QESST Engineering Research Center Overview

Christiana Honsberg,
Director QESST ERC,
Arizona State University

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QESST Partners

Arizona State University

Caltech

Massachusetts Institute of Technology

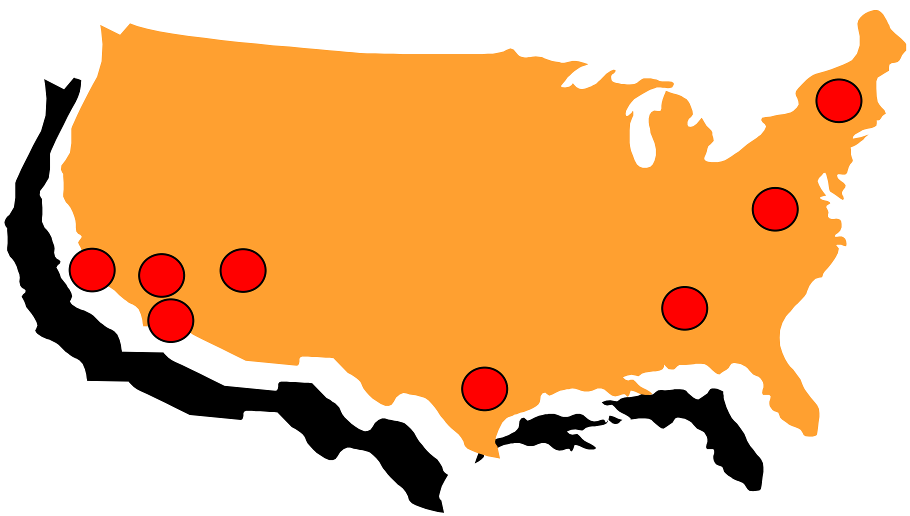
University of Delaware

The University of New Mexico

Georgia Institute of Technology

The University of Arizona

University of Houston



Quantum Energy and Sustainable Solar Technologies

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International Partners

Imperial College London

東京大学
THE UNIVERSITY OF TOKYO

THE UNIVERSITY OF NEW SOUTH WALES
SYDNEY · AUSTRALIA

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ASU & Solar Power Laboratories

- Clean room 10/100/1000 with 40,000 sf of space for University- Industry collaboration.
- Solar Power Laboratories 5,000 sf
- Full wafer size pilot line; III-V growth; characterization; module fab
- 20 MW PV installations

QESST Strategic Plan

Ensure that solar energy continues on a path of continuous cost and efficiency improvements to meet the Terawatt Challenge through development of technologies to harvest sustainable electricity, revitalization of STEM education, and reinvigoration of the US-based PV industry

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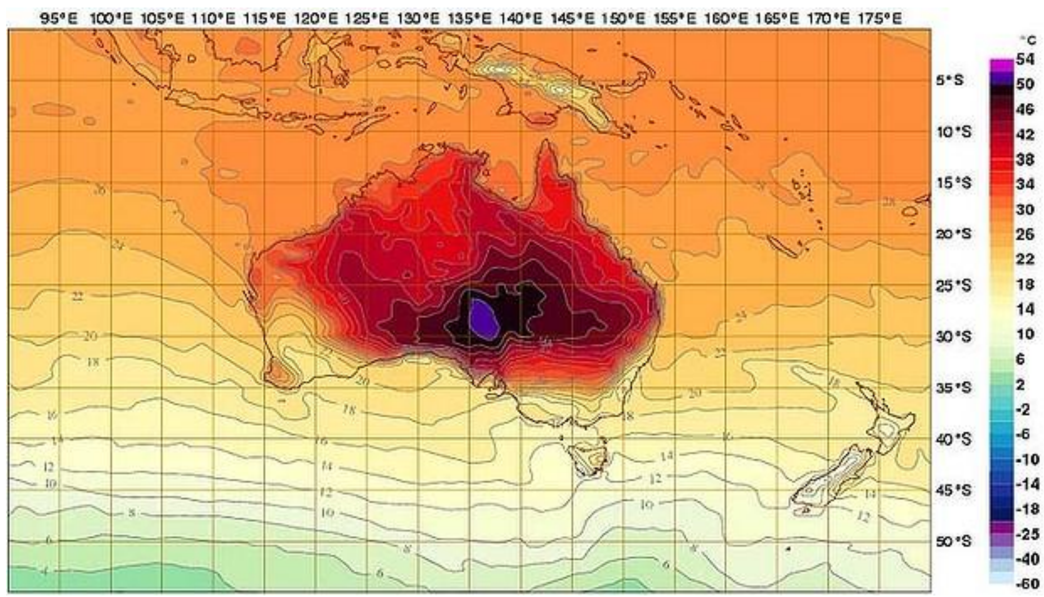
Temperature keeps rising

- In the US, July 2012 was the hottest month on record.
- In the US, 2012 was the hottest year on record.
  http://www.nytimes.com/2013/01/09/science/earth/2012-was-hottest-year-ever-in-us.html
- Australia just started using a new color of purple as the temperatures are off the charts.



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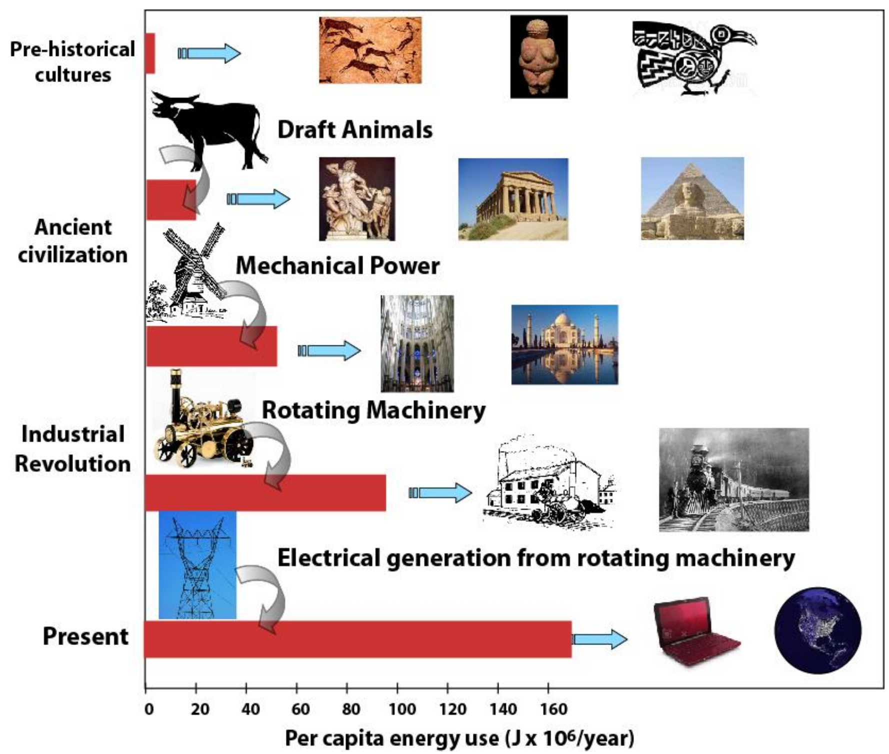
Motivation

- Quantum devices are a disruptive technology
- Thermodynamically, quantum energy conversion systems have different efficiencies, properties, and how implemented and used
- Broad goal is to exploit advantages of "quantum" energy conversion to address the Terawatt Challenge



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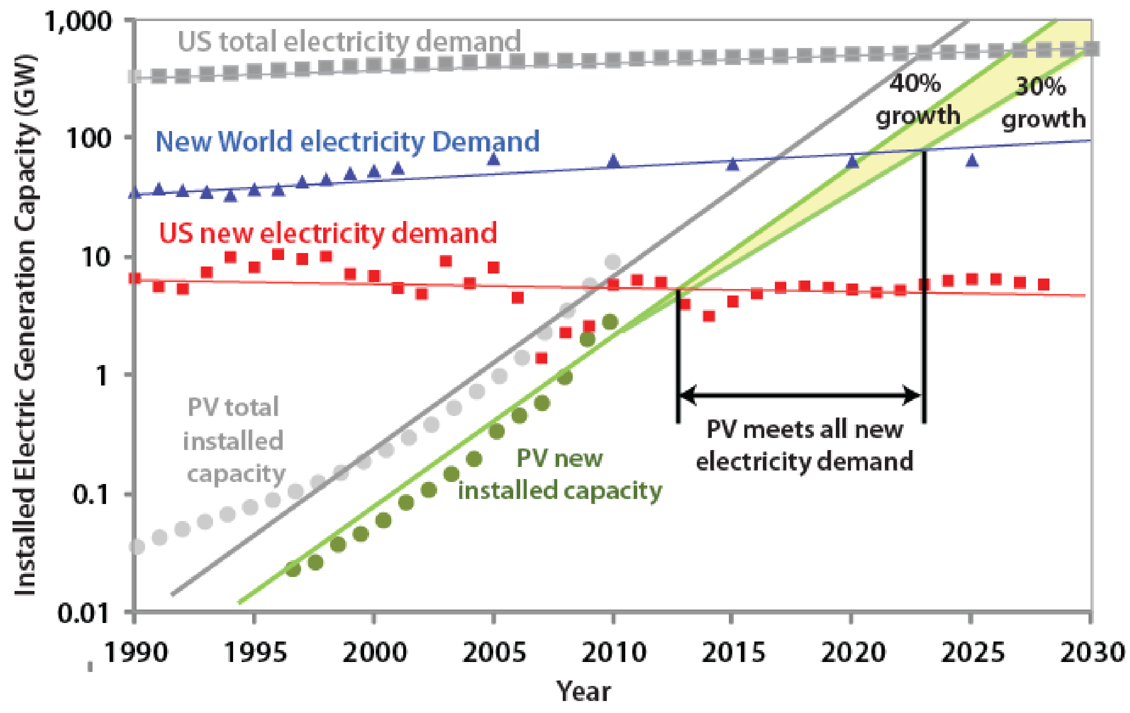
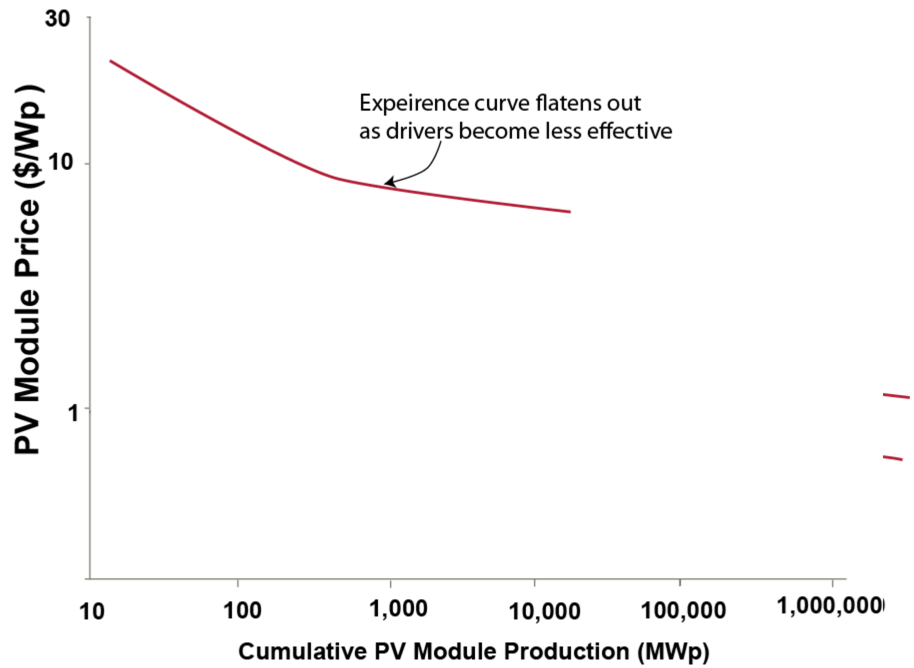
Growth, learning curves and impact

