DragonSCALES™ Space-Grade Si Solar Cells & Modules – Qualification and Production Status

mPower Technology, Inc.

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Manufacturing and Integration Partners

mPower TECHNOLOGY

mPower Technology Overview

Founded in Albuquerque

Spinout from Sandia Labs

Sandia National Laboratories

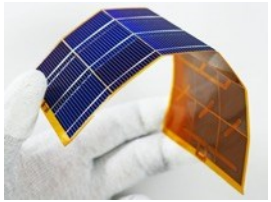
Core Innovation

DragonSCALES™ – Low-cost, flexible and reliable silicon solar modules

DragonSCALES™

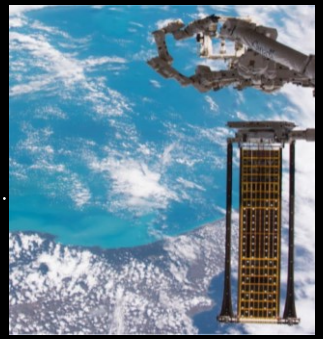
Intellectual Property

32 Patents Filed or Exclusively Licensed



Investment to Date

- $16.2M
- Builds on ~$20M in R&D at Sandia



Initial Markets

- Space (primary)
- Remote/Portable Power

SSL A MAXAR COMPANY · LYNK · AIRBUS DEFENCE & SPACE · ThalesAlenia Space · OneWeb · NORTHROP GRUMMAN · LOCKHEED MARTIN · NASA

Initial Target Space Applications

- Low-earth satellite constellations
- Electric orbit raising
- Lunar missions
- Space Power Generation/Beaming

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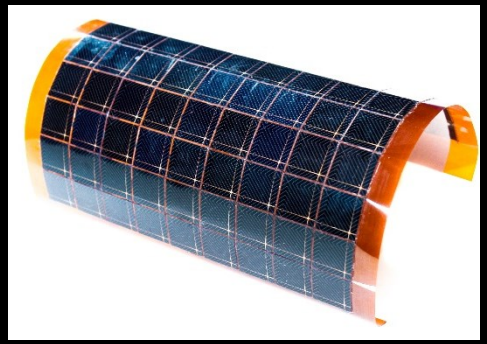
DragonSCALES™ Key Benefits

DragonSCALES™



- Significantly lower cost (>5x less than traditional GaAs)
- Reduced cost at array/wing level (simplified integration)
- Flexible and extremely resilient
- Low mass
- Voltage-adjustable
- Customizable form factor with packing factors > 95%
- Highly reliable and resilient to damage and shading
- Orders of magnitude improved stowage volume
- Radiation recovery on-orbit (self-healing)
- Rapidly scalable to ultra-high production volumes

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Current Status - Cell Technology

DS-100

DragonSCALES™

PRODUCT OVERVIEW

DS100 is a monocrystalline silicon all back contact micro-cell that is the engine of mPower Technology's DragonSCALES™ solar modules. DS100 micro-cells are customizable and available in sizes ranging from 15mm x 15mm to 50 mm x 50 mm. DS100 is based on a high efficiency silicon solar cell material to optimize power output. This datasheet provides representative specifications for mPower's 20.0 mm x 20.0 mm version. mPower works directly with our satellite customers to optimize DragonSCALES module designs that maximize power, minimize mass and dramatically reduce end of life systems costs.

APPLICATIONS

DS100 micro-cells can be interconnected and meshed into any DragonSCALES module shape or form. The resulting modules are lightweight, flexible, resilient and extremely reliable. DragonSCALES are created using standard high volume automated semiconductor and solar cell manufacturing and assembly processes. The ability to uniquely connect DS100 micro-cells in series and parallel allows customizable voltages and sub-string configurations to maximize system level efficiency. DragonSCALES modules designed with DS100 are an ideal solution for the aerospace market, offering reduced weight, minimized stowage volume, and dramatically lower cost compared to III-V solutions.

