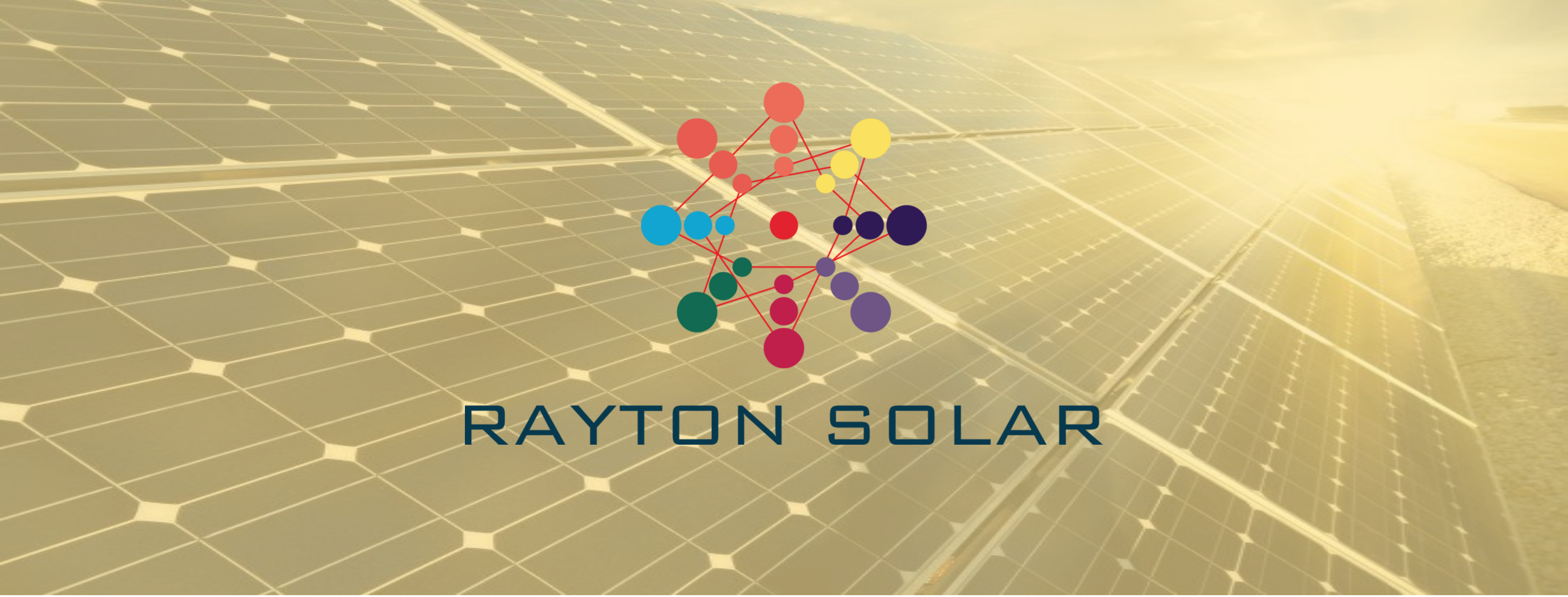


Hydrogen Implant and Cleaving to Unlock Previously Untapped Solar Real-Estate

Jeff Mc Kay, PhD

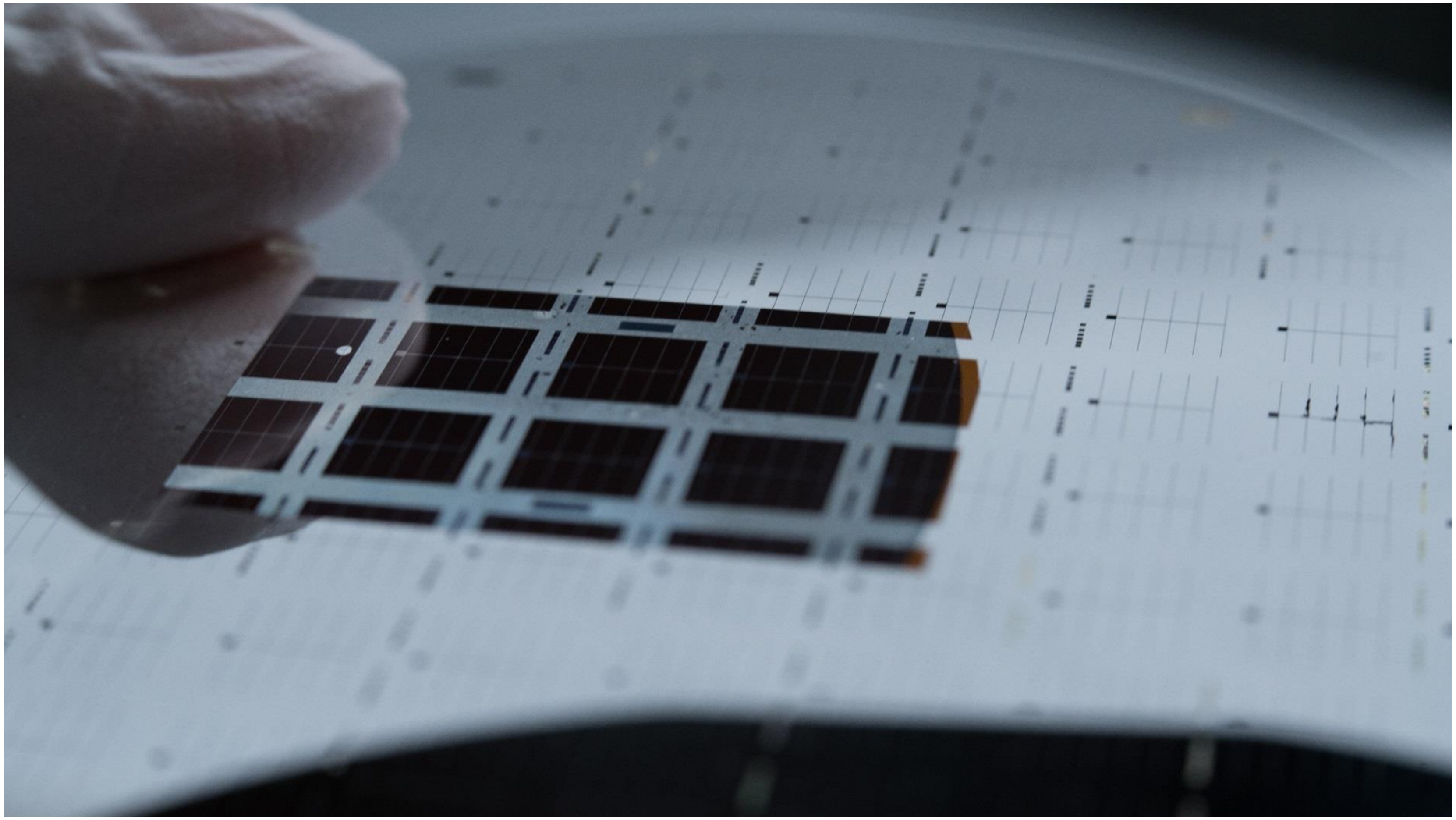
NCCAVS Junction Technologies User Group Meeting
Santa Clara, CA
October 20, 2017