- PV, like many other semiconductor or "quantum" based technologies has experienced rapid, sustained growth.
- Continued growth allows PV to have major impact on Terawatt Challenge



Sustained Growth of PV

- Promote growth by addressing experience curve barriers
- Growth rates historically driven by economies of scale



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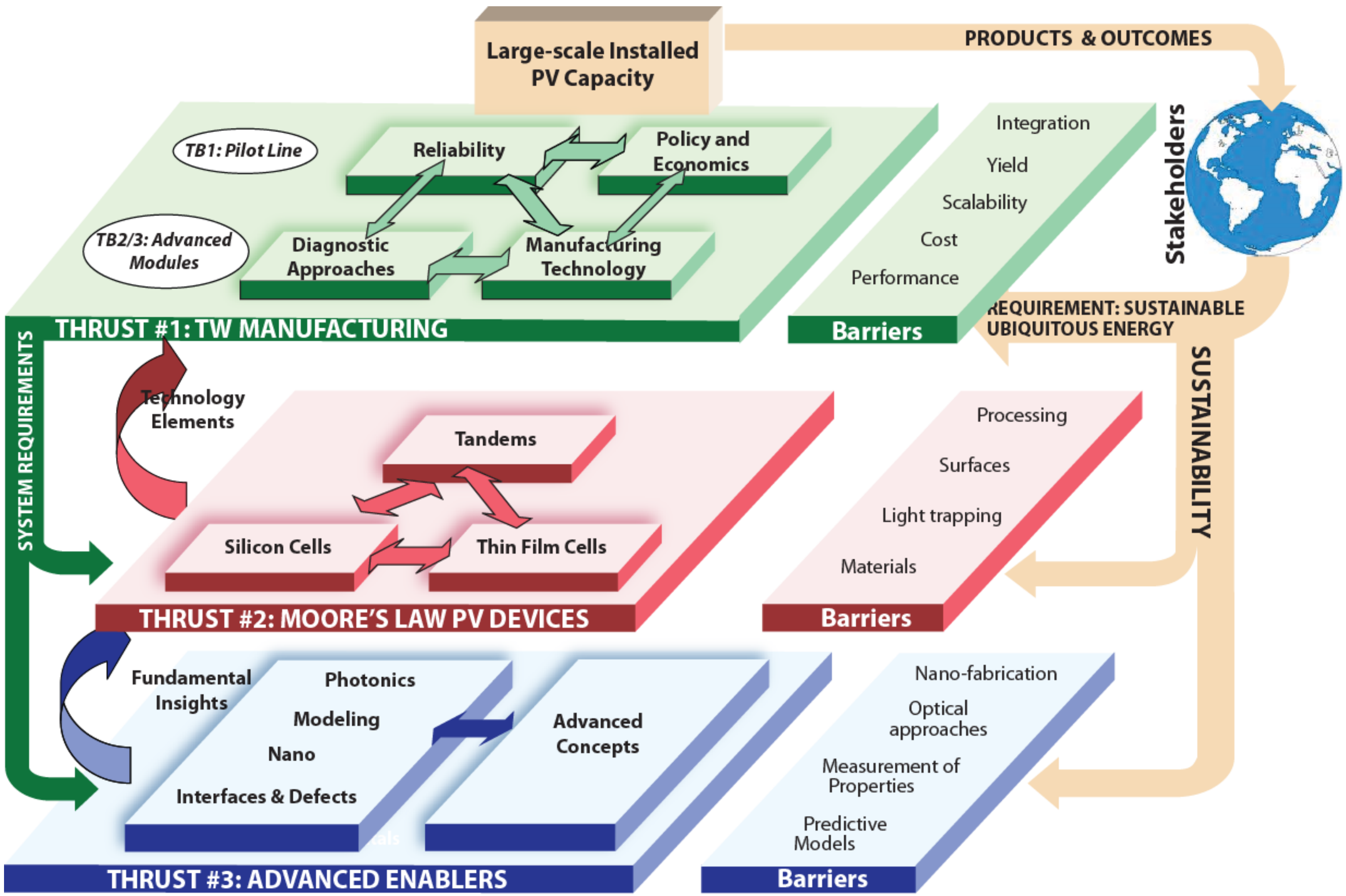
Engineered System



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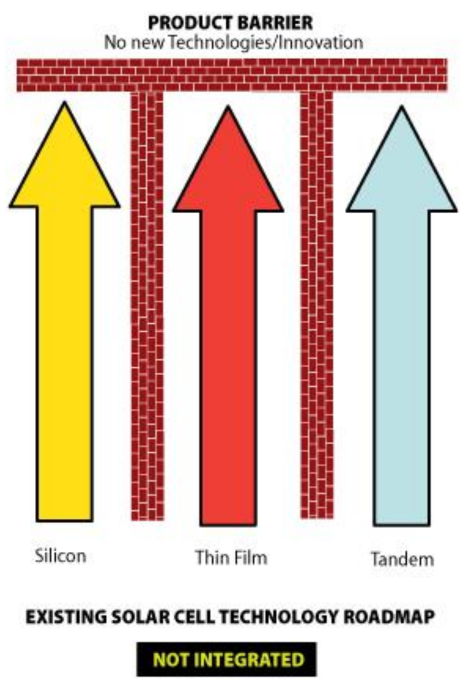
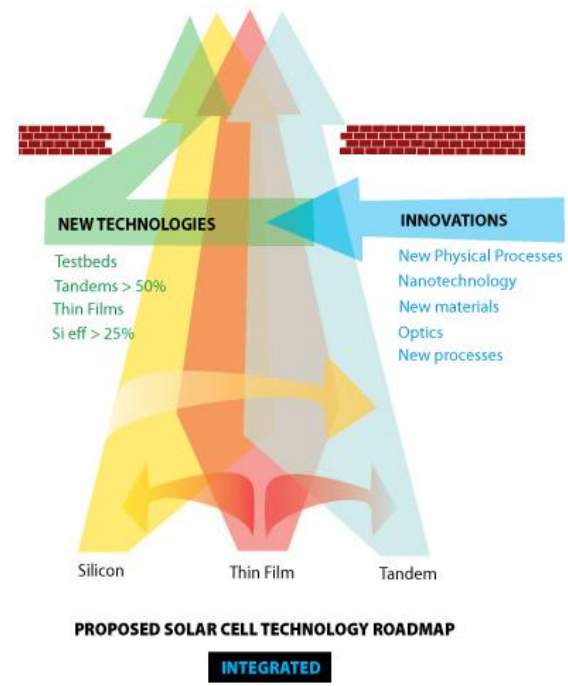
Research Themes & Projects

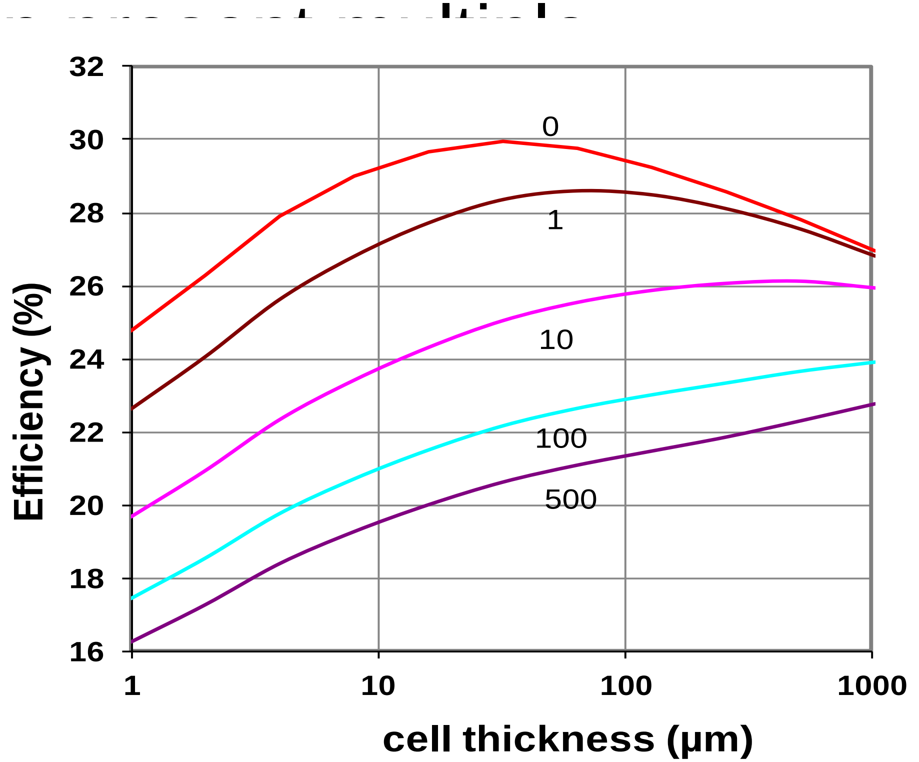
- Engineered system and three-plane diagram defines system, technologies, and issues
- Research themes represent areas of key competencies which allow QESST to make substantial advances