DS-100

- High-efficiency silicon solar cell
- Lightweight, flexible and resilient
- No low-voltage limitations as with rigid solar cells
- Can be optimized to increase packing factor
- Available in sizes from 15mm x 15mm to 50mm x 50mm

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visit us online at www.mpowertech.com

PRODUCT SPECIFICATIONS

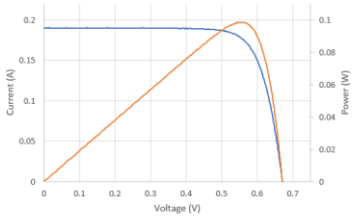
Qualification and characterization to AIAA-S111-2014 Standards – In Progress

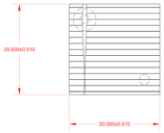
Design and Mechanical Data	
Base Material	p-type monocrystalline silicon wafer, diffused n on p junction
AR-Coating	silicon nitride
Cell Area	4 cm²
Average mass	0.16 g
Die Thickness	0.170 mm
Grid Design	two-contact back-side connection with front side linear grid

Electrical Data (BOL, AM0, 28C, 135.3 mW/cm²)*		
	Units	nom
Open Circuit Voltage	V	0.67
Short Circuit Current Density	mA/cm²	47.9
Max Power Voltage	V	0.56
Max Power Current	A	0.19
Fill Factor		0.78
Max Power (per cell)	W	0.10
Efficiency (condition)	%	18.7

*Nominal values for 20.0 mm x 20. 0 mm unglassed die. Detailed specifications applied at the module level.

Temperature Coefficients		
Open Circuit Voltage	mV / K	-2.10
Current	%/K	0.0405
Power	%/K	-0.375





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- High efficiency (18.7% AM0) silicon cells designed for space application
  - Unique cell structure – enabling higher reliability and lower assembly cost with improved radiation response

BOL performance at cell level characterized by multiple measurement labs

EOL performance – round robin with three different test facilities reviewed with multiple prime satellite manufacturers

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DragonSCALES™ Modules

Completely customizable solar modules composed of singulated silicon cells interconnected on a hyper-flexible substrate

- Cells connected both in parallel and series
- Enables innovative, high-power density designs that could not be achieved with conventional cells

Production-ready

- Flown in space (TRL - 8/9)
- Initial manufacturing line up and running

mPower is in flight production for a large LEO constellation

Highly promising radiation recovery results – new cell structures enable higher radiation resilience and recovery at lower temperatures

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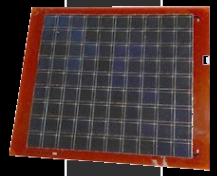
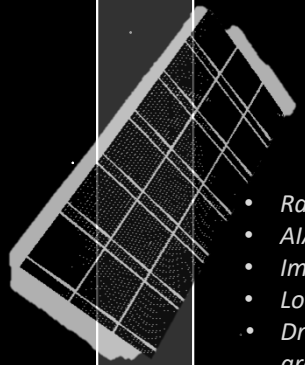
Technology Roadmap

DS-100
19% BOL



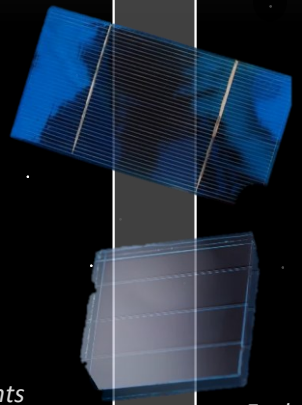
- *Radiation Recovery Capability*
- *First launch 6/2021, second launch 4/2022*
- *AIAA qualification in progress*
- *Baselined for large constellation*

DS-200
21% BOL



- *Radiation Recovery Capability*
- *AIAA qualification underway*
- *Improved temperature coefficients*
- *Lower mass*
- *Drop-in to DragonSCALES existing architecture*

DS-300
>28% BOL



- *Evaluation underway*
- *Higher efficiency*
- *High reliability*
- *Drop-in to DragonSCALES existing architecture*

Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4

2021 2022 2023

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DragonSCALES™ Mature and Ready for Integration