Outline

1. Company Introduction
    1. Purpose
    2. Technology
    3. Competitive Advantages
2. Ion Implantation Specifications
3. Thermal Simulations
4. Future Outlook
5. Summary

Rayton Solar's Company Vision:

Developing the world's most cost efficient source of renewable energy



Via ion implantion, bonding, and exfoliation; to form ultra-thin PV Modules

The Rayton Solar Team

RAYTON SOLAR

ANDREW YAKUB
(Founder and CEO)

- 2x CleanTech Entrepreneur
- Worked for UCLA Particle Beam Physics Lab & NASA JPL
- Managed 6MW of Commercial Solar Panels and Installation
- Education: Bachelors of Science in Physics at UC Santa Barbara

DR. MINGGUO LIU
(Chief Technology Officer)

- Thin Solar Engineering Expert
- Led the Design of 35.9% Efficient Cell at Amonix
- Director of Product Engineering at Arzon Solar
- Education: PhD Soild State Electronics, MS Electrical Engineering

RAYTON SOLAR

DR. JAMES ROSENZWEIG
(Board Director)

- UCLA Department Chair of Physics
- Co-Founder of Meridian Advanced Technology Systems
- Owner and Chairman of RadiaBeam Technologies
- Authored / co-authored over 400 scientific articles

DR. MARK GOORSKY
(Director)

- UCLA Professor Materials Science
- Expert in Ion Implantation, Layer Transfer, Wafer Bonding, Material Integration
- Education: PhD Materials Science & Engineering at MIT
- Postdoctoral Fellow at IBM T.J. Watson Research Center

Problem and Opportunity

RAYTON SOLAR

Problem: Kerf loss makes PV Modules expensive

The diamond wire cutting process utilizes 50-100x the ingot material needed for it to be a charge carrier

1. It saws half the ingot material into kerf
2. It cannot slice thinner than 150-200 microns

Opportunity: 2016 PV Module Market Size:

$37.8B or 54GW

California's Renewable Portfolio Standard:

23% in 2016 → 33% in 2020

Rayton's Technology

<u>Patent Issued:</u>

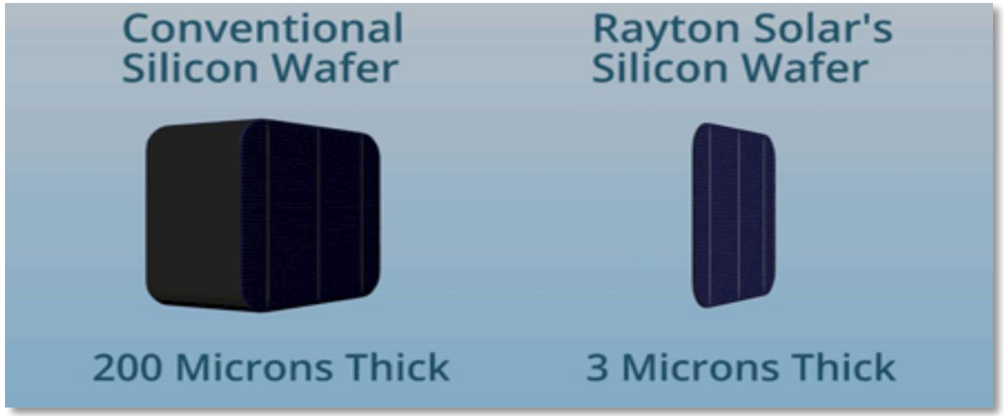
Process and Apparatuses for Manufacturing Wafers

(Patent US 9,404,198)

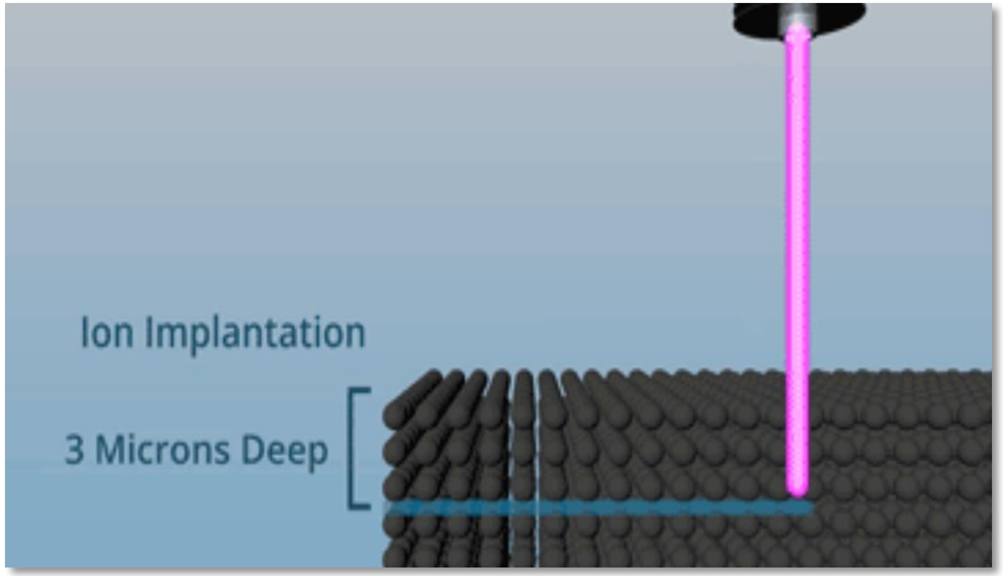
<u>Patent Issued:</u>

Float Zone Silicon Wafer Manufacturing System

(Patent US 9,499,921)



- **300 keV H+ implantation at high current (100 mA)**
- **Throughput of 300 6" wafers per hour**
- **6 MW of production annually per Implanter**
- **18 seconds to implant a six inch wafer**
- **Ingot waste is completely reduced**