Silicon Solar Cells: Moore's Law Analog

- Higher efficiency and lower cost realized by thinner solar cells
- Diffused junctio
  barriers to
  higher efficienc
  photovoltaics
- Carrier selectiv
  contacts allow
  thermodynamic
  efficiencies,
  simple process



Existing and Target Silicon Solar Cells

	Area (cm^2)	V_{oc} (mV)	FF (%)	J_{sc} (mA/cm^2)	Efficiency (%)
S-Q		875	87.1	43.8	33.4
UNSW	4	706	82.8	**42.7**	25.0
Panasonic	101.8	**750**	**83.2**	39.5	24.7
SunPower	155.1	721	82.9	40.5	24.2
ASU Target	**100**	**785**	**83**	**42**	**27**

- Highest V_{oc} to date was achieved with carrier-selective contacts; concept can be pushed to the S-Q limit
- Advanced light trapping will replace thick wafers

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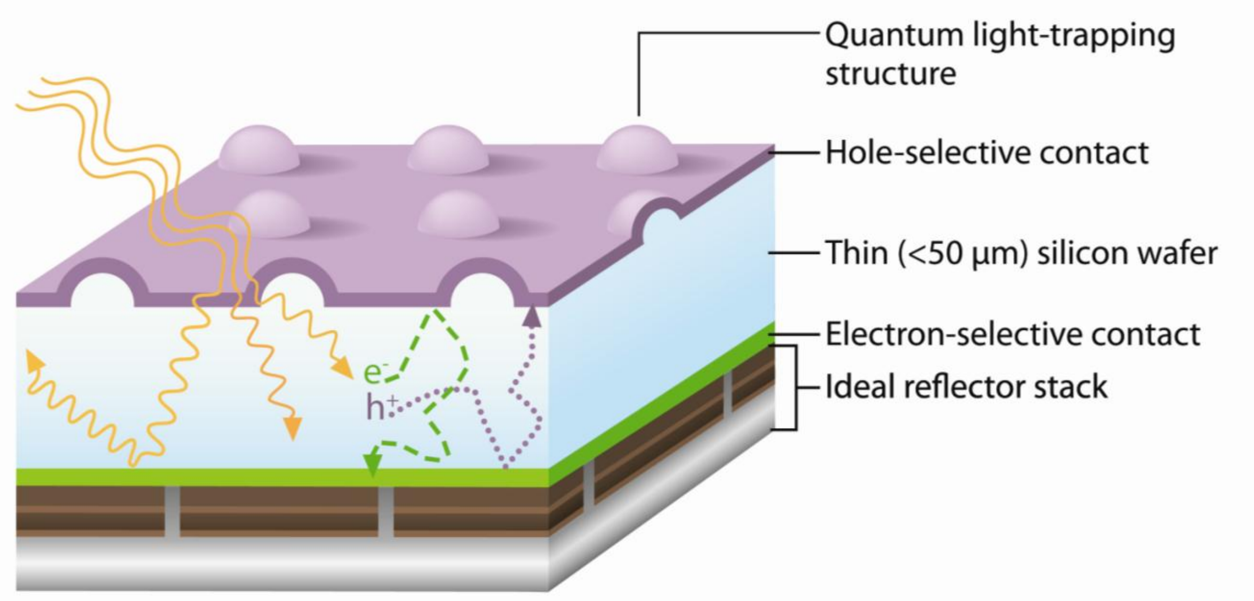
Silicon Single Junction Solar Cells

- Silicon solar cell path to 40%
  - Carrier selective contacts
  - Auger limits
  - Hot carrier effects
  - Limited acceptance angle
  - Novel light trapping



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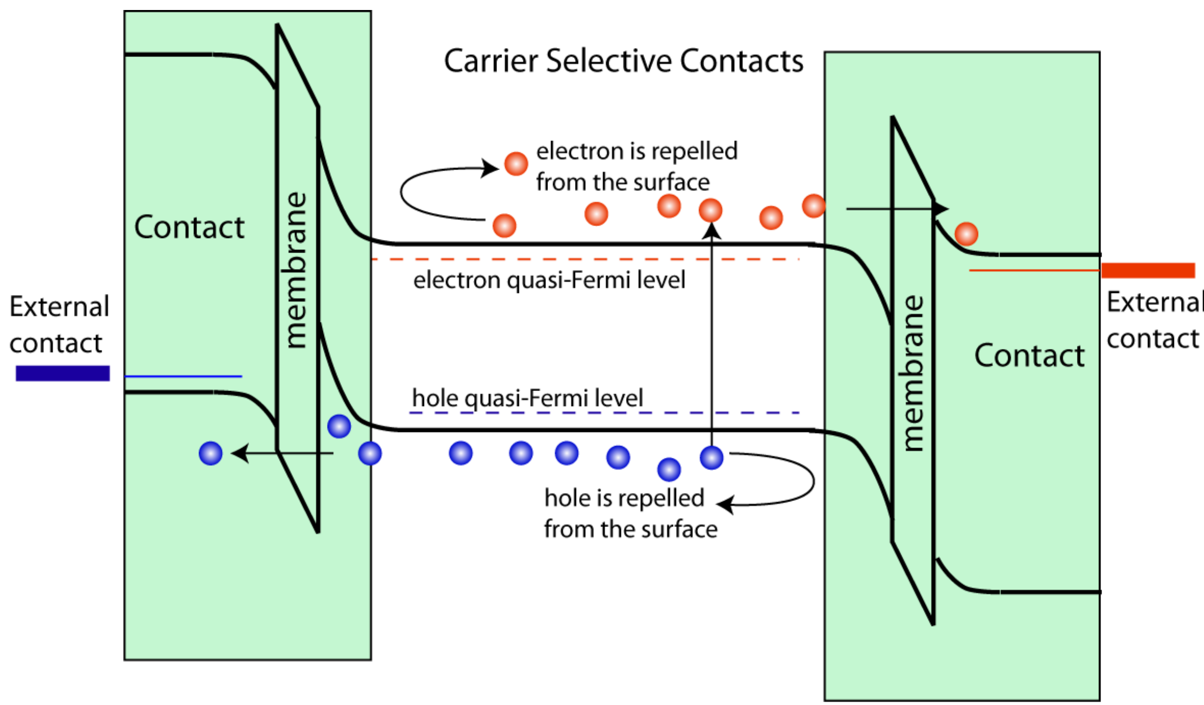
Carrier-Selective Contacts

- Carrier-selective contacts enable ideal V_{OC}
- CSC approach comes from thermodynamic limits and detailed balance
- aSi/cSi is a close approximation to CSC



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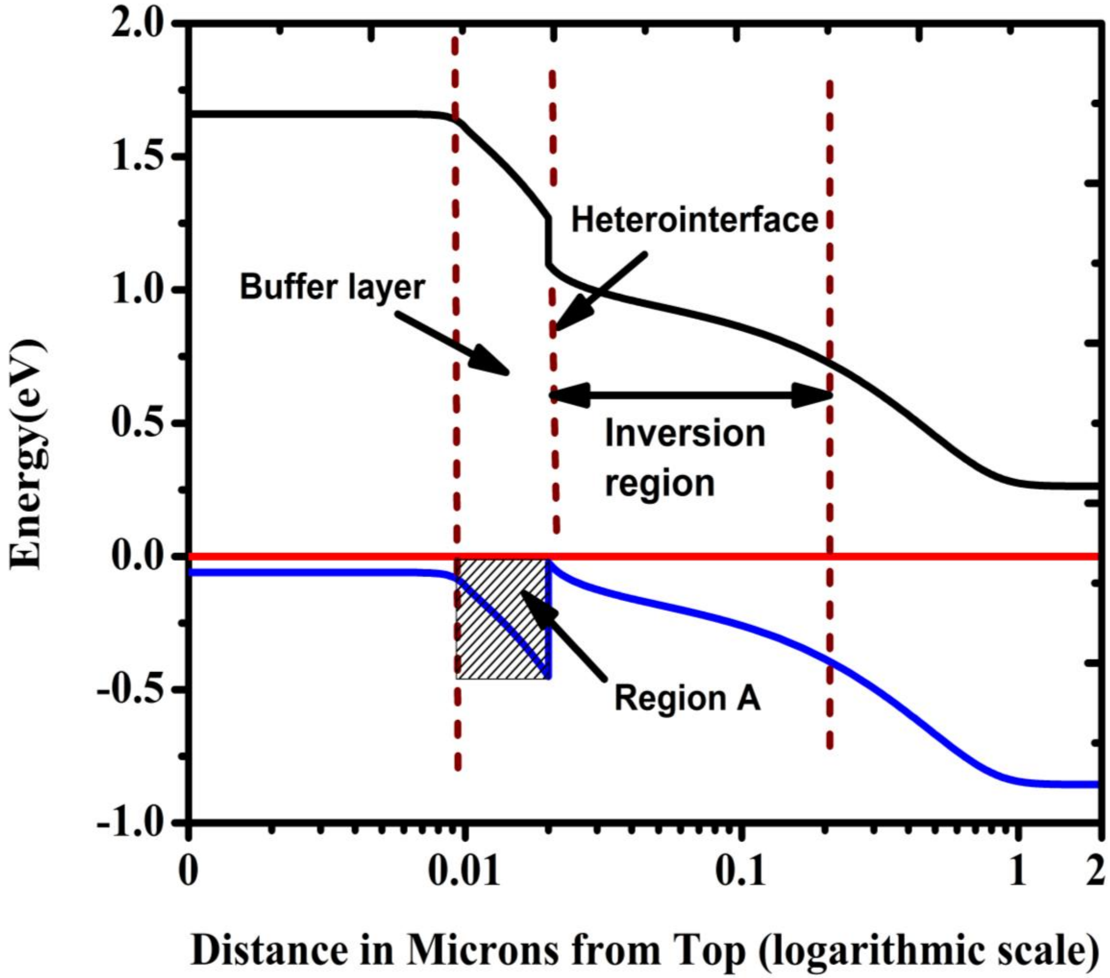
aSi/cSi Heterostructure