Well-characterized for EOL performance

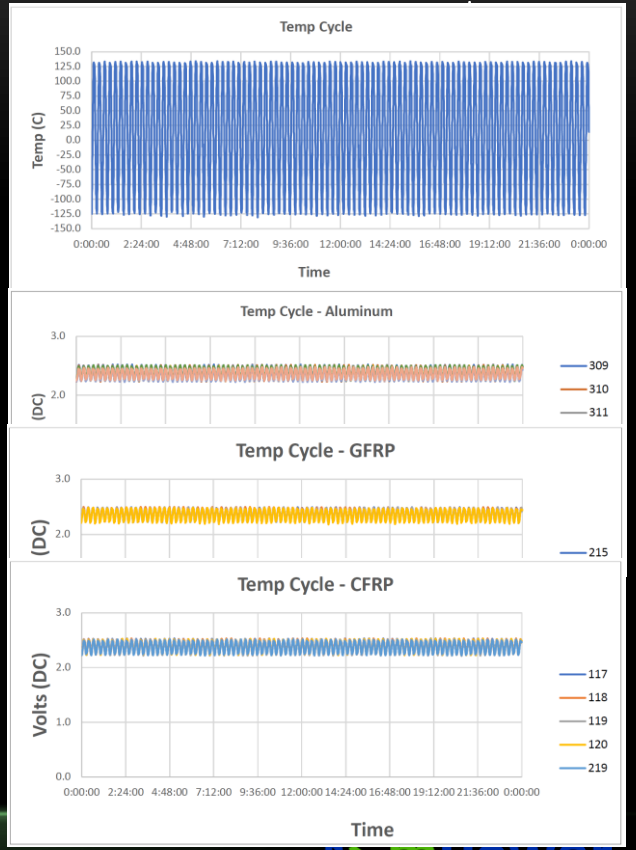
- Radiation loss factors, electrons and protons
- Temperature coefficients (BOL and EOL)
- Light IV performance (Balloon flight standards planned)

Survivability

- Thermal cycling at PVA level past 11,000 cycles
- Multiple modules bonded to different substrate types going from -120°C to +120°C

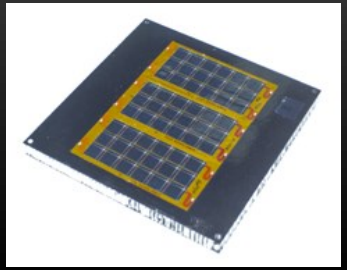
Radiation Recovery

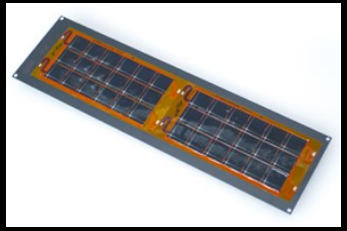
- Recovery post-exposure well characterized
- Many hours of recovery at different temperatures showing recovery rate (2 years of data)
- New radiation recovery data showing enhanced annealing at lower temperatures



Thermal Cycling Coupon Configuration

Test Item	# Cycles (as of 3/22/22)
CFRP Module 1	11,397
CFRP Module 2	11,397
CFRP Module 3	11,397
GFRP Module 1	11,397
GFRP Module 2	11,397
Aluminum (1.6mm) AP1 RTV566 Panel 1 Module 1	10,796
Aluminum (1.6mm) AP1 RTV566 Panel 1 Module 2	10,796
Aluminum (1.6mm) AP1 RTV566 Panel 2 Module 1	10,796
Aluminum (1.6mm) AP1 RTV566 Panel 2 Module 2	10,796





