sparkwing/MLD arrays for SDA Tranche 3 constellation array (>66kW)
  - Need APFIT or other support for high-volume space scale-up
- Coupons were fabricated using MicroLink SPMs with multiple module-to-module interconnects
- Qualification testing:
  - 10x TVAC (+144/-142C)
  - 1000x APTC (+112/-108C)
  - 20k APTC (+100/-100C)

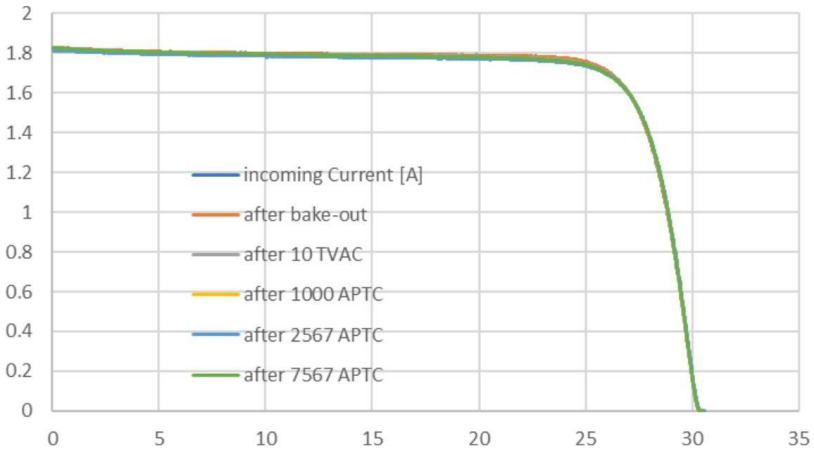


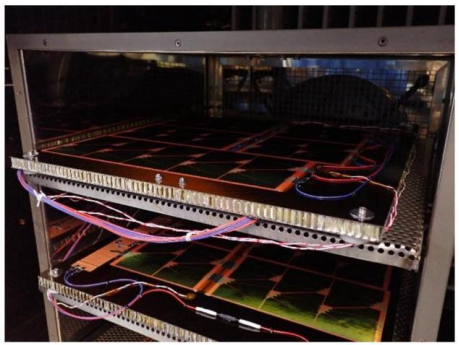


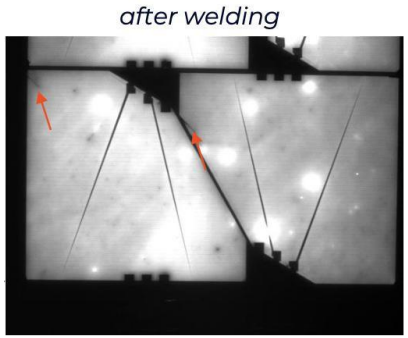

Sparkwing

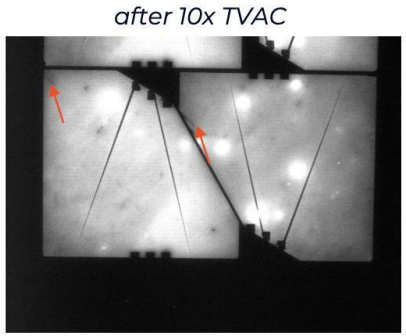
# MicroLink - Airbus/Sparkwing Demonstration Coupon

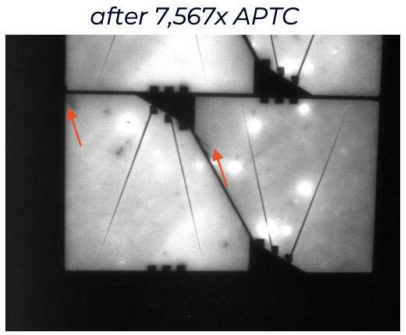
- >20,000 thermal cycles complete
- No changes in I-V or EL after thermal cycling
- Small cracks in cells did not degrade
- Key TRL 6 status achieved, high technology credibility for SDA proposal





# Summary

- Flexible solar sheets for HAPS aircraft with very high efficiency (>30% AM0) and high specific power (>1500W/kg).
- Textured encapsulations are an important technology to extend light collection in high latitude applications and reduce battery requirements.
- Laser Power Converters provides an additional power source to UAV and HAPS
- ELO Solar Models are being qualified for Space Satellites

AFWERX

PM – Eric Follstad (CENTCOM) and Alec Jackson (AFRL)