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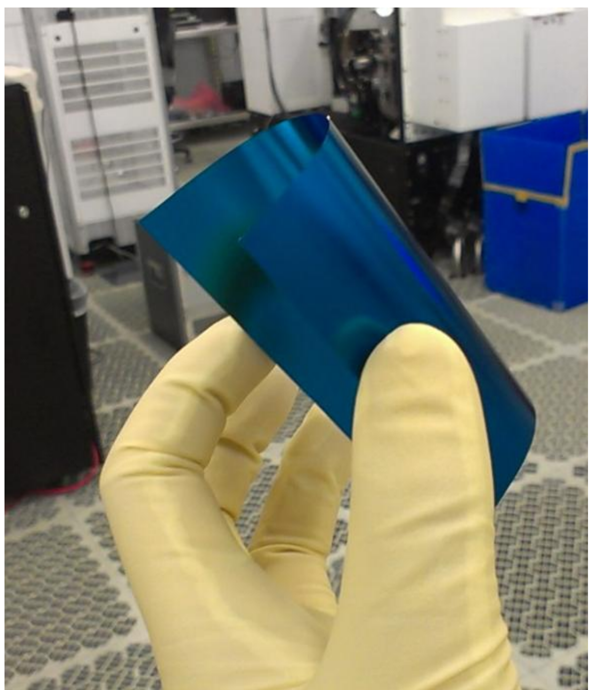
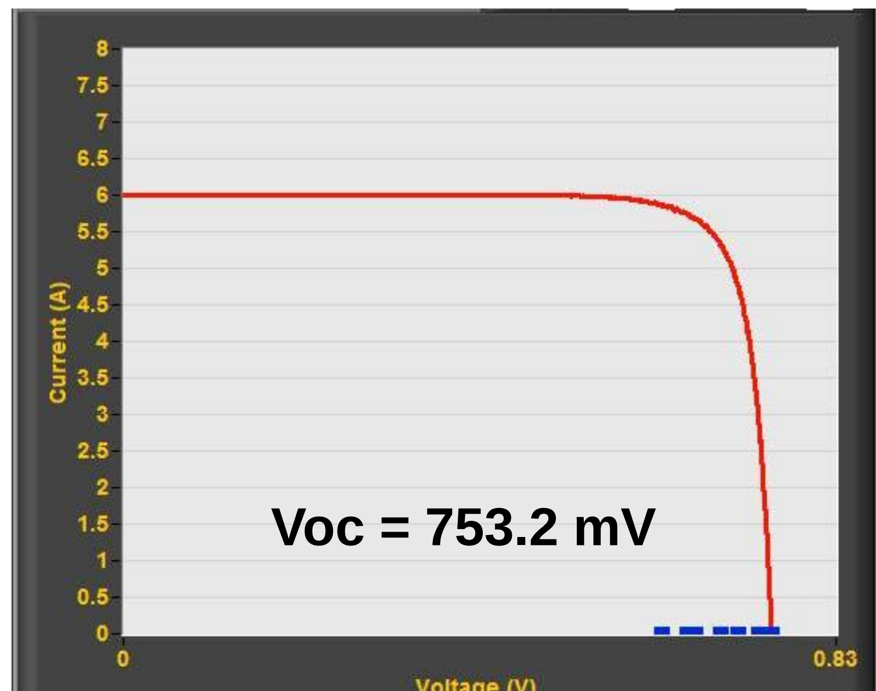
V_{OC} > 750 mV Heterostructure

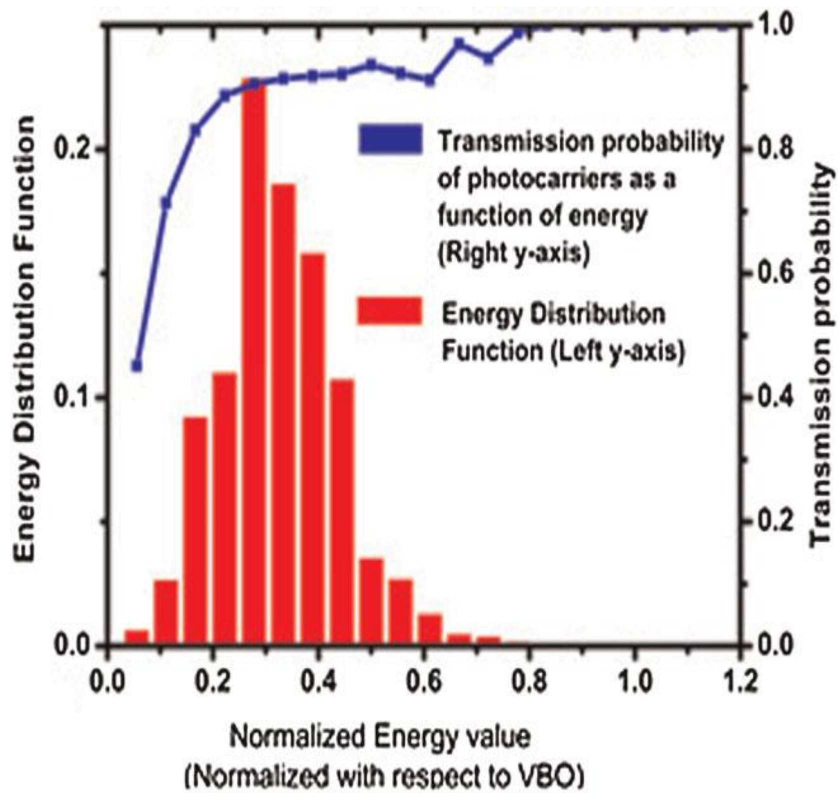
- Surface recombination velocity of 2 cm /s on 50 µm thin wafer .
- J_0 of surfaces is 1-2 fA/cm^{2}.
- Completed solar cell with ITO on both sides





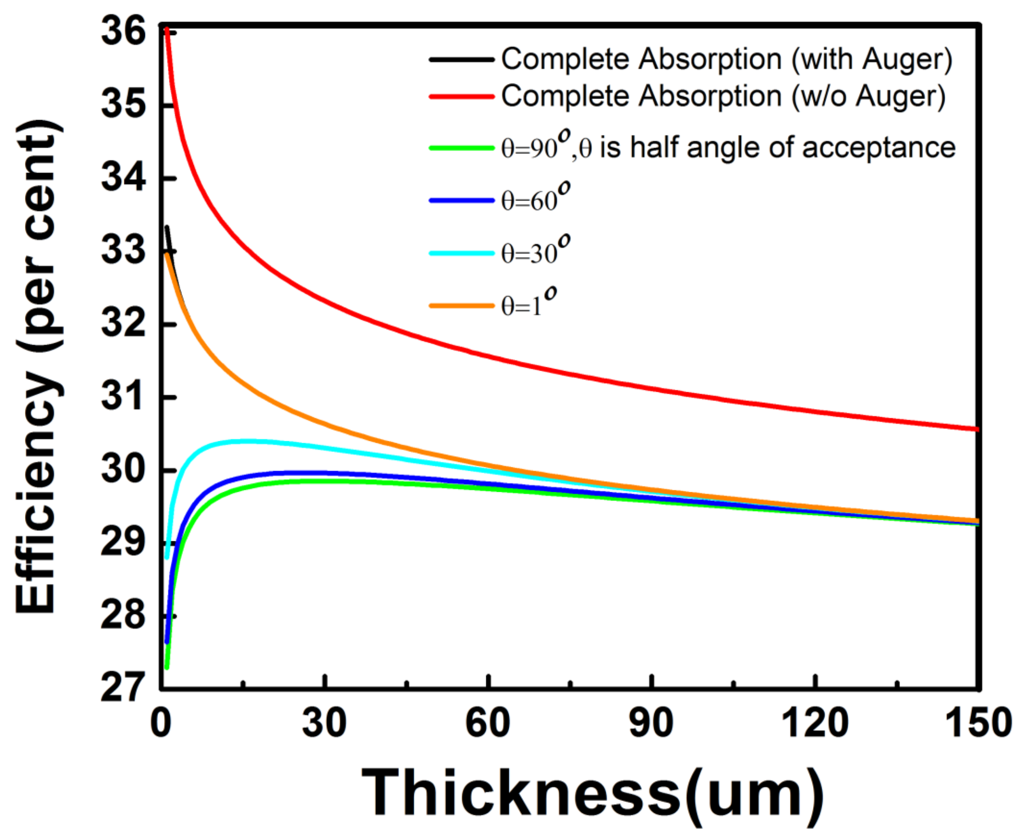
Transport at interface

- Transport at interface involves tunneling, transport over barrier, conventional drift diffusion
- Hot carrier transport aids transport over the barrier extracting 300 meV