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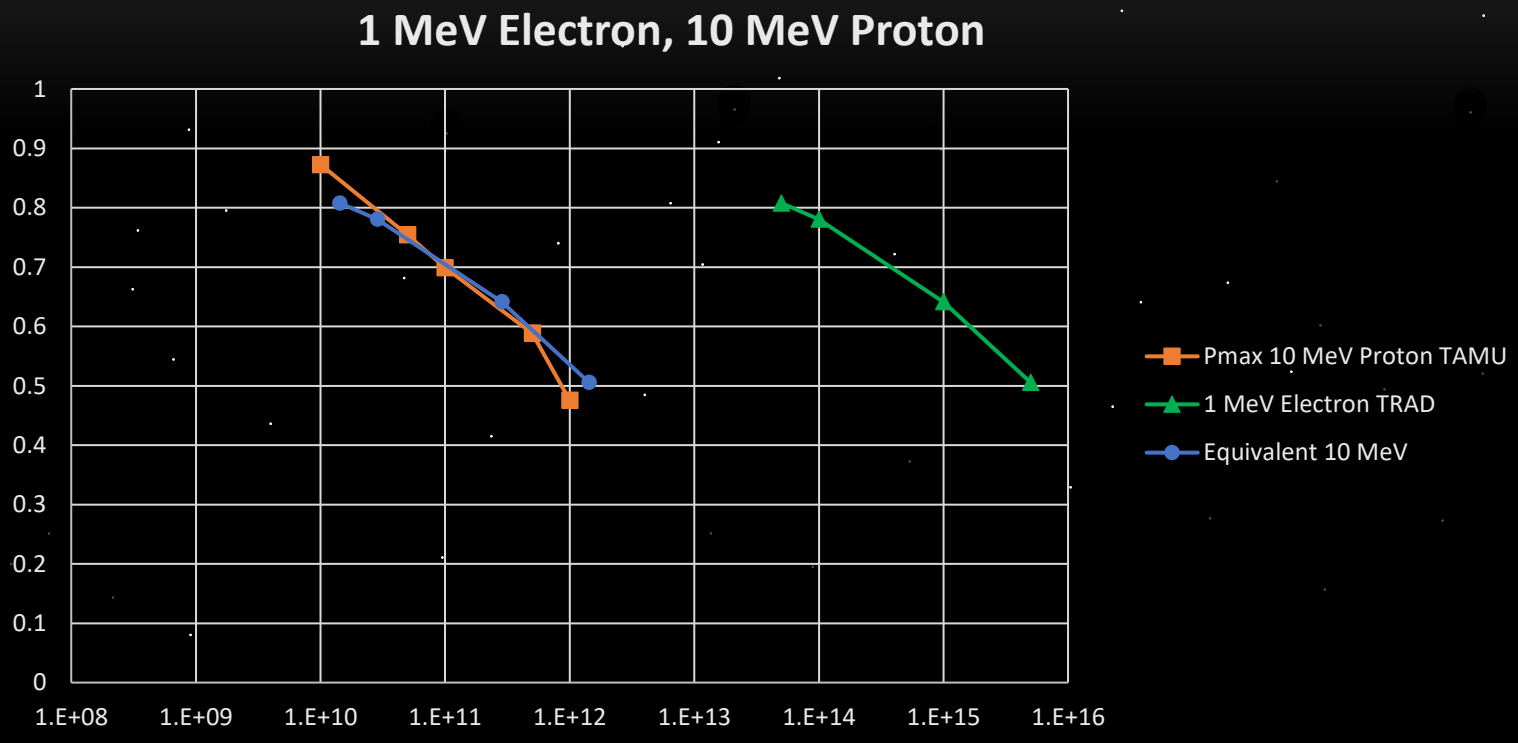
mPower Data for BOL Product Line

1 MeV Equivalence

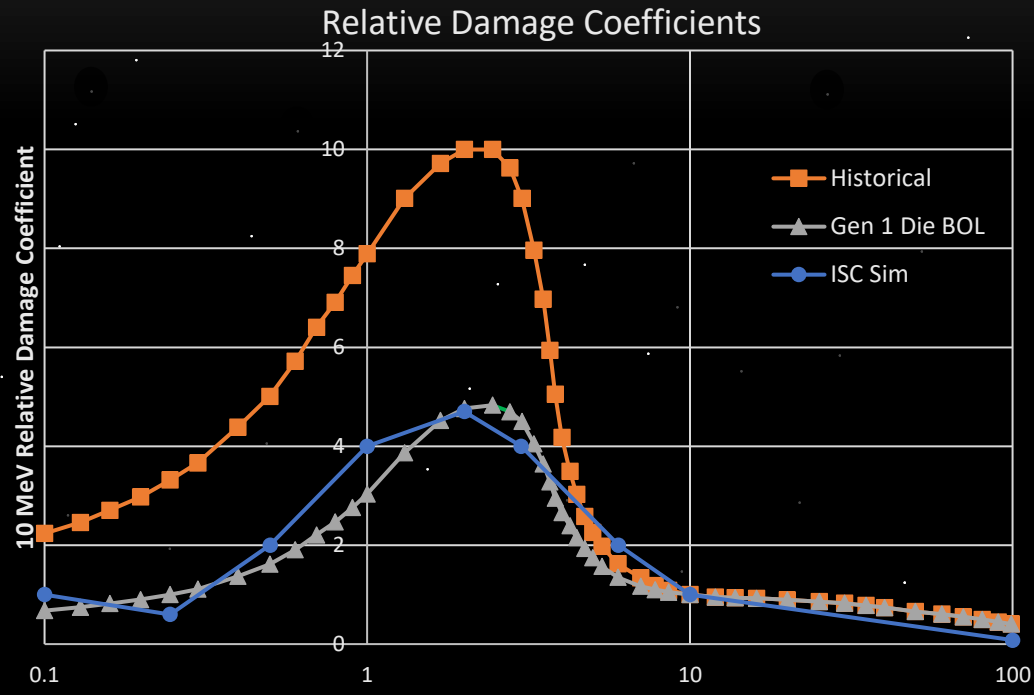


Relative Damage Coefficient Simulations

Simulated proton damage as a function of proton energy and fluences

RDCs from simulations close to measured data - additional data for further refined estimates in progress