Rayton’s Process

Step 1:
Ion Implantation

Protons are implanted 3 microns deep into the ingot

Step 2:
Bonding

The implanted ingot is then bonded to a substrate directly onto the ingot

Industry Standard Method

Step 3:
Exfoliation

The transferred layer is separated from the ingot without any waste

Step 4:
Cell Formation

PN Junction Formation
Metallization
ARC

Step 5:
Cell Wiring

Testing Cells and Binning
Formation of Modules

Step 6:
Laminating and Testing

Automated assembly line: lamination

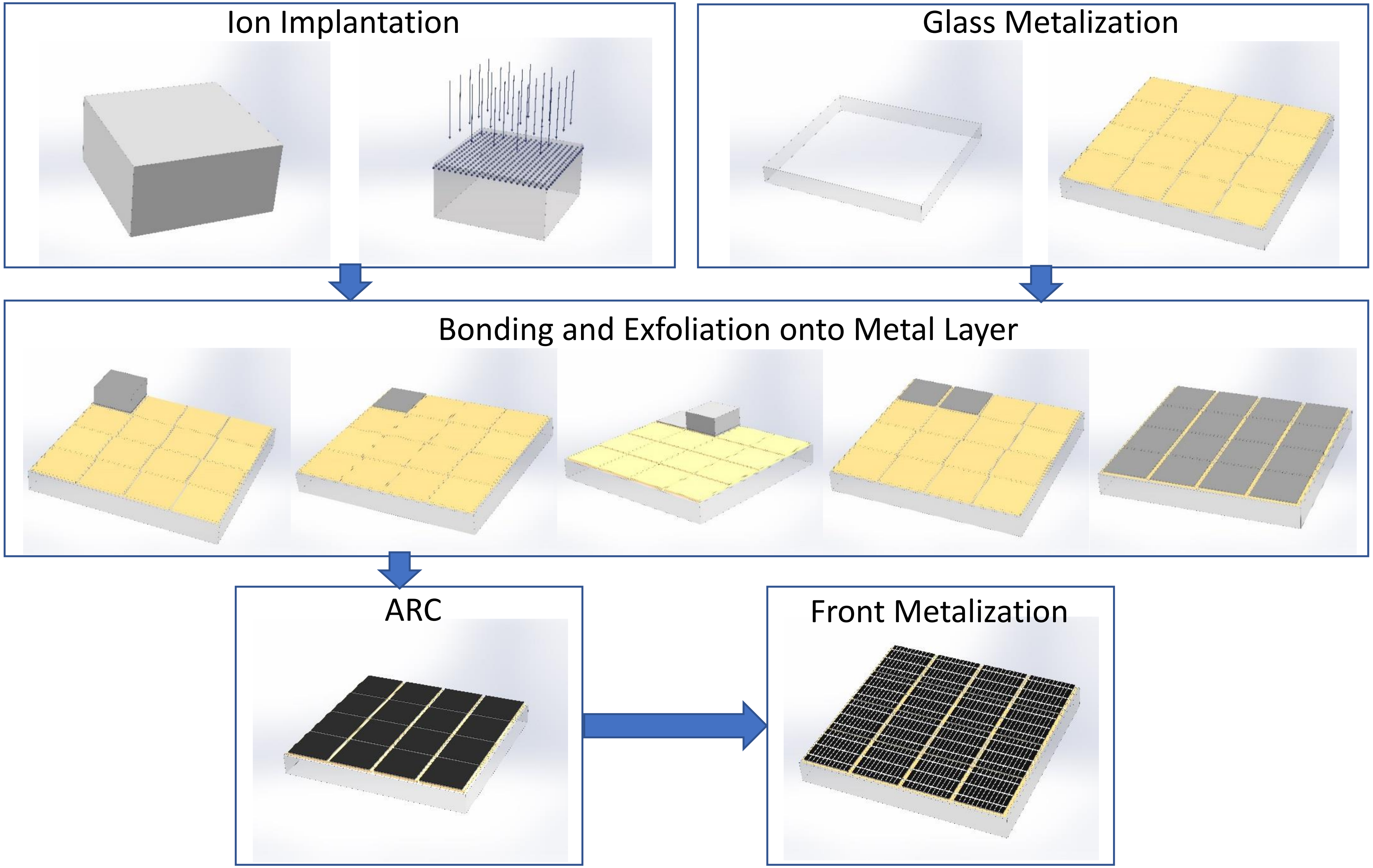
Step 7:
Final Photovoltaic Testing

IEC Standard Testing, Quality Assurance Testing

Step 8:
Send to Customers

Packaging and Supply Chain Management

Manufacturing Flow Images



‘The’ Silicon Product

RAYTON SOLAR

The world’s most cost effective PV Modules

Manufactured at a cost of $0.227 per Watt (projected)

- 52%+ cheaper than the industry best

24% efficient modules (projected)

- 14%+ higher than industry best
- Thus, relaying to a 14%+ decrease in Cost of Systems

Produces zero silicon waste

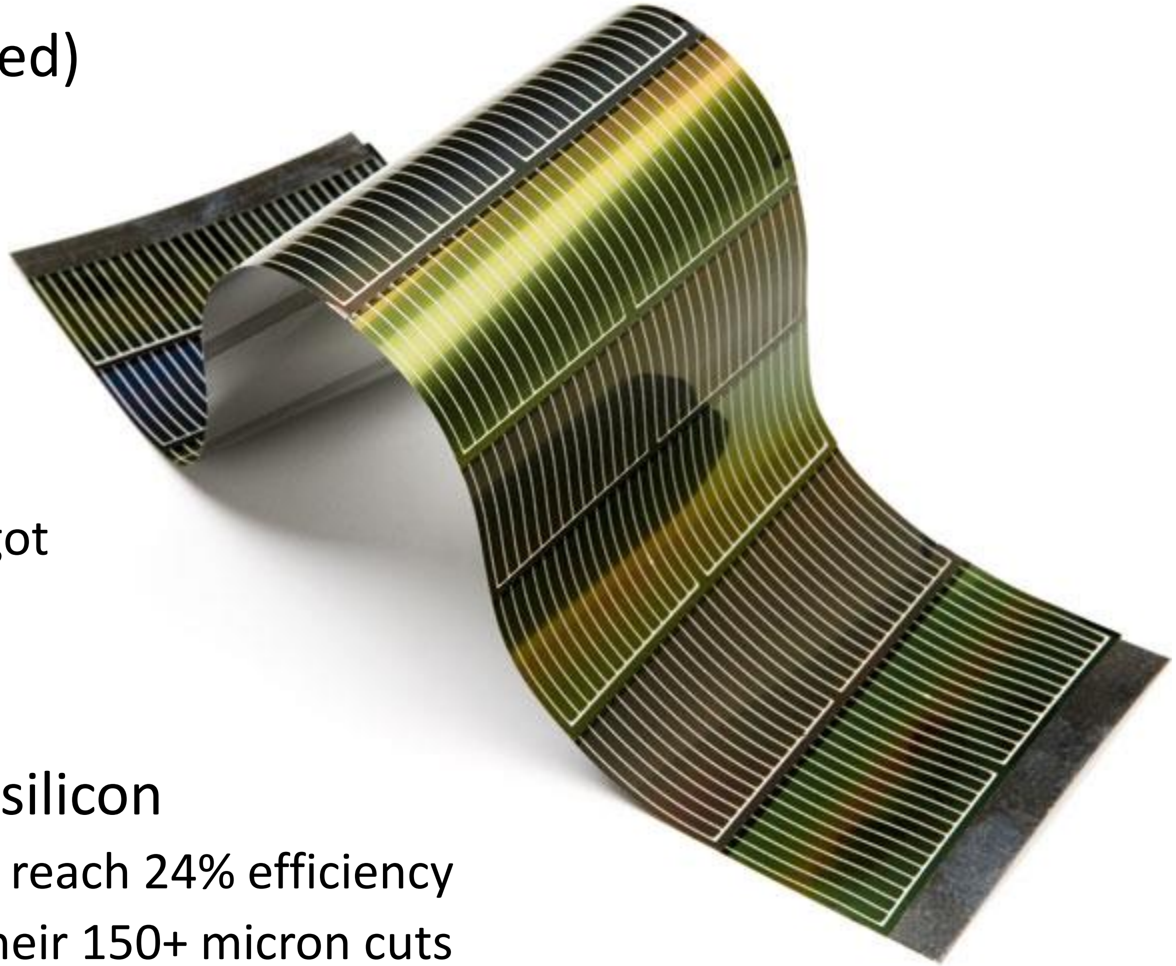
- Industry standard process wastes 40-50% of the silicon ingot

