

SOARS 2024  
March 13, 2024

## ***Textured Solar Arrays for Enhanced Low-Angle Light Collection on HAPS Aircraft***

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# Outline

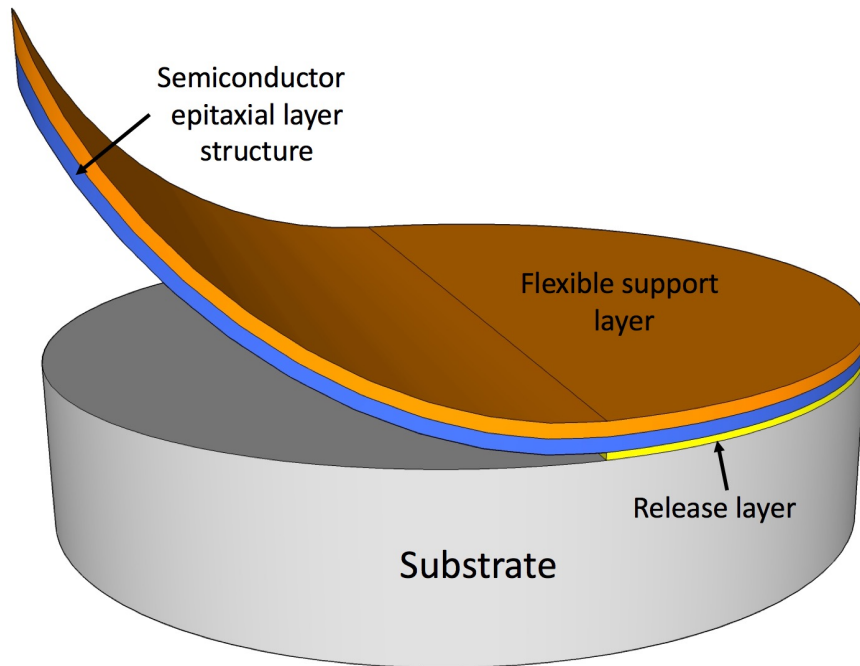
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- ❑ MicroLink IMM ELO solar cell technology
- ❑ Lightweight and flexible solar sheets to power HAPS
- ❑ Motivation for texturing, optical model
- ❑ Recent work at MicroLink on textured encapsulation solutions