Estimates can be bound by worst case simulation for higher retention DS-100 cells



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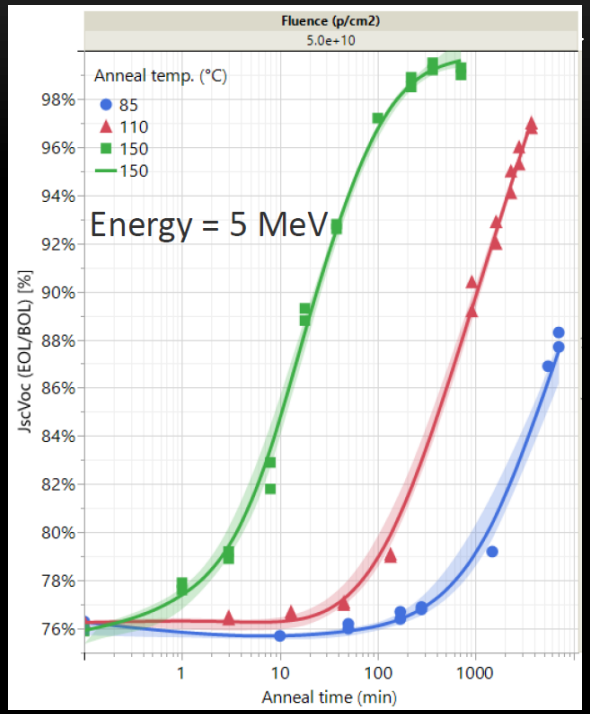
Radiation Levels and Exposure Summary

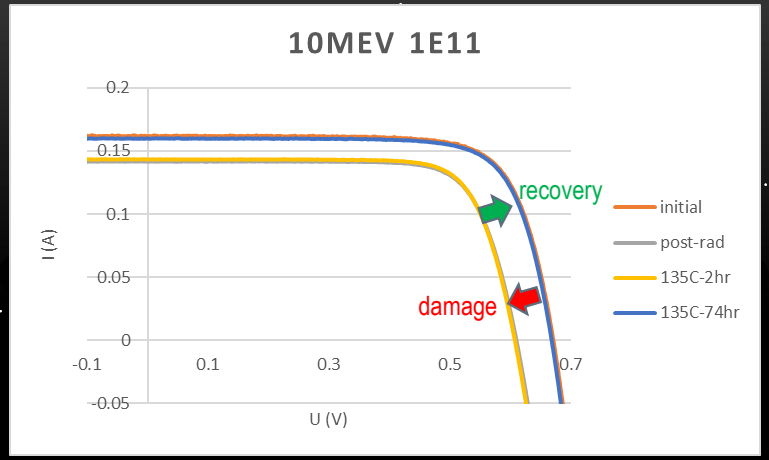
Particle	Energy Level	Fluence (1MeV Eq)	Complete	Comments
Proton	10MeV	3.5E13	Yes	Graceful degradation, per specification
Proton	10MeV	8.5E13	Yes	Graceful degradation, tracks historic Si
Proton	10MeV	3.5E14	Yes	Graceful degradation, tracks historic Si
Proton	10MeV	8.5E14	Yes	Graceful degradation, tracks historic Si
Proton	10MeV	3.5E15	Yes	Graceful degradation, tracks historic Si
Proton	2.8MeV	3.5E13	Yes	Graceful.degradation, tracks to models
Proton	2.8MeV	3.5E14	Yes	Graceful degradation, tracks to models
Proton	2.8MeV	3.5E15	Yes	Graceful degradation, tracks to models
Proton	285KeV	4.5E13	Yes	Graceful degradation, tracks to models
Proton	285KeV	3.5E15	Yes	Graceful degradation, tracks to models
Proton	100KeV	Multiple	No	Planned in 5/22