Only uses a 3 micron layer of silicon

- We use 50x-100x less silicon than the standard

Only PV Module manufacturer that uses float zone silicon

- Float zone silicon is the highest grade silicon and is able to reach 24% efficiency
- No other manufacturer is using float zone due to cost of their 150+ micron cuts



Differentiation – Other Ion Impanted PV Companies

RAYTON SOLAR

twincreeks technologies

Currently not in production

Rayton has a significant cost/technology advantage

Cannot implant ions in depths less than 25 microns

Making Float Zone Silicon uneconomical → thus Rayton has higher efficiency

Implant wafers, not the ingot itself → have 50% ingot waste

Accelerators cost $8.5M a piece vs. ours is significantly less

Machines requirement 4x the electricity intake

Accelerators operate at a much more difficult to handle energy level of 1.2 MeV vs. our 300KeV → high volume of machine breakdowns

Don’t have the expertise to handle 4 micron thick silicon

Due to our patents no one can replicate our processes

Sold to GT Advanced Technologies

Differentiation – Other Ion Impanted PV Companies

RAYTON SOLAR

SIGEN
SILICON GENESIS

Currently not in production

Rayton has a significant cost/technology advantage

Cannot implant ions in depths less than 30-50 microns

Making Float Zone Silicon uneconomical → thus Rayton has higher efficiency

Use radio frequency quadrupole vs. direct current beams

They convert 20% of input energy into the beam while we convert 80%

Focus is in other industries (solar is a neglected side business)

Don't have the expertise to handle 4 micron thick silicon

Due to our patents no one can replicate our processes

Ion Implanter Specifications

RAYTON SOLAR

- The HCII provides 6 nominal voltage/current operational set points commissioned by an Engineer user
  - Four settings are achieved with a continuous ion beam

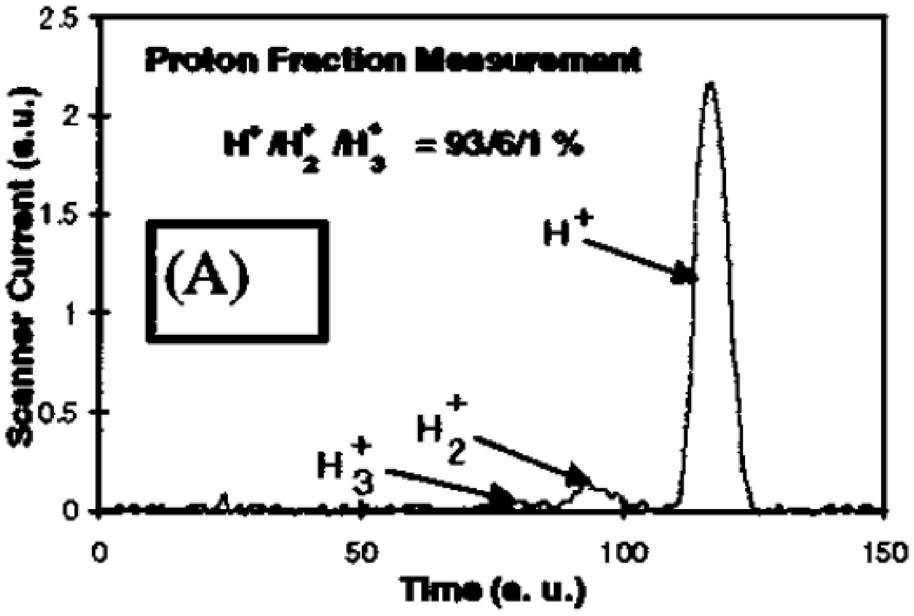
Continuous Operation	
300 kV / 50 mA	250 kV / 50 mA
300 kV / 100 mA	250 kV / 100 mA

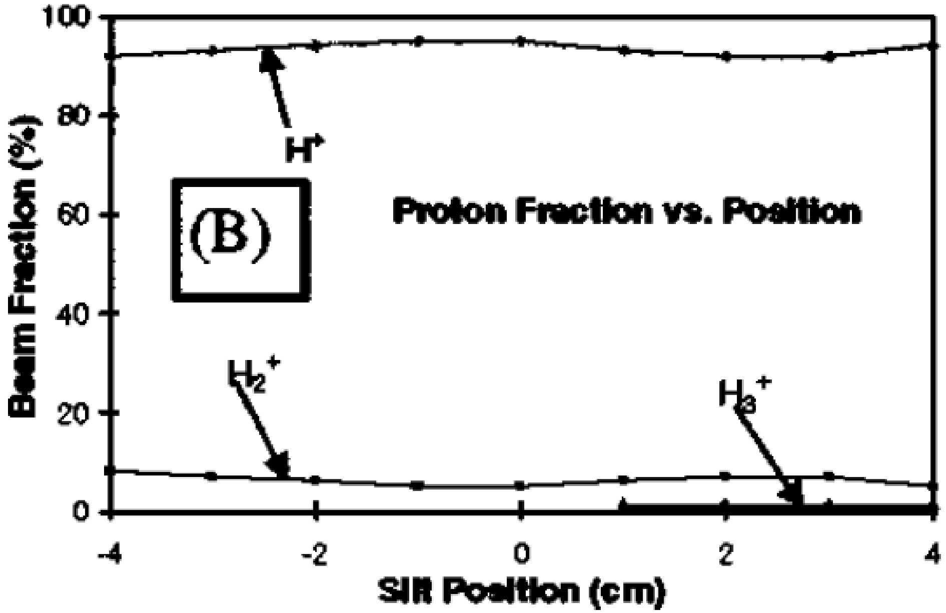
  - Two settings are achieved by pulsed operation using the 50 mA continuous ion beam Set Point

Pulsed Operation - duty cycle 20%	
300 kV / 10 mA	250 kV / 10 mA

Ion Implanter Specifications

- H^+ fraction ≥ 90% typical for microwave sources [1-4]
- PNL design is similar to LEDA injector (Los Alamos): Reported 92-94% H^+ fraction at 680 W, 5 sccm [1]
- Magnetic focus solenoid acts as Q/M filter removing majority of H2+ fraction from primary H+ beam



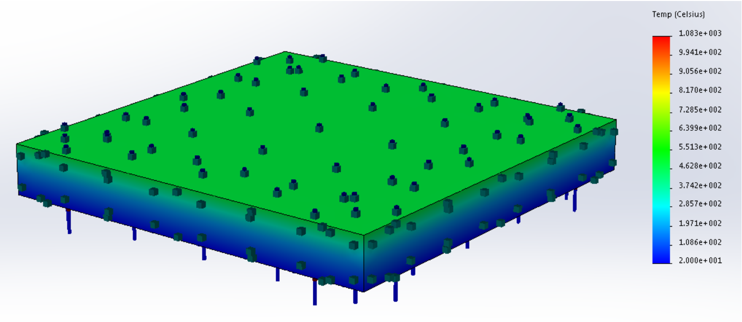


[1] J. Sherman et al., Rev. Sci. Instrum. 69, 1003 (1998).
[2] D. Spence et al., Rev. Sci. Instrum. 67, 1642 (1996).
[3] T. Taylor et al., Nucl. Inst. Meth. A309, 37 (1991).
[4] Y. Okomoto et al., Rev. Sci. Instrum. 43, 1193 (1972).

