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

Jeff Mc Kay, PhD

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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 implantation, bonding, and exfoliation; to form ultra-thin PV Modules
The Rayton Solar Team

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 Solid State Electronics, MS Electrical Engineering

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

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

**Patent Issued:**
Process and Apparatuses for Manufacturing Wafers
(Patent US 9,404,198)

**Patent Issued:**
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

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Manufacturing Flow Images

Ion Implantation → Glass Metalization

Bonding and Exfoliation onto Metal Layer

ARC → Front Metalization
‘The’ Silicon Product

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
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
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

➢ The HCII provides 6 nominal voltage/current operational set points commissioned by an Engineer user

➢ Four settings are achieved with a continuous ion beam

<table>
<thead>
<tr>
<th>Continuous Operation</th>
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<tbody>
<tr>
<td>300 kV / 50 mA</td>
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<tr>
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➢ Two settings are achieved by pulsed operation using the 50 mA continuous ion beam Set Point

<table>
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<th>Pulsed Operation - duty cycle 20%</th>
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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

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

Autowesh

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

Thermal Simulations

Thickness: 12.5mm
Max temp: 481.6°C

Thickness: 25mm
Max temp: 983.7°C

Thickness: 50mm
Max temp: 1082.7°C
At 30kW, with a 12.5mm (~0.5 inch) silicon thickness, the temperature plateaus under 500°C, below the exfoliation temperature.
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.
50mm scanning: Continuous Beam 15kW x 16 sec

Q1: Max Temp: 1349.4°C
- 15kWx16sec continuous
- 0.1sec step

Q2: Max Temp: 1352.5°C
- Duration: Total 16sec
- One quarter: 4 sec

Q3: Max Temp: 1352.5°C

Q4: Max Temp: 1353.0°C
- Initial and Boundary: 20C
- Automesh
Thermal Simulations

50mm scanning: Continuous Beam 15kW x 16 sec

50mm beam scan on 100x100x12-5mm silicon 1 cycle 15kW total 16secs
50 mm scanning: Continuous Beam 3 kW x 80 sec

- 3kWx80s continuous
- 0.1sec step
- One scan: Total: 80sec
- One quarter: 20sec
- Automesh
- Boundary and initial temp: 20°C

Q1: Max Temp: 145.38°C
Q2: Max Temp: 145.38°C
Q3: Max Temp: 145.36°C
Q4: Max Temp: 145.36°C
Thermal Simulations

50 mm scanning: Continuous Beam 3 kW x 80 sec

![Graph showing temperature changes over time for a 3 kW continuous beam on 100x100x12.5mm silicon. The graph displays temperature in Celsius (°C) on the y-axis and time in seconds (s) on the x-axis. The data shows a pattern of temperature spikes every 20 seconds.]
The Future – Gallium Arsenide Photovoltaic Cells

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
Thank you for your attention.