Radiation Levels and Exposure Summary

Particle	Energy Level	Fluence (1MeV Eq)	Complete	Comments
Electron	1MeV	1E14	Yes	Graceful degradation, tracks historic Si
Electron	1MeV	1E15	Yes	Graceful degradation, tracks historic Si
Electron	1MeV	5E15	Yes	Graceful degradation, tracks historic Si
Electron	1MeV	1E16	Yes	Graceful degradation, tracks historic Si
Electron	3MeV	1E14	Yes	Graceful degradation, tracks to models
Electron	3MeV	1E15	Yes	Graceful degradation, tracks to models
Electron	3MeV	5E15	Yes	Graceful degradation, tracks to models
Electron	3MeV	1E16	Yes	Graceful degradation, tracks to models
Electron	100keV	1E14	No	Planned in 5/22
Electron	100keV	1E15	No	Planned in 5/22
Electron	100keV	5E15	No	Planned in 5/22

Radiation Recovery





- Close to 100% recovery of radiation damage observed in our baseline high efficiency single crystal silicon cells (DS100)
  - Results are applicable for next gen product (DS100+, DS200, DS200+, DS300)
- Recovery observed for both n-type and p-type substrates
- 3D device physics model (including defect levels, recovery rates) developed to simulate cell efficiency, proton/electron exposures and annealing of cells
  - Cross calibration with other models planned

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Low Fluence/Multi-cycle Exposures and Anneals

In order to test as close to in-flight conditions, multiple low fluence proton exposures and anneals have been planned and are in progress

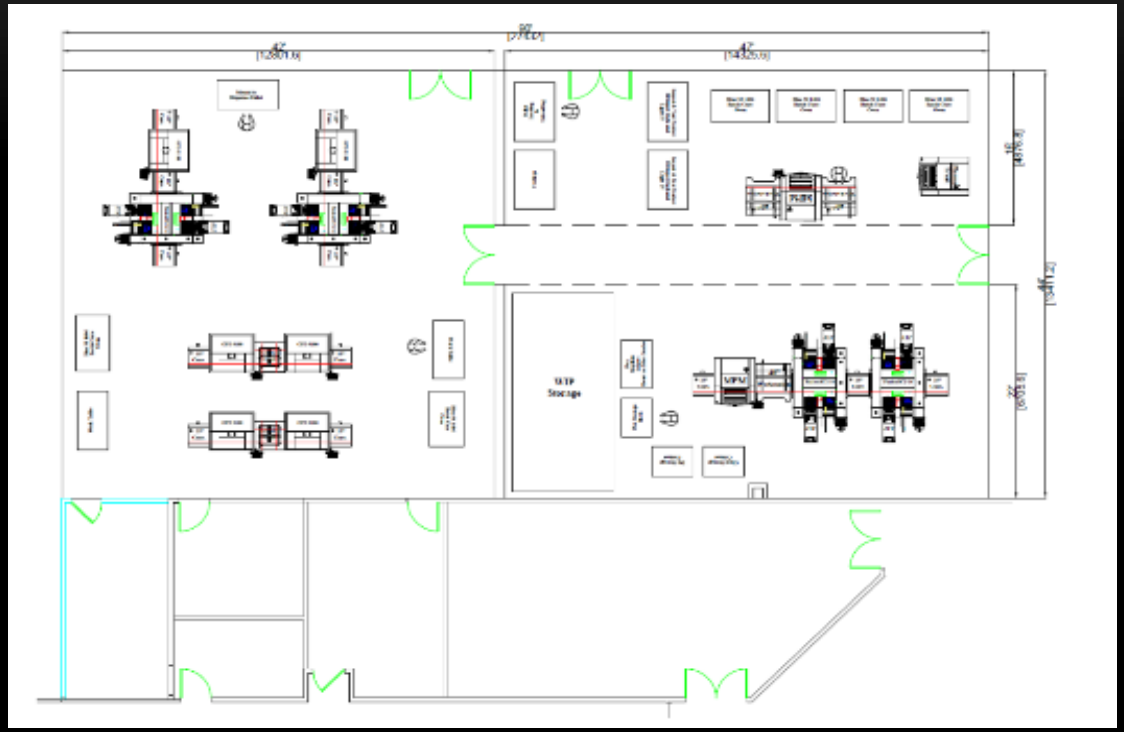
- 1E10 and 5E9 protons/cm2
- 0.3, 1, 3 and 5 MeV energy
- Anneals at 85°C, 110°C, 135°C
- Repeat proton exposures and anneals (4 cycles)
- Multiple cell types and configurations (n type and p type substrates)