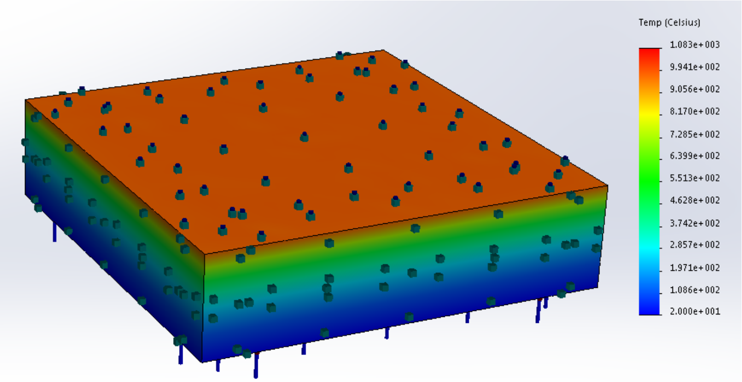
Thermal Simulations

RAYTON SOLAR

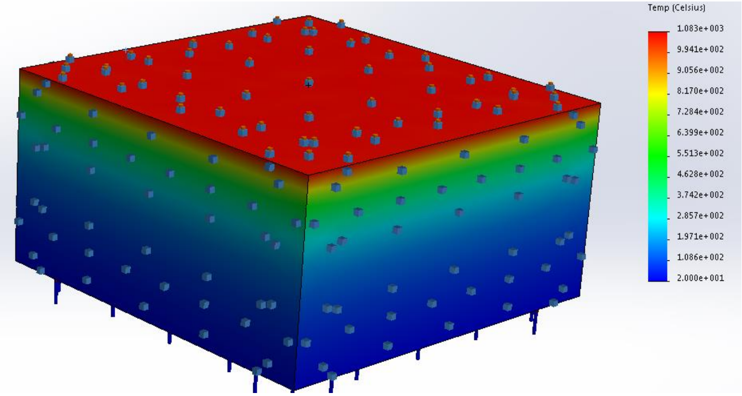
Thickness: 12.5mm
Max temp: 481.6°C



Thickness: 25mm
Max temp: 983.7°C



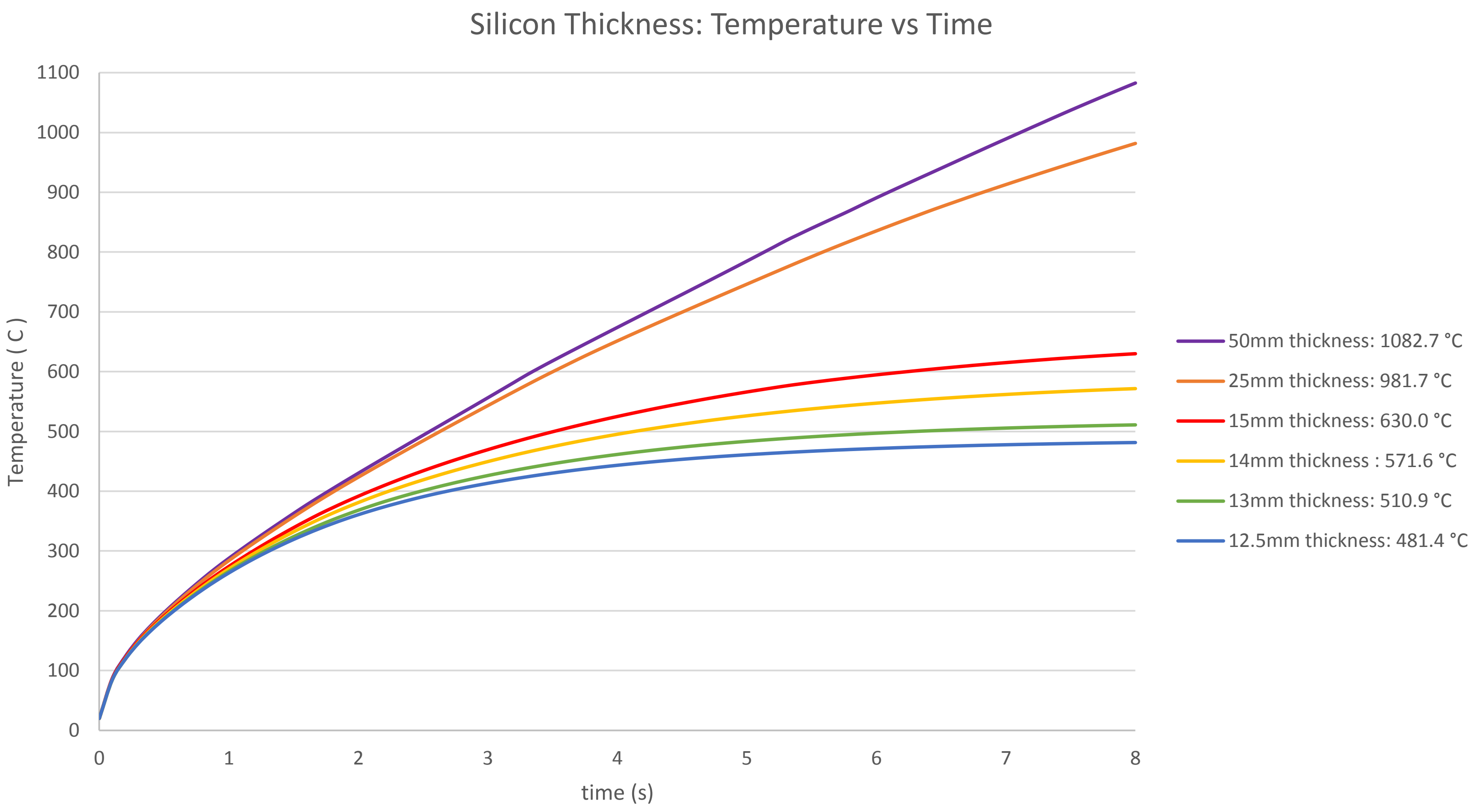
Thickness: 50mm
Max temp: 1082.7°C



These cases are run with best decided conditions:
0.1 sec timestep
20° C initial temp
20° C boundary temp
30 kW heat power
Automesh