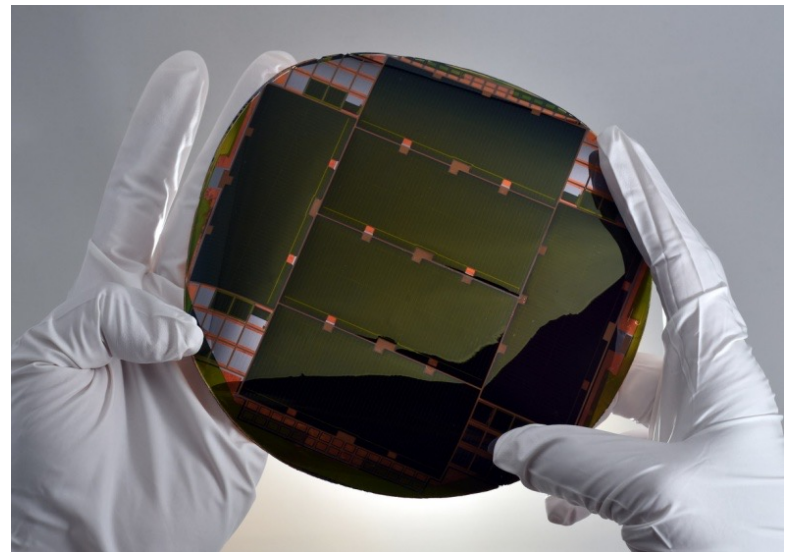


# Epitaxial lift-off (ELO) process technology

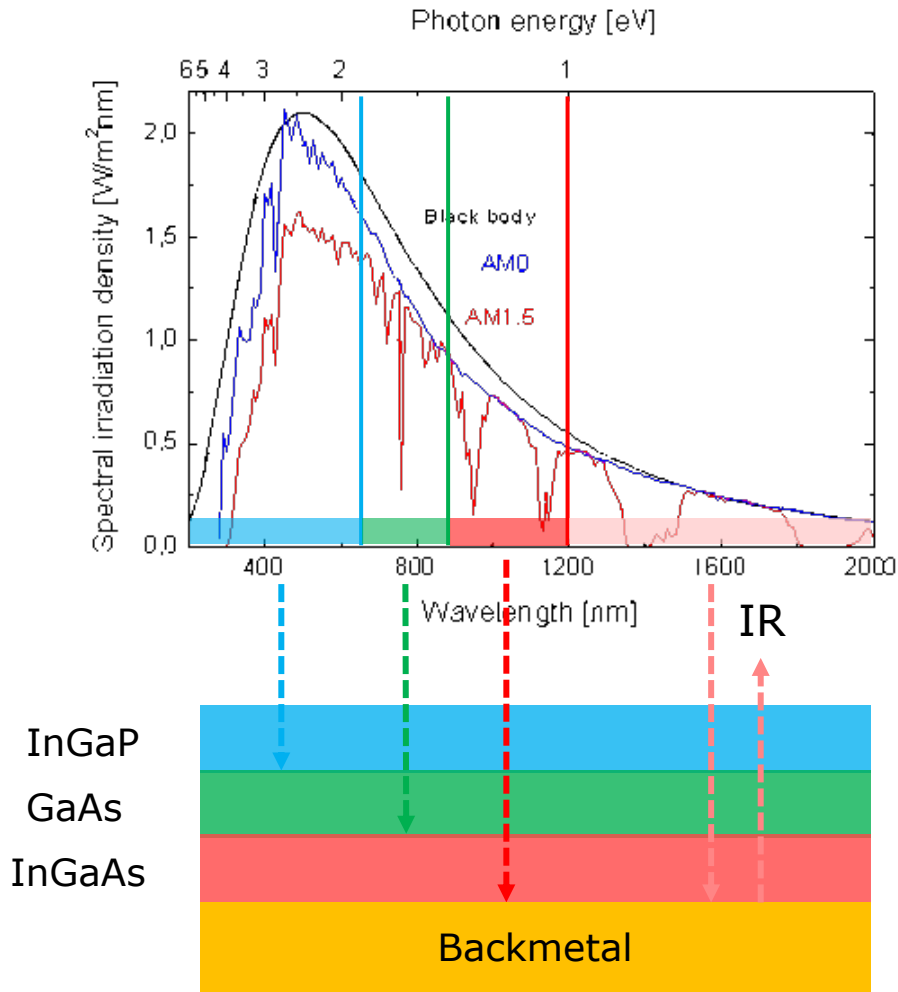
- ELO uses highly selective wet chemical etching to dissolve a release layer and “peel” III-V epi-layers from their original growth substrate
- Lifted-off semiconductor material supported by metal layer
- GaAs substrate reused for cost reduction



6-inch processed ELO foil –  
25- $\mu\text{m}$  thick, flexible and lightweight



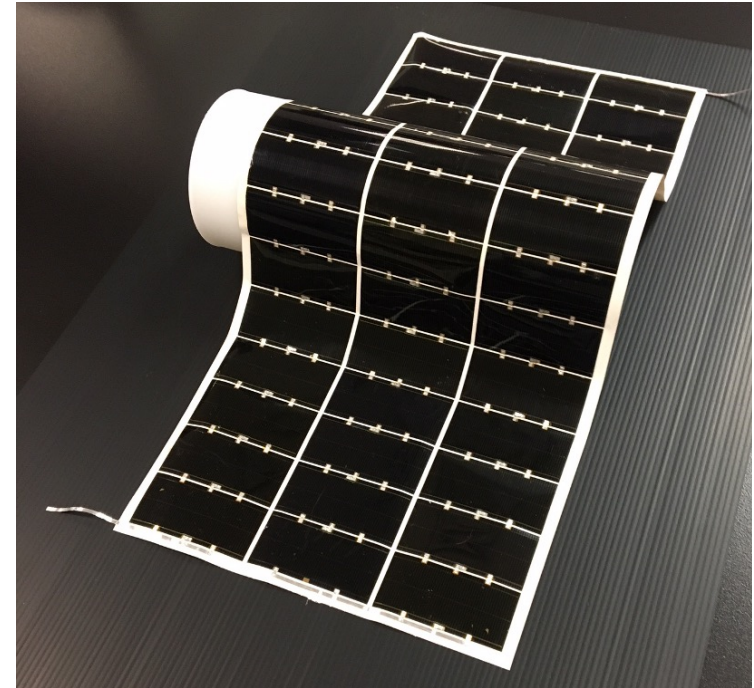
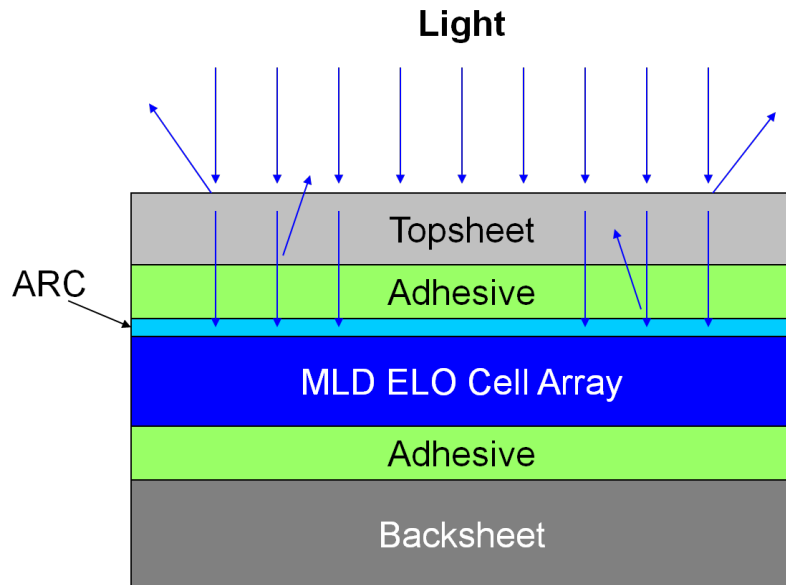
# Triple-junction IMM solar cells