Results are being modeled in a device physics simulation framework for both initial degradation and subsequent recovery with anneals

- This allows a more precise prediction of solar cell degradation and recovery behavior

On-orbit demonstration and validation flights under discussion/in planning phase

Production Line (1.5 MW/Year - 2 shifts)



Current manufacturing line established with partner : 50-100kW/year

- State-of-the-art manufacturing facility
- Leverages integrated circuit packaging processes and technology
- Customer deliveries in process

High volume production line in build

- Capacity: 1.5MW/year (2 shifts)
- Volume production Q3 2022

Readily scalable to tens of MWs/year (as needed)

- Each new line adds 1.5MW+/year
- Further expansion is planned in New Mexico

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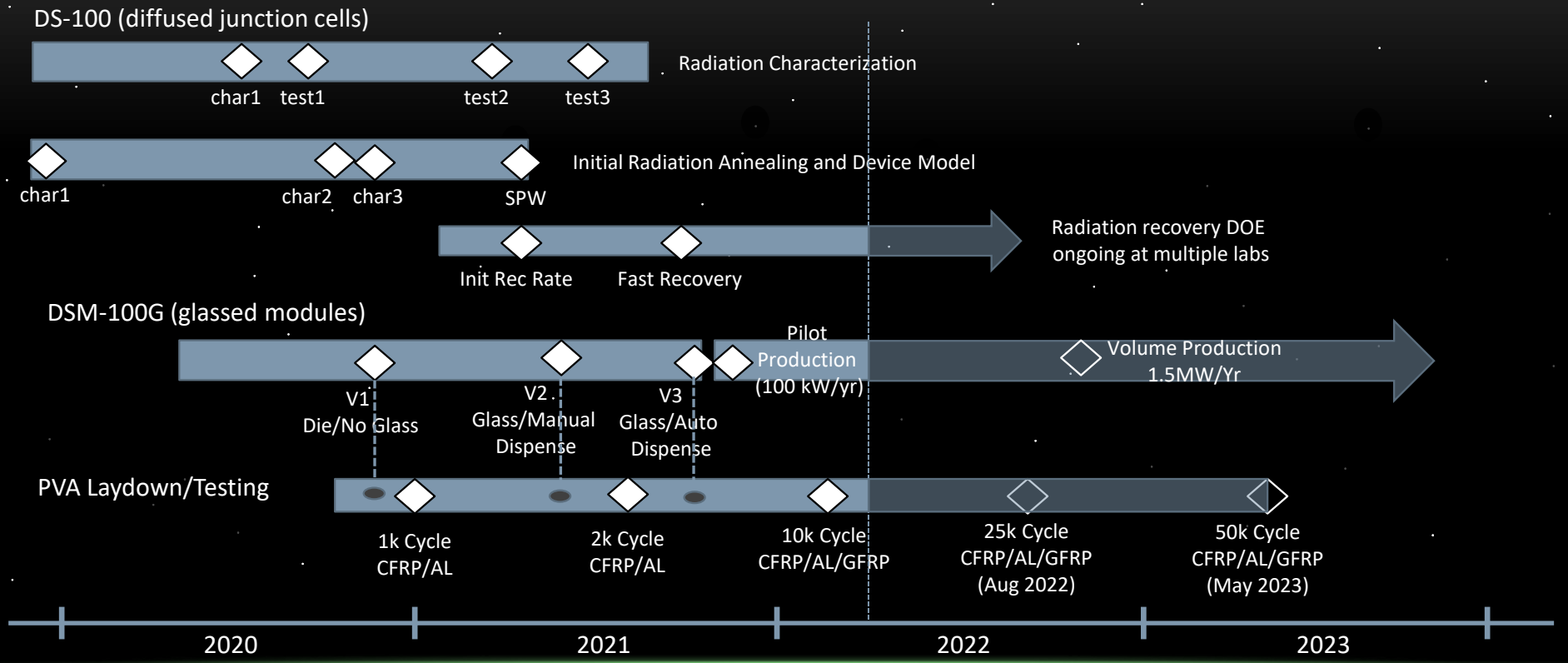
DragonSCALES™

Customizable Solar Power Modules - Production Ready & Available at high volume (multiple MWs/yr)



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Thank You for Your Attention

Acknowledgements

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