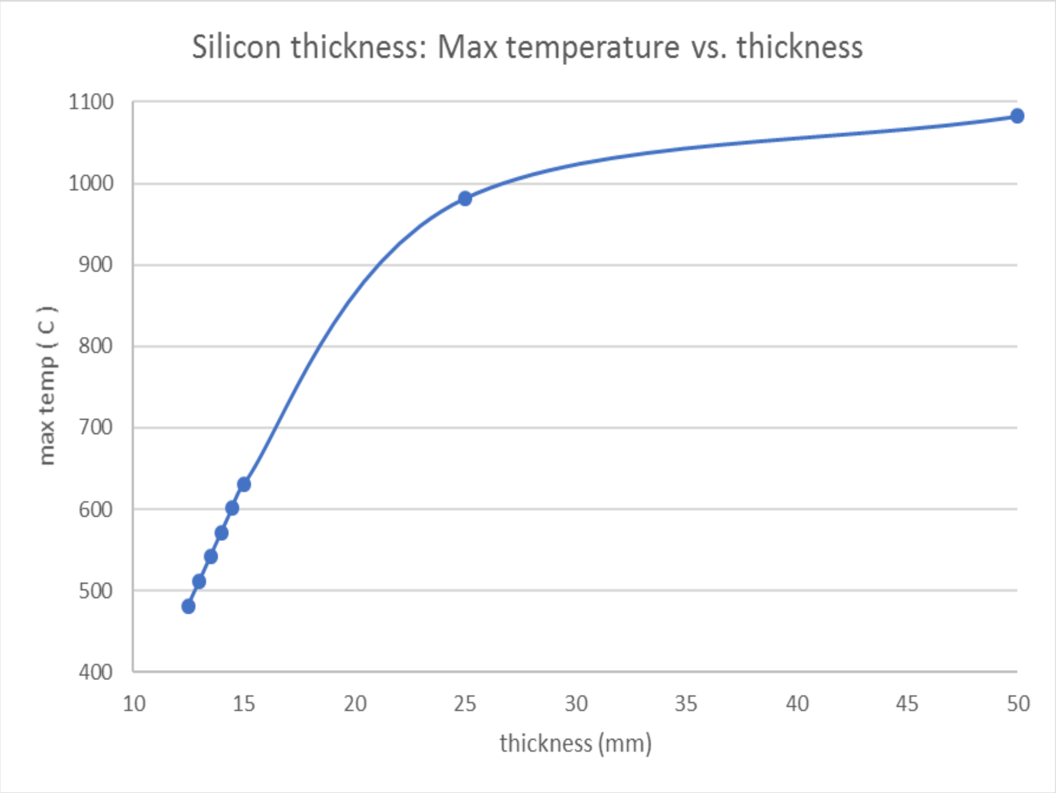
Temperature color: normalized to max temp of 50mm silicon simulation.

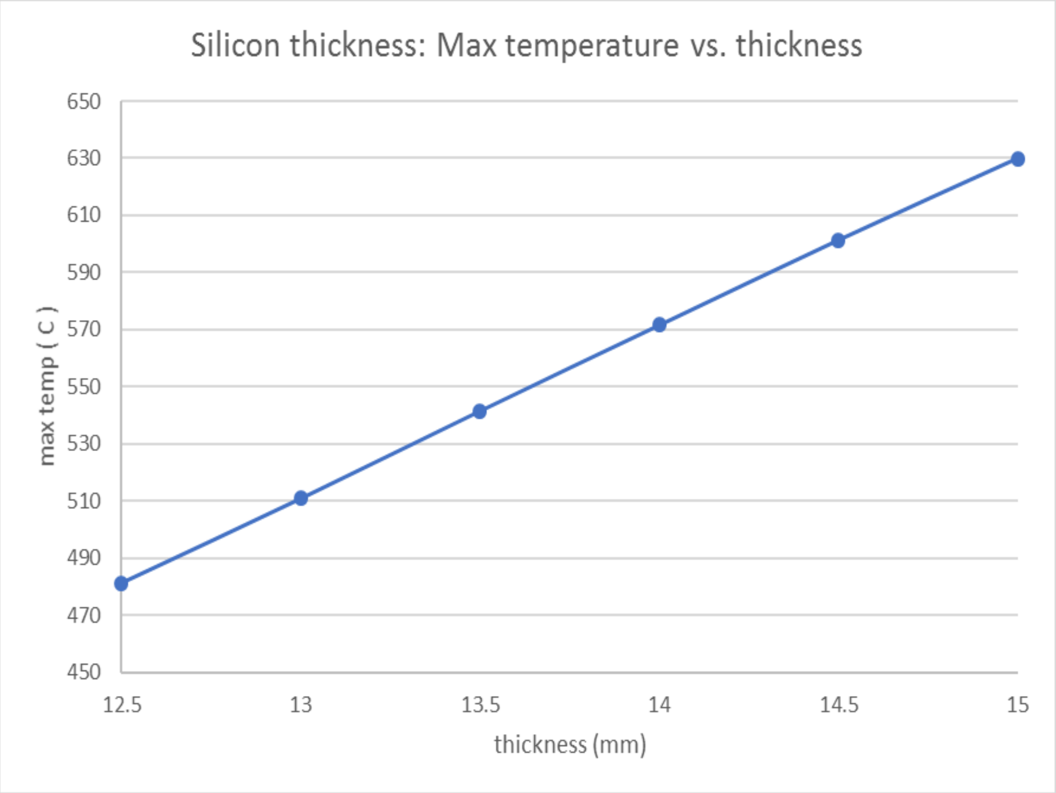
Thermal Simulations



At 30kW, with a 12.5mm (~0.5 inch) silicon thickness, the temperature plateaus under 500°C, below the exfoliation temperature.

Thermal Simulations



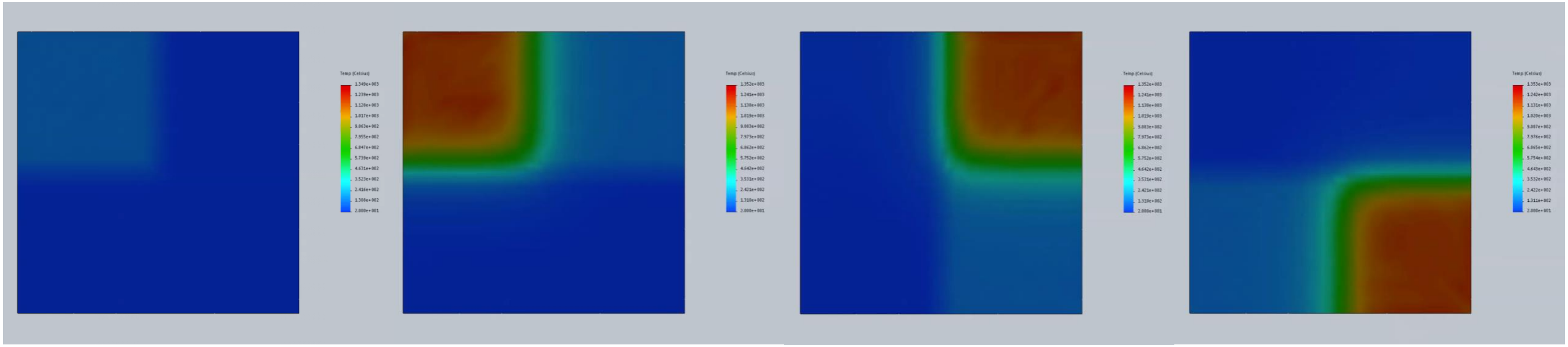


At higher thicknesses, the temperature plateaus. But between 12.5mm and 15mm thickness, the relationship is linear, and the temperature increases by about 30°C for every 0.5mm.