- Multi-junction devices contain series-connected subcells of decreasing bandgap
  - Utilize full spectrum/reduce thermalization losses → higher efficiency performance
- MicroLink manufactures 3J Inverted Metamorphic Multi-junction (IMM) designs (exclusive NREL license):
  - 1.87 eV InGaP top cell
  - 1.42 eV GaAs middle cell
  - 1 eV (metamorphic) InGaAs bottom cell
- Record 37.7% AM1.5 NREL-certified performance
- Production efficiency > 30% AM0
- Specific power up to 3000 W/kg

# Flexible solar sheets for HAPS

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- ❑ Laminated Teflon FEP top sheet
- ❑ Space-grade welded silver interconnects and bypass diodes
- ❑ Backside adhesive for direct bonding to wing surfaces
- ❑ Sheet-level specific power  $> 1500$  W/kg

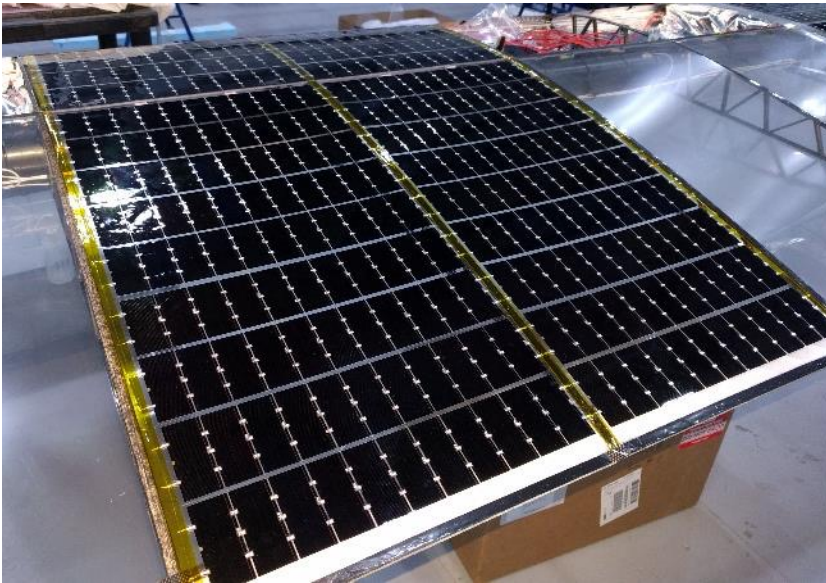


# HAPS aircraft powered by MicroLink ELO IMM

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High efficiency and low mass solar critical for HAPS. Airbus Zephyr 7 has wingspan of 25m and weighs 75kg.