Optical Approaches

- Angular control allows higher than accepted thermodynamic limits



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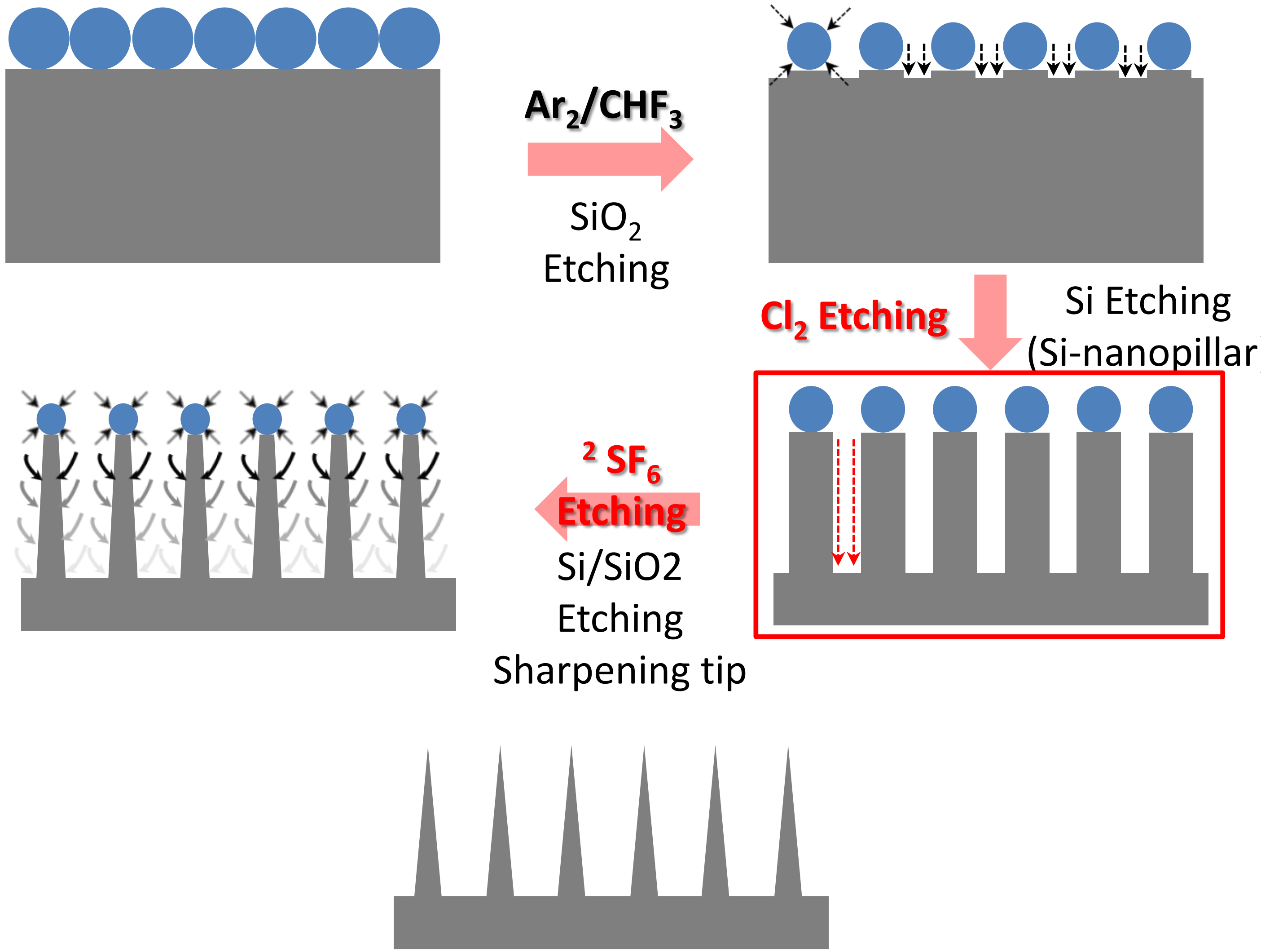
Patterned silicon



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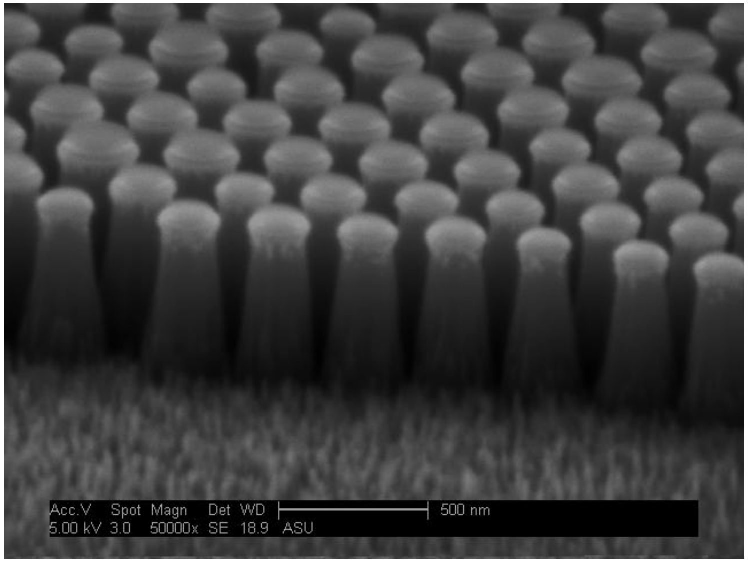
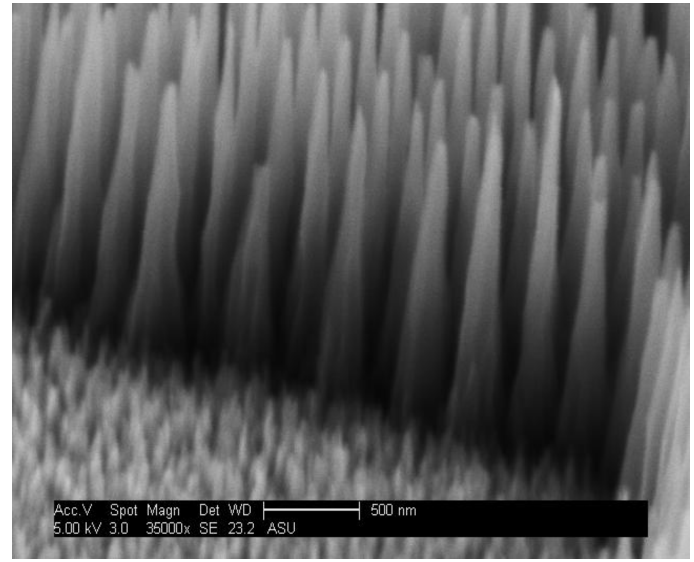
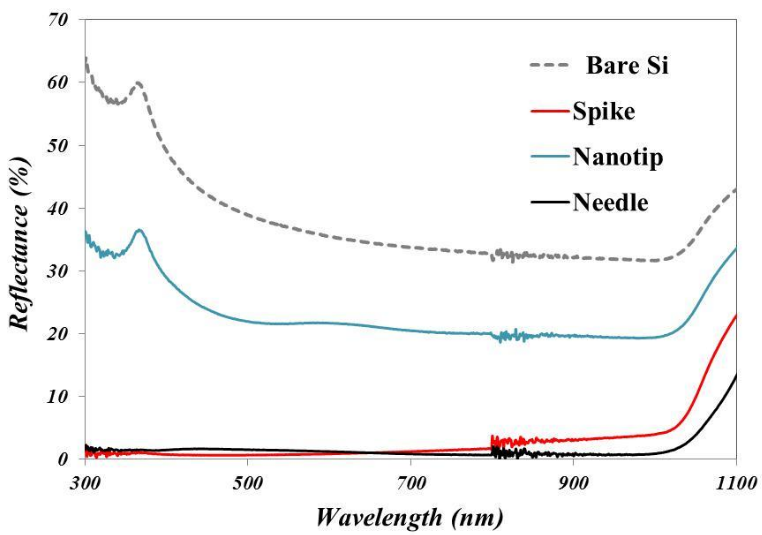
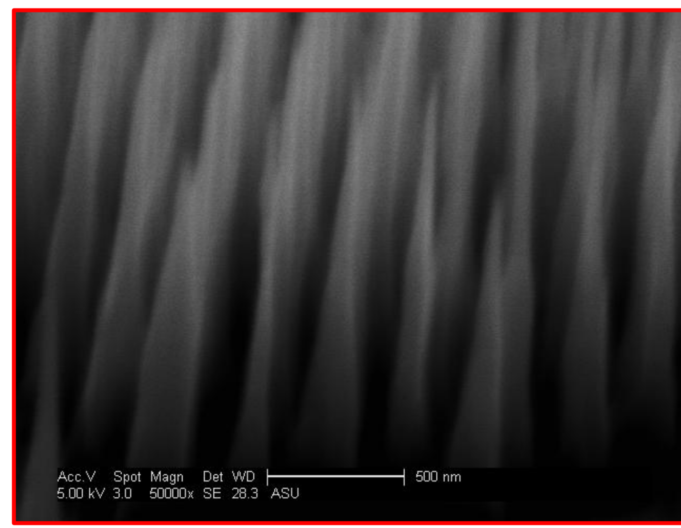
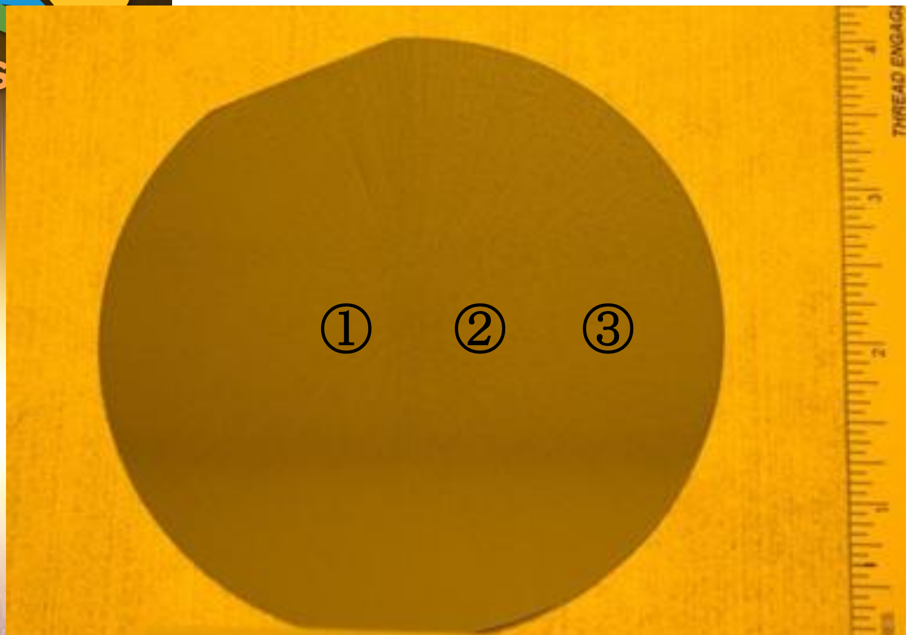
Surface Control with SNS