Thermal Simulations

RAYTON SOLAR

50mm scanning: Continuous Beam 15kW x 16 sec



Q1: Max Temp: 1349.4°C   Q2: Max Temp: 1352.5°C   Q3: Max Temp: 1352.5°C   Q4: Max Temp: 1353.0°C

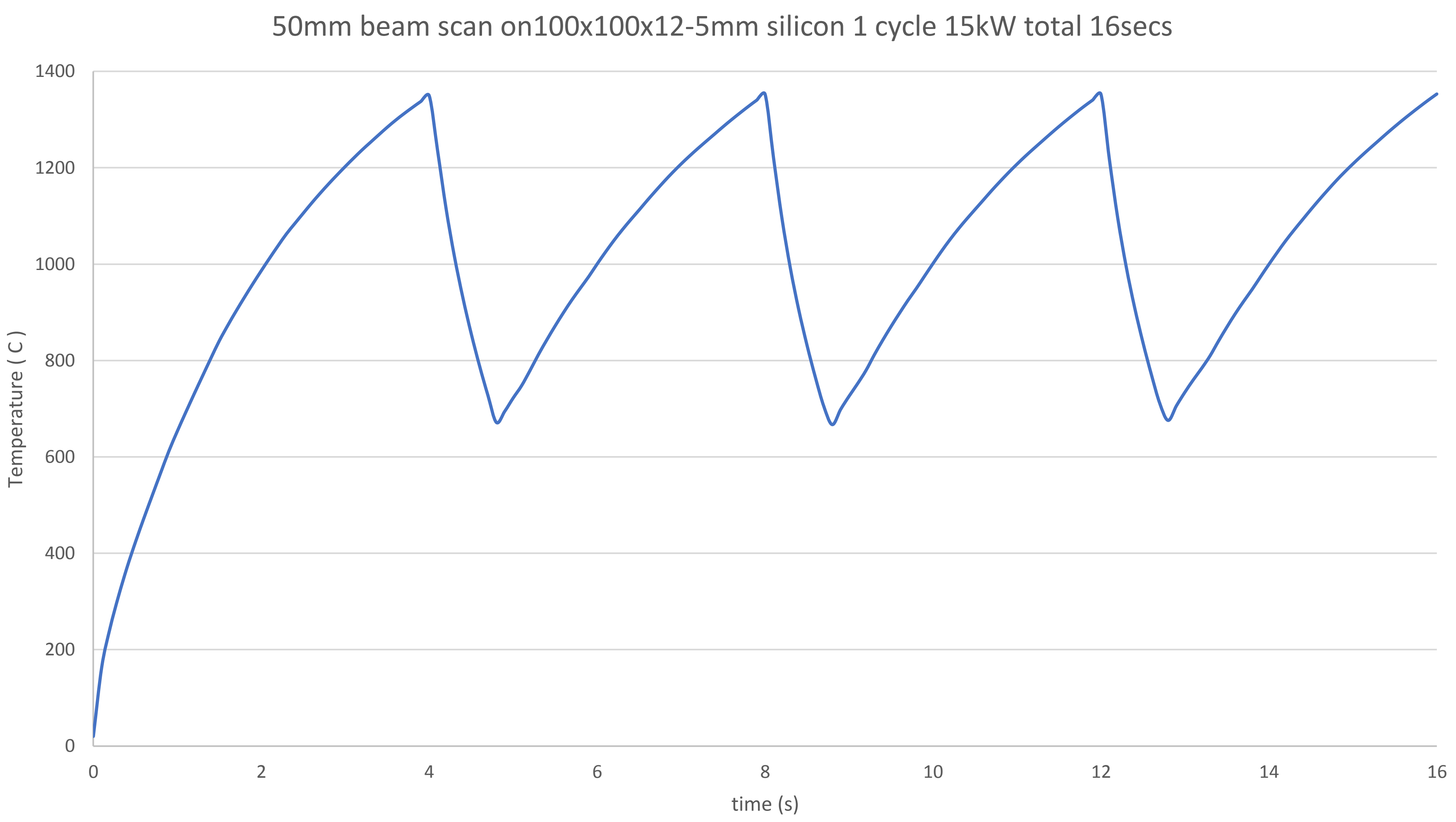
- 15kWx16sec continuous
- 0.1sec step

- Duration: Total 16sec
- One quarter: 4 sec

- Initial and Boundary: 20C
- Automesh

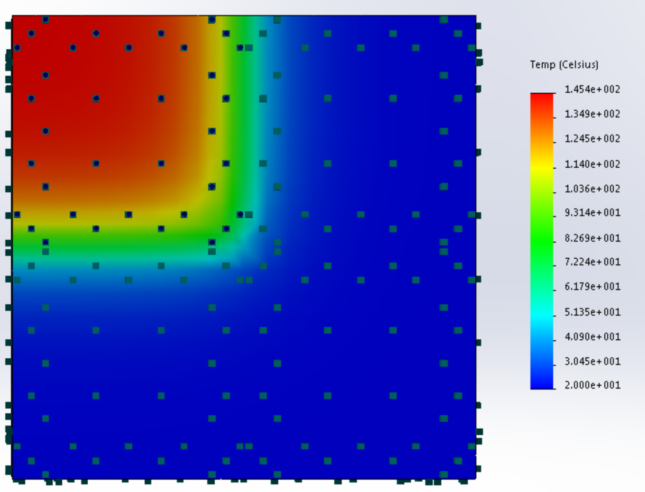
Thermal Simulations

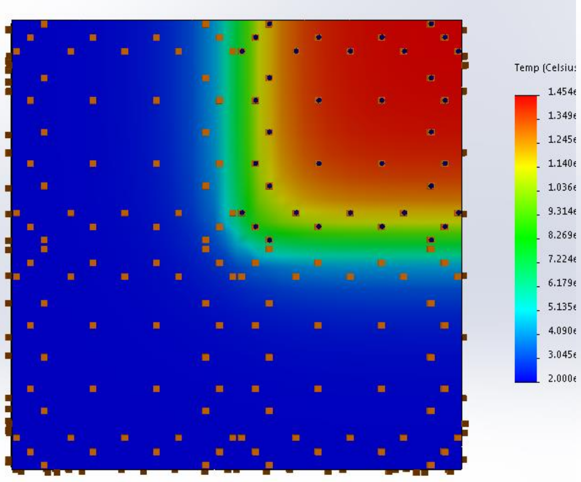
50mm scanning: Continuous Beam 15kW x 16 sec