## Airbus/Aalto Zephyr

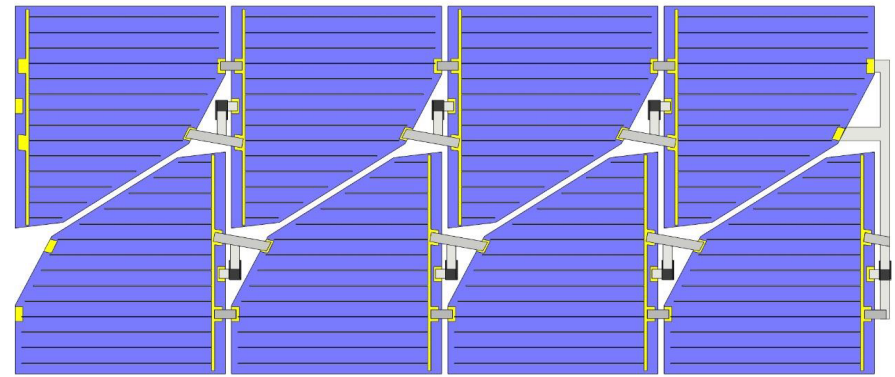
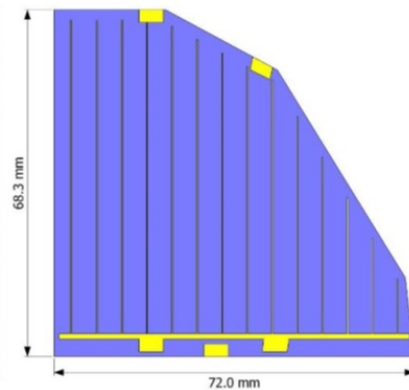
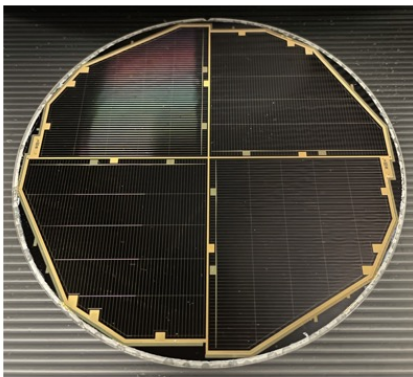
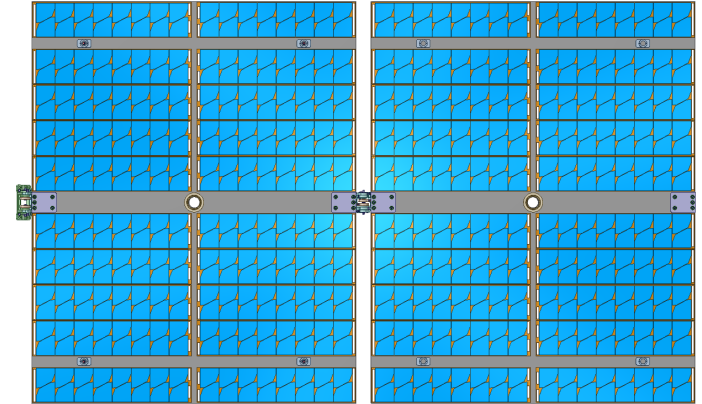


## BAE/Prismatic PHASA-35



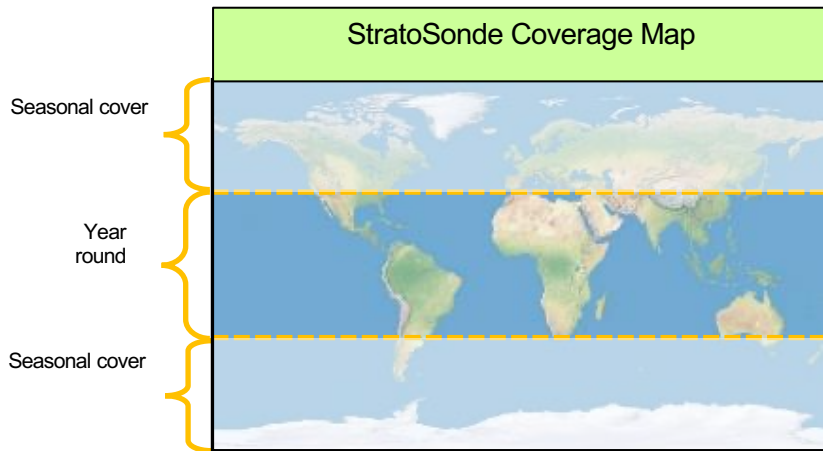
# Quartex™ cell geometry for lowest cost

- MicroLink's production process is based on 6-inch GaAs substrates.
- "Quartex" cell geometry enables four 37-cm<sup>2</sup> cells per 6-inch wafer that efficiently utilize >90% of active area per wafer for lowest cost.
- Quartex cells can form intermeshed strings with high array-level fill factor (>90%).