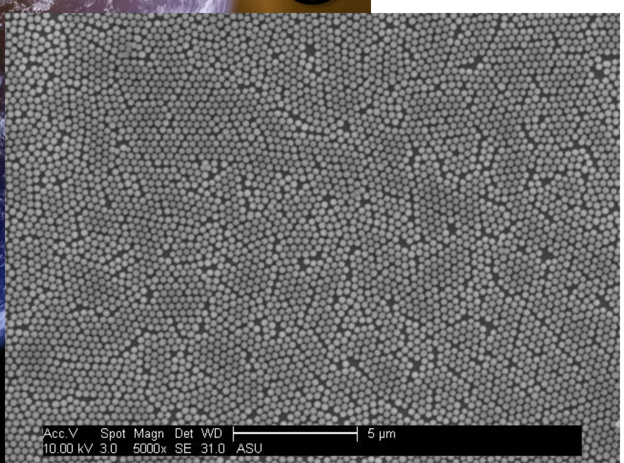




Uniform monolayer from center to edge

w/ 4-inch silicon substrate

①



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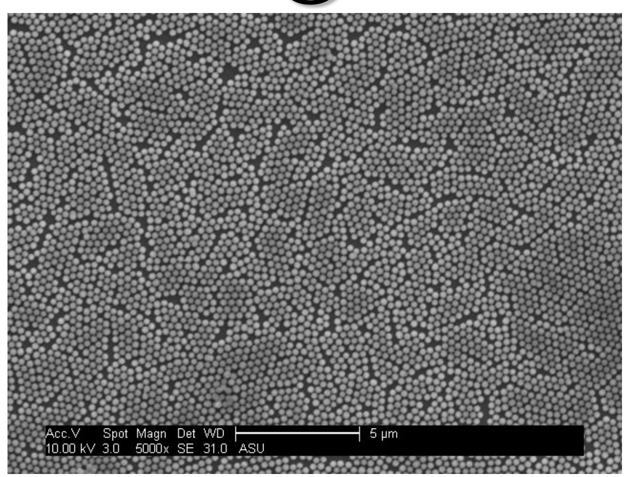

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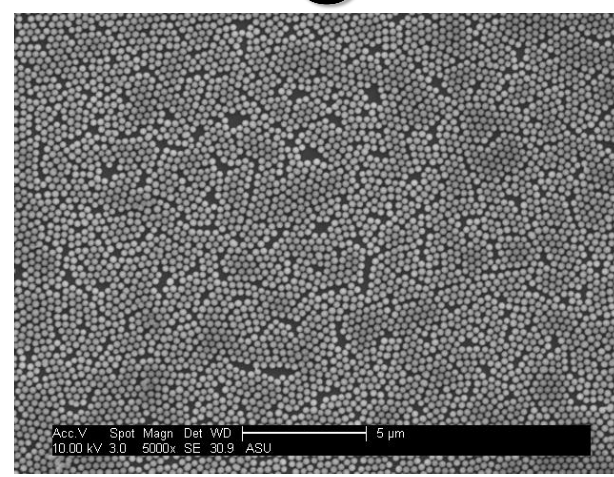
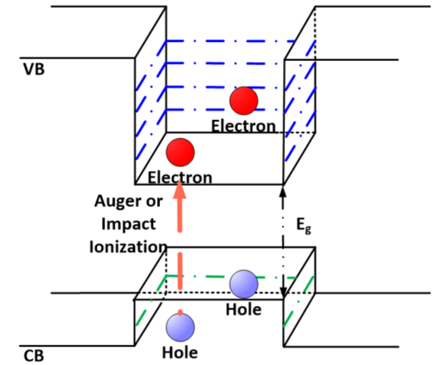
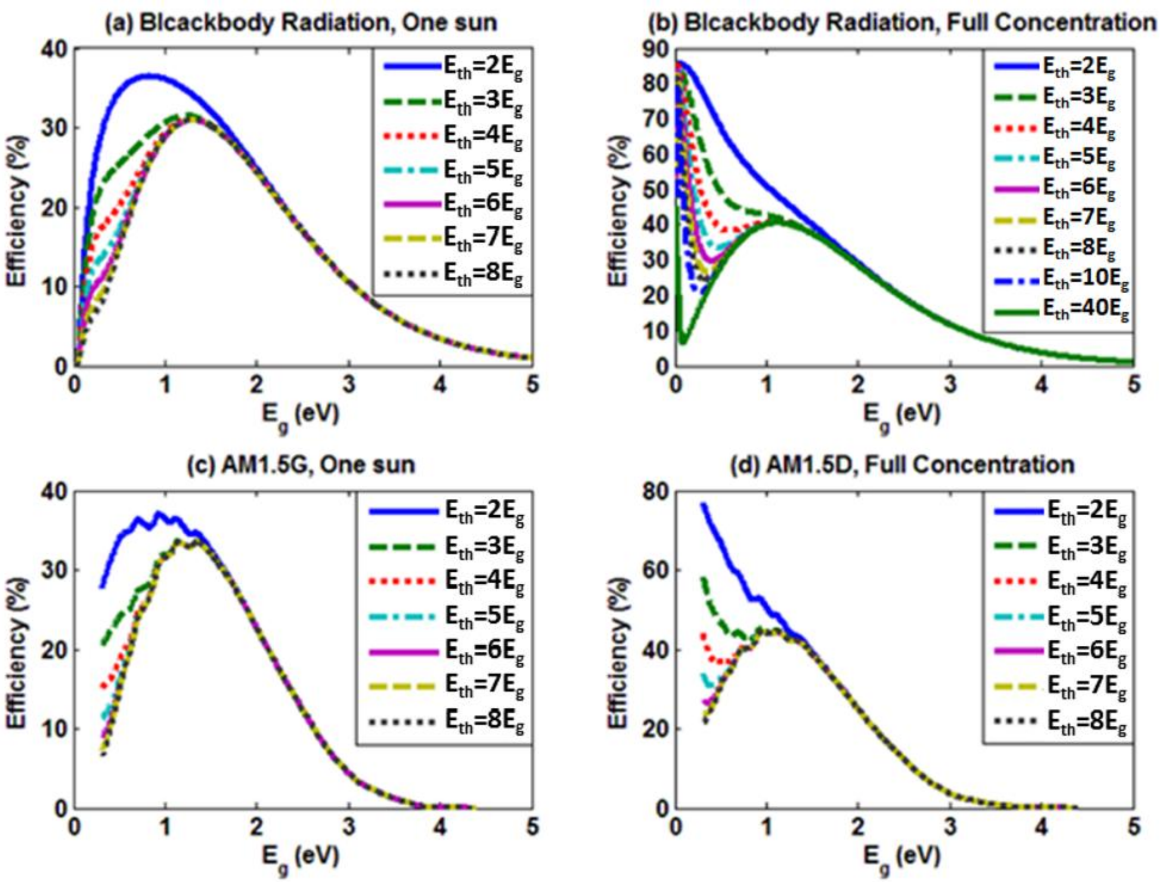


Advanced Concepts in Si

- MEG with non-idealities in silicon

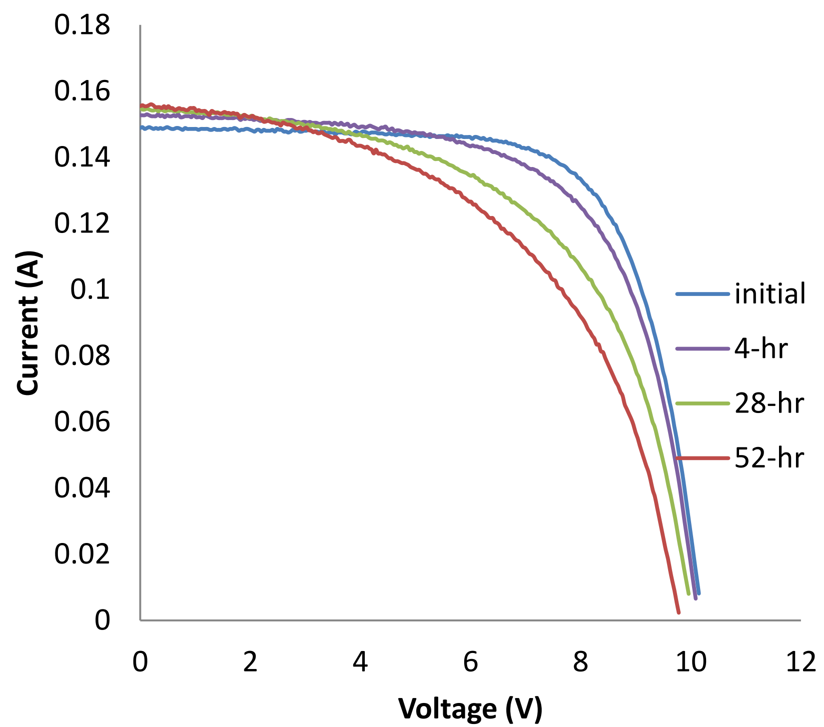


(b) TWO EHPs Generation



Potential Induced Degradation (PID)

- Test condition
  - 85 C/0% Rel. Humidity
  - Negative bias (-600V)
  - Duration: 56 hours



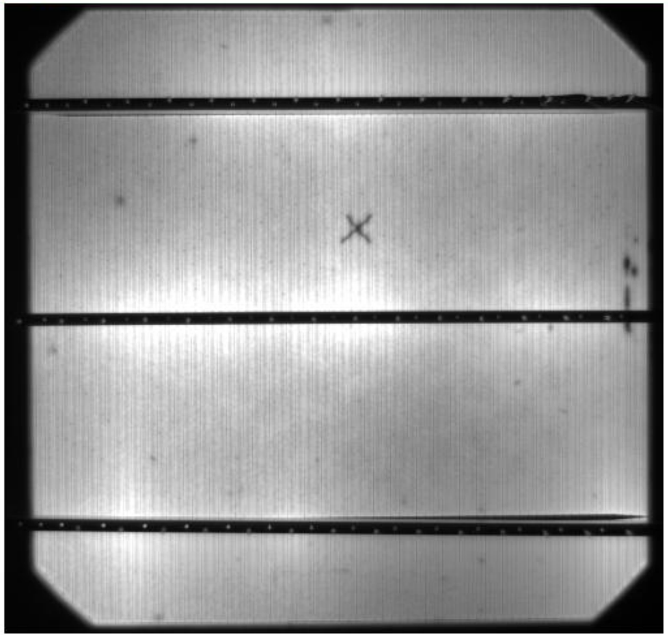
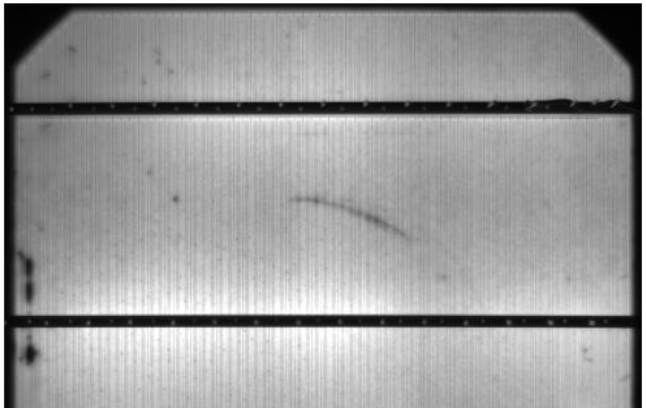
Home | View eTraveller Data | Log Data | Report News | Maintain PV Data | User Data | Calculators | Help & Docs