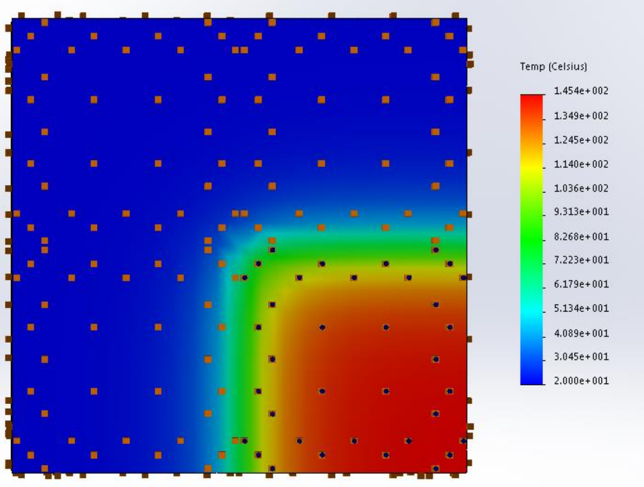


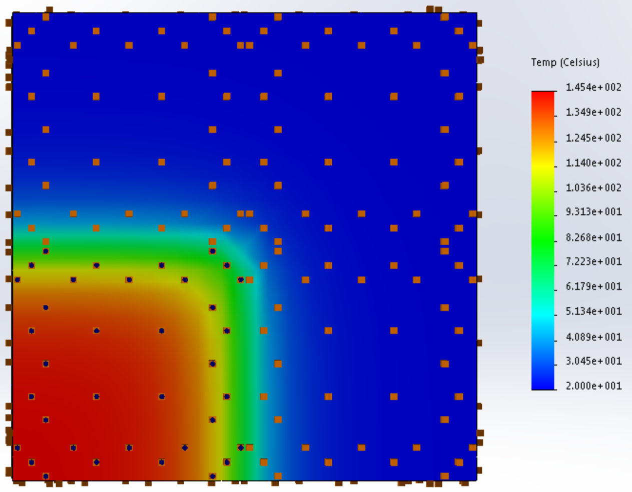
Thermal Simulations

50 mm scanning: Continuous Beam 3 kW x 80 sec









Q1: Max Temp: 145.38°C

Q2: Max Temp: 145.38°C

Q3: Max Temp: 145.36°C

Q4: Max Temp: 145.36°C

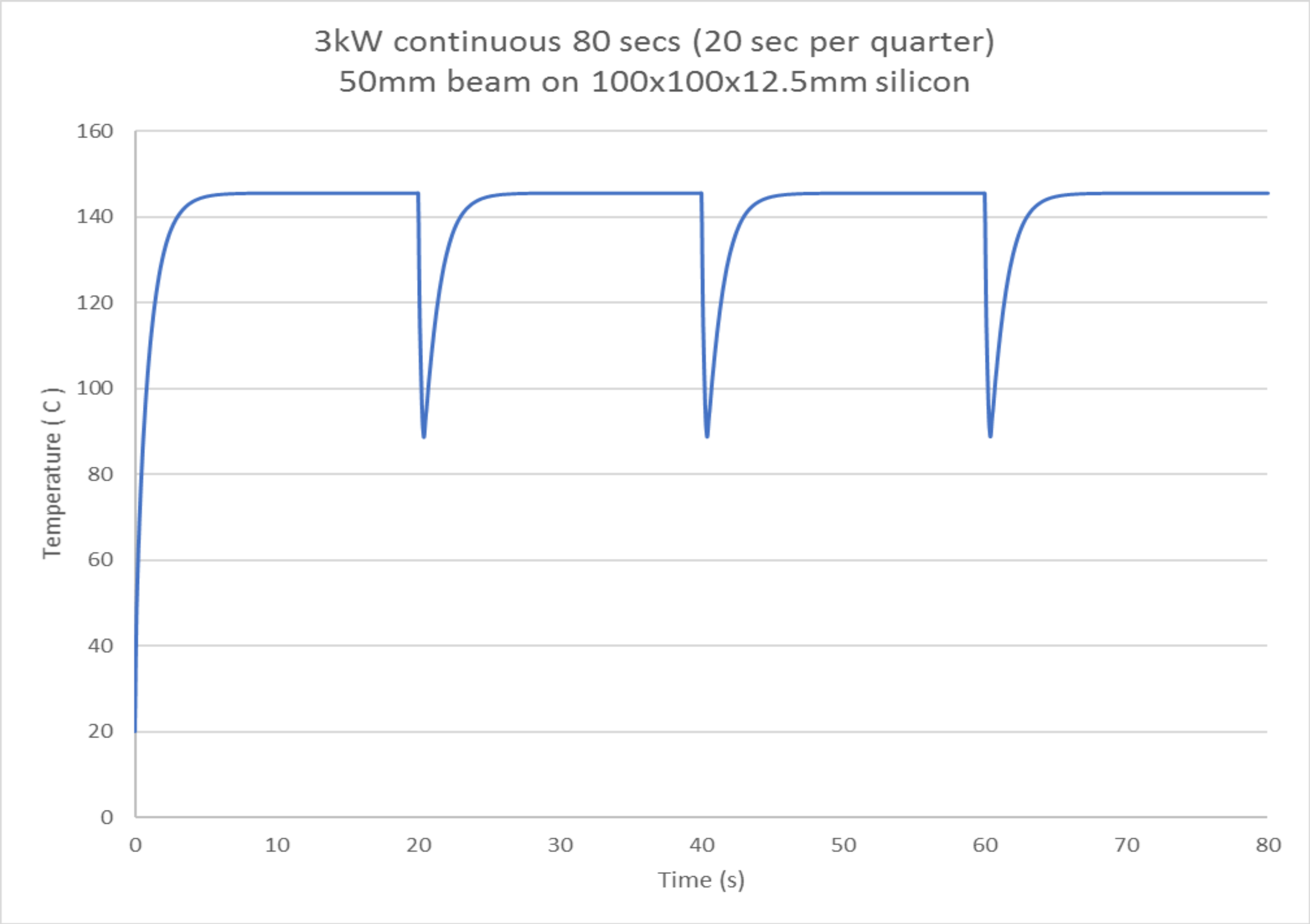
- 3kWx80s continuous
- 0.1sec step

- One scan: Total: 80sec
- One quarter: 20sec

- Automesh
- Boundary and initial temp: 20C

Thermal Simulations

50 mm scanning: Continuous Beam 3 kW x 80 sec



The Future – Gallium Arsenside Photovoltaic Cells

RAYTON SOLAR

NREL scientists recently set the solar cell efficiency record at 32.8% with GaAs cells

Solar Efficiency

With **25%+ efficiency, GaAs cells** can use ambient sunlight to power any electronic devices, including EVs and cell phones

Capabilities

An EV equipped with **3 square meters of GaAs** cells can extend the range of a Tesla Model S by roughly **45 miles using 7 hours of sunlight** to charge

GaAs technology retails at **$7.15 per watt**, roughly 10x more expensive than silicon

Current GaAs applications are limited to UAV and military projects due to cost

Summary

- Diamond sawing during wafer production results in half of the starting material to be lost. In addition, wafers are limited in the thinness one can reasonably achieve during sawing, resulting in even more wasted material.
- Normal ion implanters were not commercially viable for low cost ion cut substrates until now
- With a newly designed high current, high voltage implanter available to Rayton solar, we are able to produce ion-cut substrates at a competitive cost for the PV market
- Thermal simulation studies show reasonable targets for ingot cooling performance during ion implantation
- Ion-cutting technology can be used for any suitable material and can produce high quality substrates

RAYTON SOLAR

Thank you for your attention.