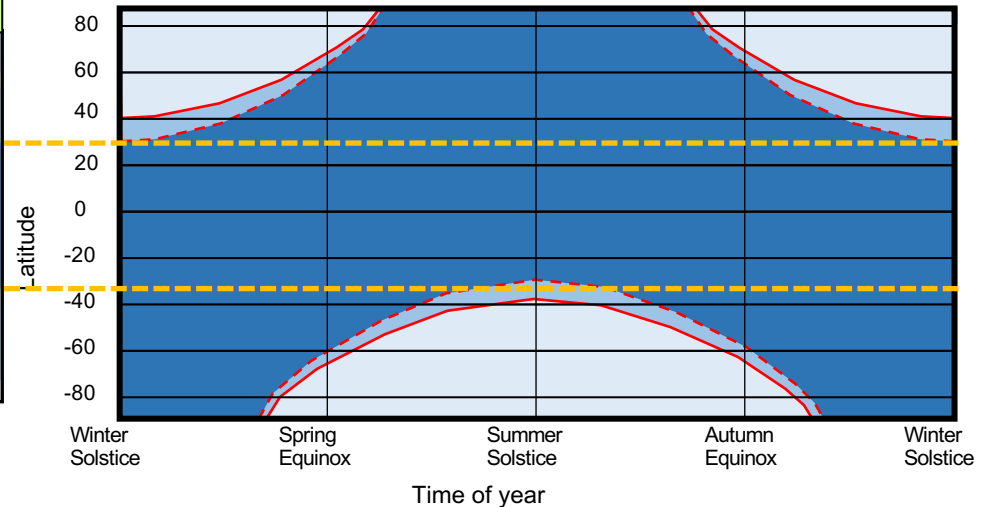


# HAPS applications in high latitudes during solstice periods are challenging

- ❑ Year-round coverage generally restricted to latitudes within +/- 30 degrees
- ❑ High incident angles during morning and evening



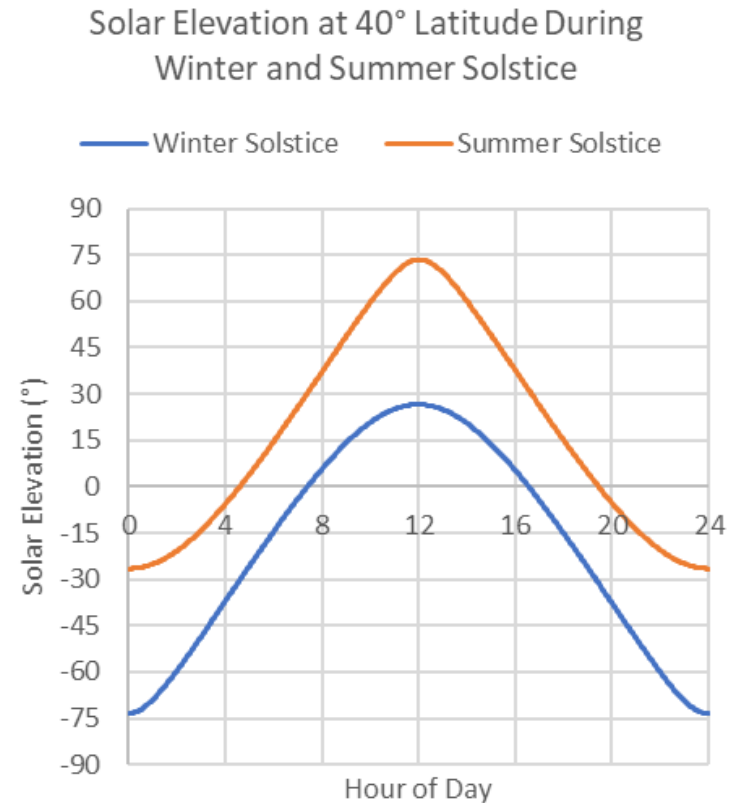
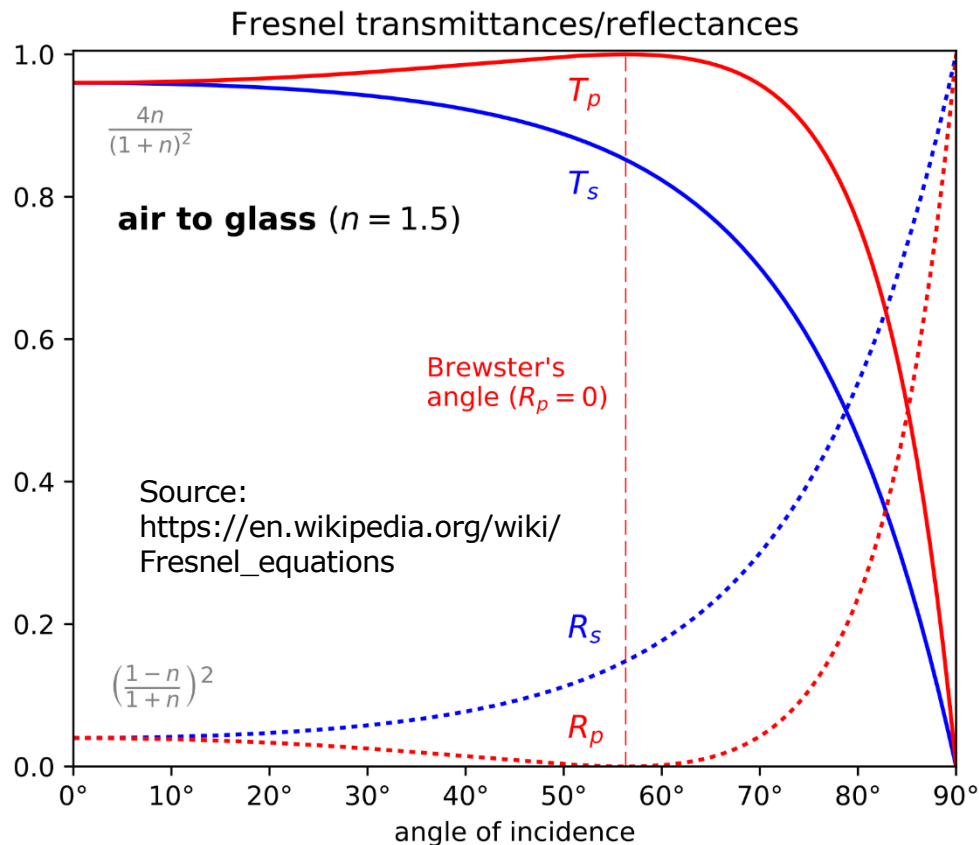
Coverage vs time of year