Sign Out of eTraveller

Data for PV Lot: **DI0097 - Split for etched in time and p5000 SiN**

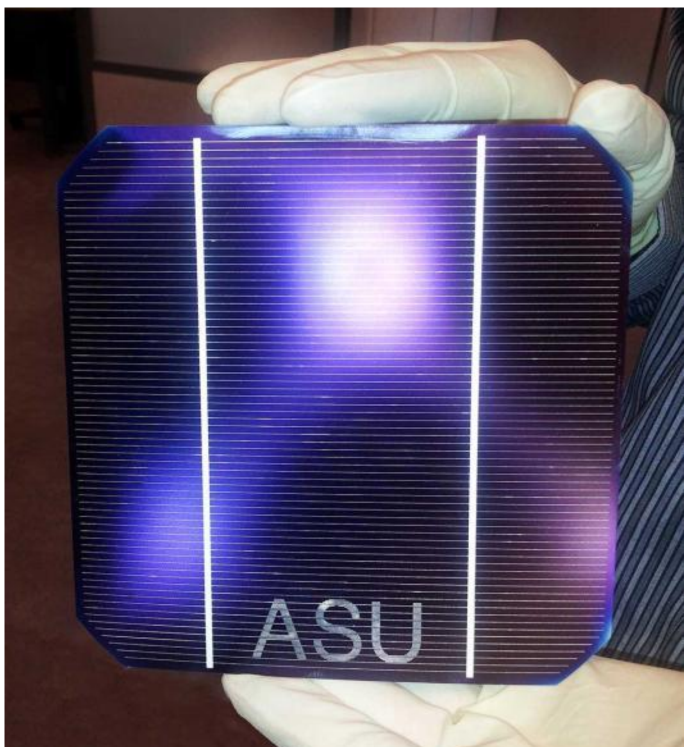
Lot Summary | Fabrication Data | Characterization Data | Reference Files | Lot News | Cell News | Engineers | Subscribers

Summary | I-V | Q.E. | E.L. | P.L. | S.E.M. | 4-Point-Probe | Mass | Reflect. | P.C. Cheat Sheet | Photocond.

Log Info	Image
PV Cell Serial #: DI0097-01 **Logged By:** gpickett **On:** 2013-03-04 12:41 **User Notes:**	
PV Cell Serial #: DI0097-03 **Logged By:** gpickett **On:** 2013-03-04 12:41 **User Notes:**	

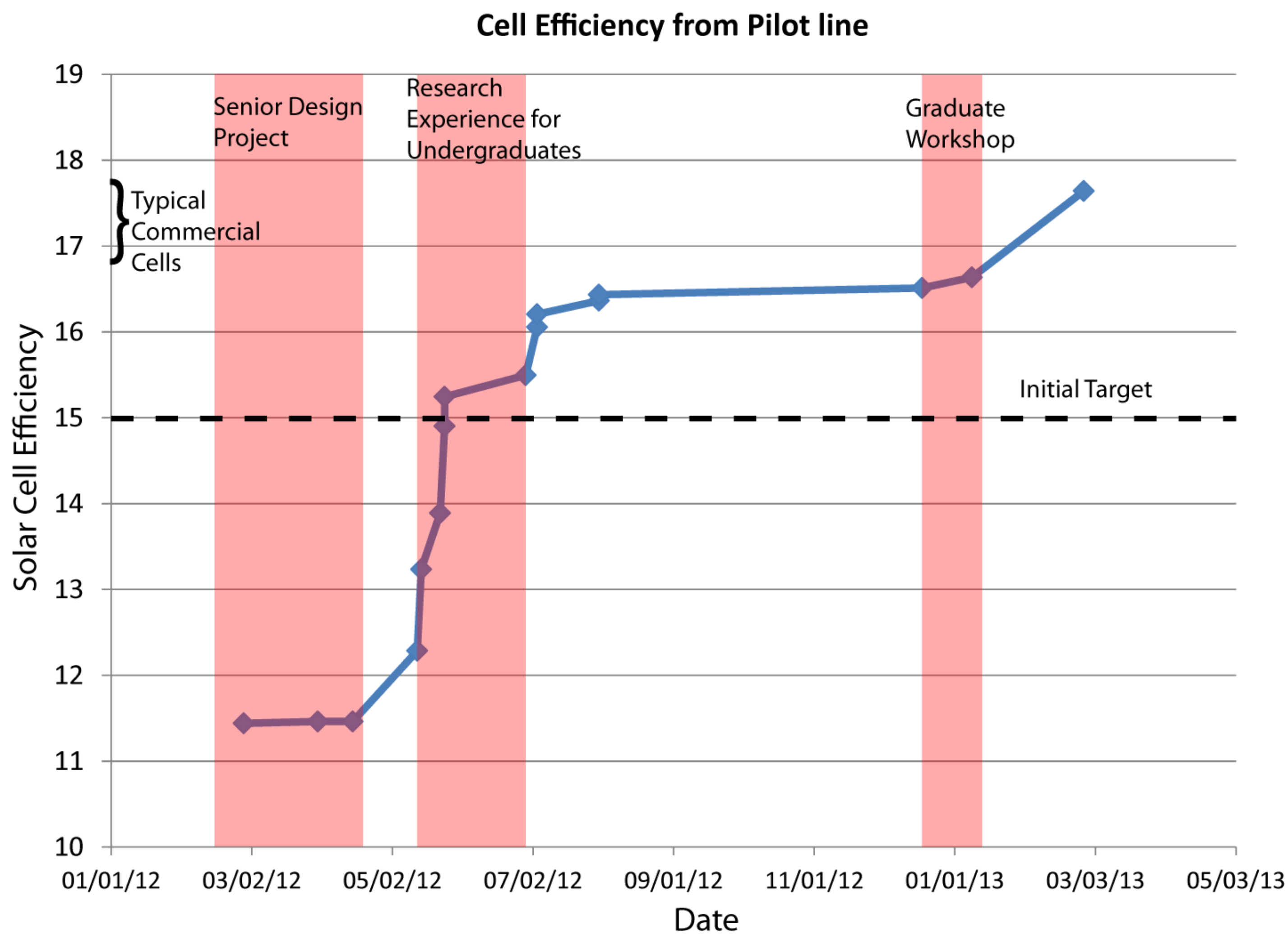
Baseline Process

- Implementation of a 'standard' screen print process that we can add on to for each user.



- Wafer
- Texturing
- Cleaning
- Phosphorus Diffusion
- Cleaning
- Silicon Nitride
- Screen Print Back
- Screen Print Front
- Fire in Belt Furnace