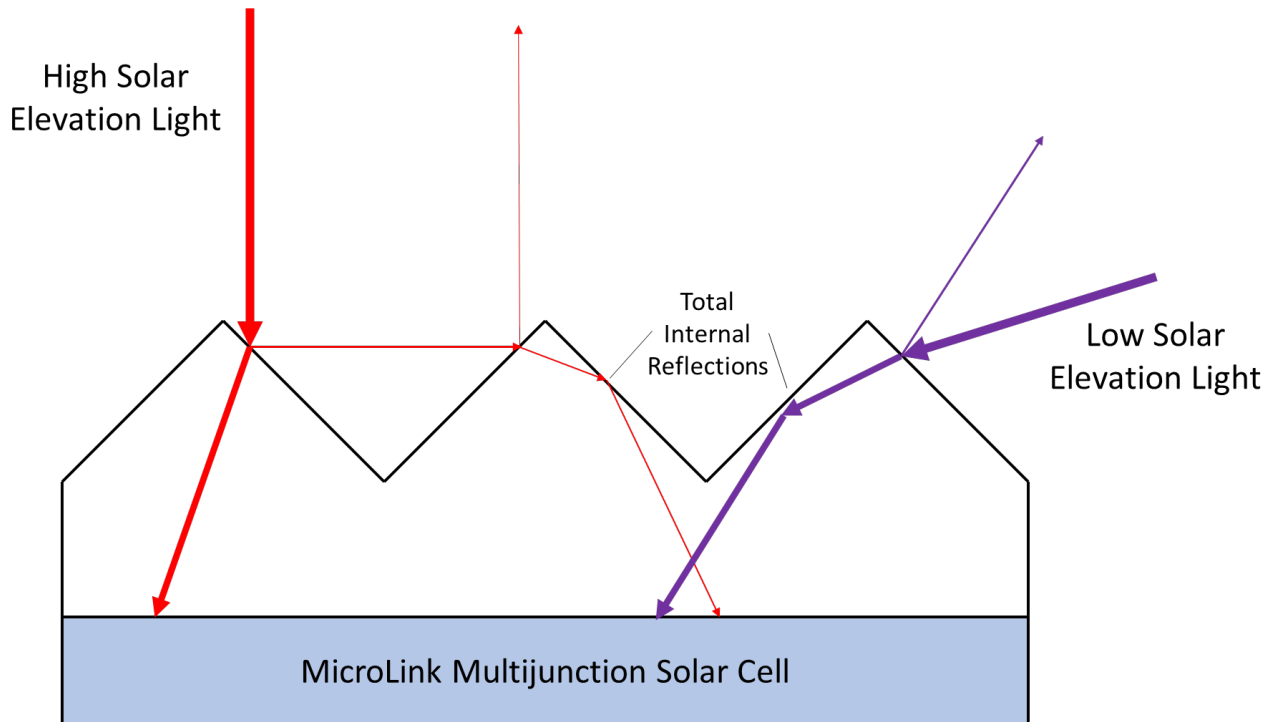
# The problem: Fresnel transmission losses increase at high angles of incidence $> 60^\circ$