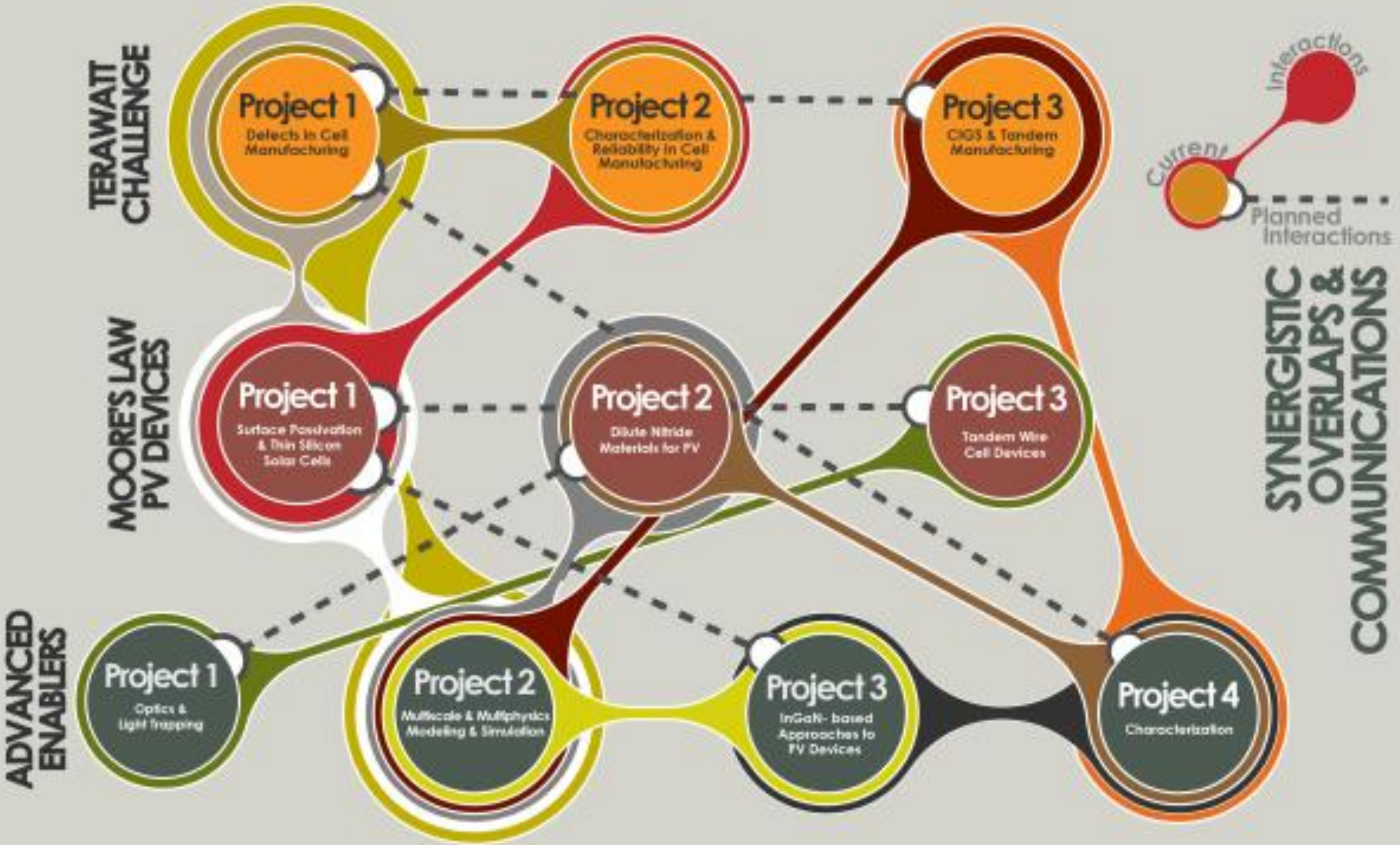
Line Development: Efficiency



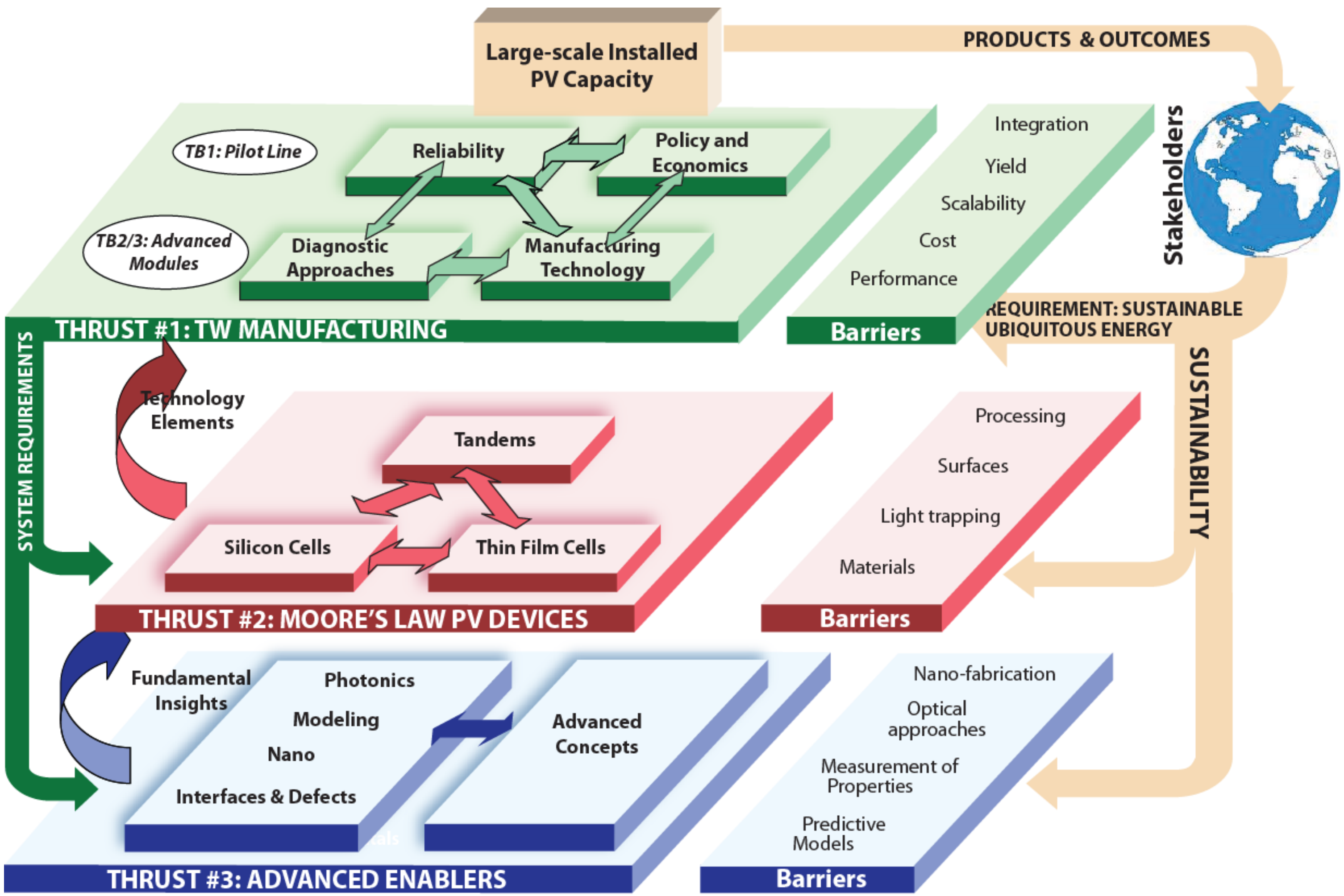
Central goals of QESST

- Simultaneously increase efficiency and reduce costs
  - Commercial solar cells at laboratory efficiencies: silicon, thin film
  - Increase commercial efficiencies to SQ limit
  - New approaches to higher efficiency modules and cells
    - Low cost tandems (Si-III-V, tandem thin films)
    - Low X spectral splitting
- Sustainability
- TW scale manufacturing; scalable, commercially compatible manufacturing
- Synergistic module approaches; integrated power electronics and optics
- Education training of workforce

QESST Interactions



Example QESST Interactions



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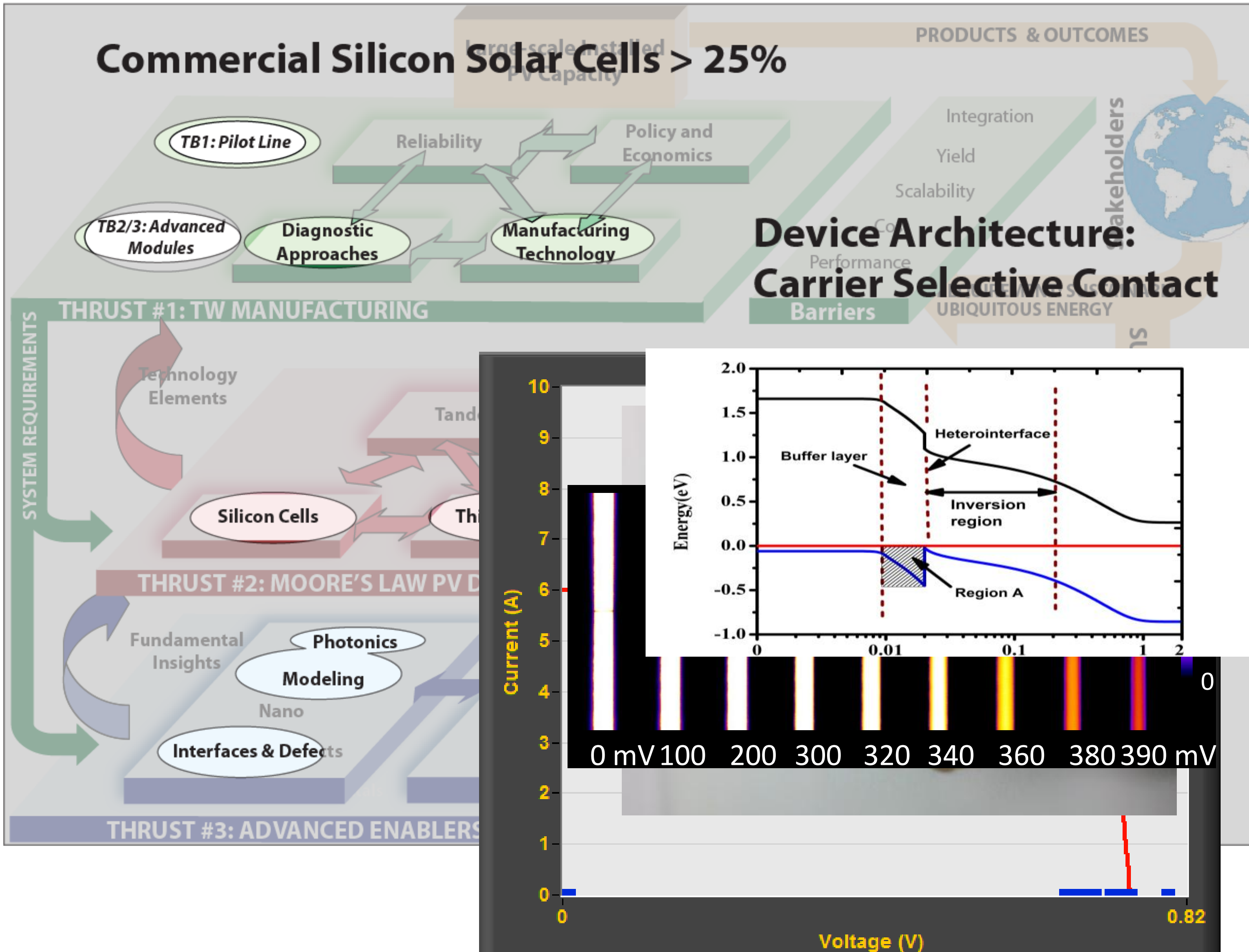
Example QESST Interactions



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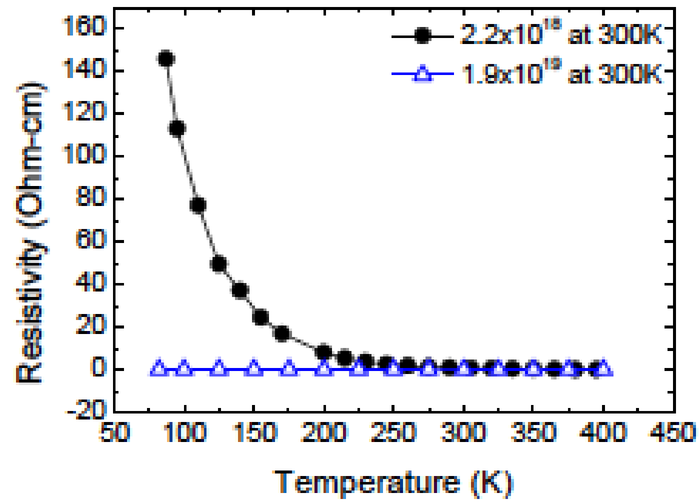
Research Highlight

Exceeding Previous Limits for Doping of Gallium Nitride

- Demonstrated extremely high-hole concentrations in gallium nitride (GaN) and indium gallium nitride (InGaN),
- Work surpasses previously accepted limits to carrier concentration for this material system.
- More than 50% of the magnesium is active, compared to the 1-5% activation in traditional layers.



Resistivity as a function of temperature for p-type GaN films is shown in black prior to the current work and shows a 150x increase in resistivity due to carrier freeze-out as the temperature is decreased to 80K. The blue line shows the results from this current work where a high-hole concentration p type GaN film grown at Georgia Tech with the resistivity is relatively unchanged at lower temperatures.

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Solar Decathlon

Education

- 19 Courses on PV and Sustainability
- www.pveducation.org
- Individual projects

Thank you.