- Transmission losses occur at both encapsulation and semiconductor interfaces



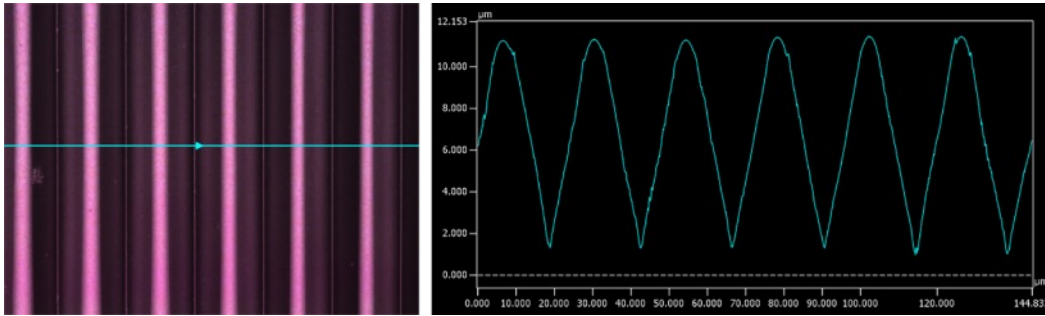
# The solution: Pyramidal surface texturing

- Low-elevation rays are refracted/internally reflected towards surface normal
- High-angle rays are recaptured



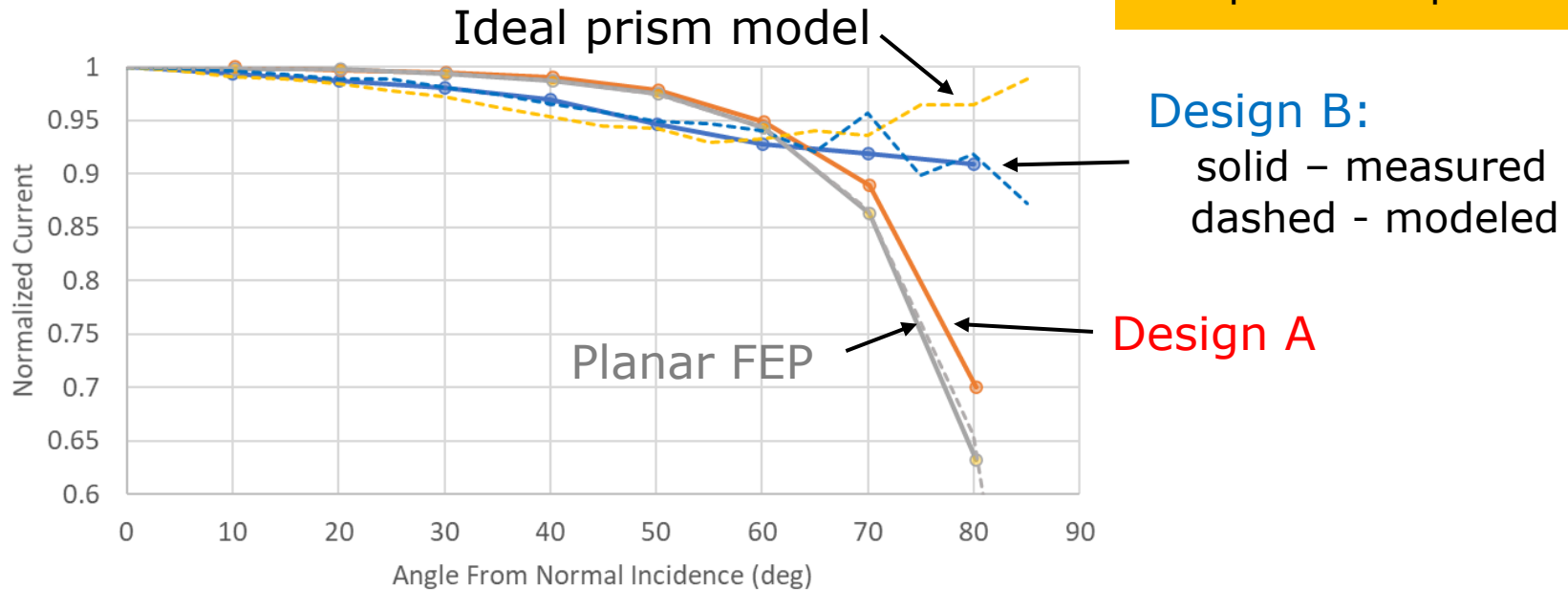
# Modeled and measured prism performance

Laser confocal microscope scan of design B



Measurements of two prism designs:

- **Design A:** Non-optimized prism shape
- **Design B:** Optimized prism shape

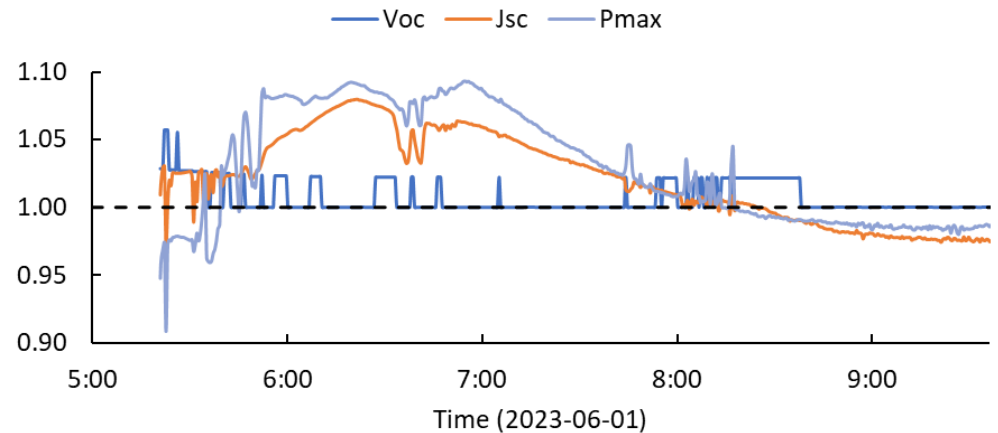


# Rooftop textured array demonstration

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



Ratio of textured vs planar array  
Jsc and Pmax





# Bring on the Day...

	Percent Increase Over Planar FEP		Hours Increased Compared to Planar FEP	
	Winter Solstice Total Power	Summer Solstice Total Power	Winter Solstice Hours Above 15%	Summer Solstice Hours Above 15%
Azimuth Averaged	<b>11%</b>	<b>2.7%</b>	<b>0.67</b>	<b>0.50</b>
Normal to Prisms	<b>15%</b>	<b>2.7%</b>	<b>0.87</b>	<b>0.67</b>

- ❑ Texturing can extend useful light collection by nearly an hour during winter solstice
- ❑ Translates into reduced battery requirements, estimated at ~130g per 1kW of solar array

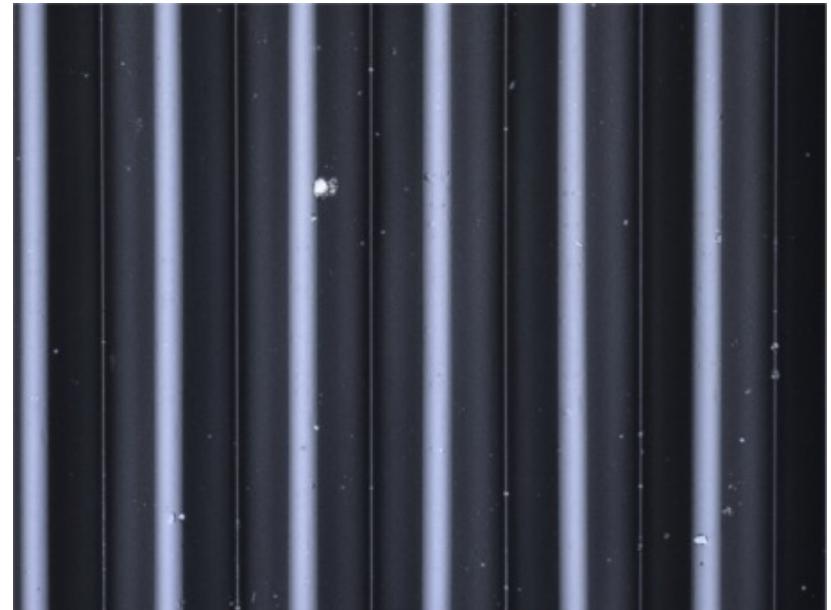
# Cleaning of textured surfaces

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- ❑ Textured surfaces have the potential to trap dust particles.
- ❑ Films coated with ISO 12103-1 A1 Ultrafine Test Dust (0-10  $\mu\text{m}$ ). High-pressure nitrogen could not remove dust, but a low-pressure water spray was successful.



Nitrogen blasted



Water cleaned

# Summary

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- ❑ MicroLink Devices manufactures flexible solar sheets for HAPS aircraft with very high efficiency ( $>30\%$  AM0) and high specific power ( $>1500\text{W/kg}$ ).
- ❑ Textured encapsulations are an important technology to extend light collection in high latitude applications and reduce battery requirements.
- ❑ Prototype sheets with encapsulation to be available in 2024, production transfer in 2025.
- ❑ Supported under AFWERX contract FA864922P0550 (Eric Follstad program manager)
- ❑ Contact: [npan@mldevices.com](mailto:npan@mldevices.com)

Thank you!

