SiOnyx, Inc.

James Carey – Feb 26th 2012

The winding road from researcher to entrepreneur – photovoltaics

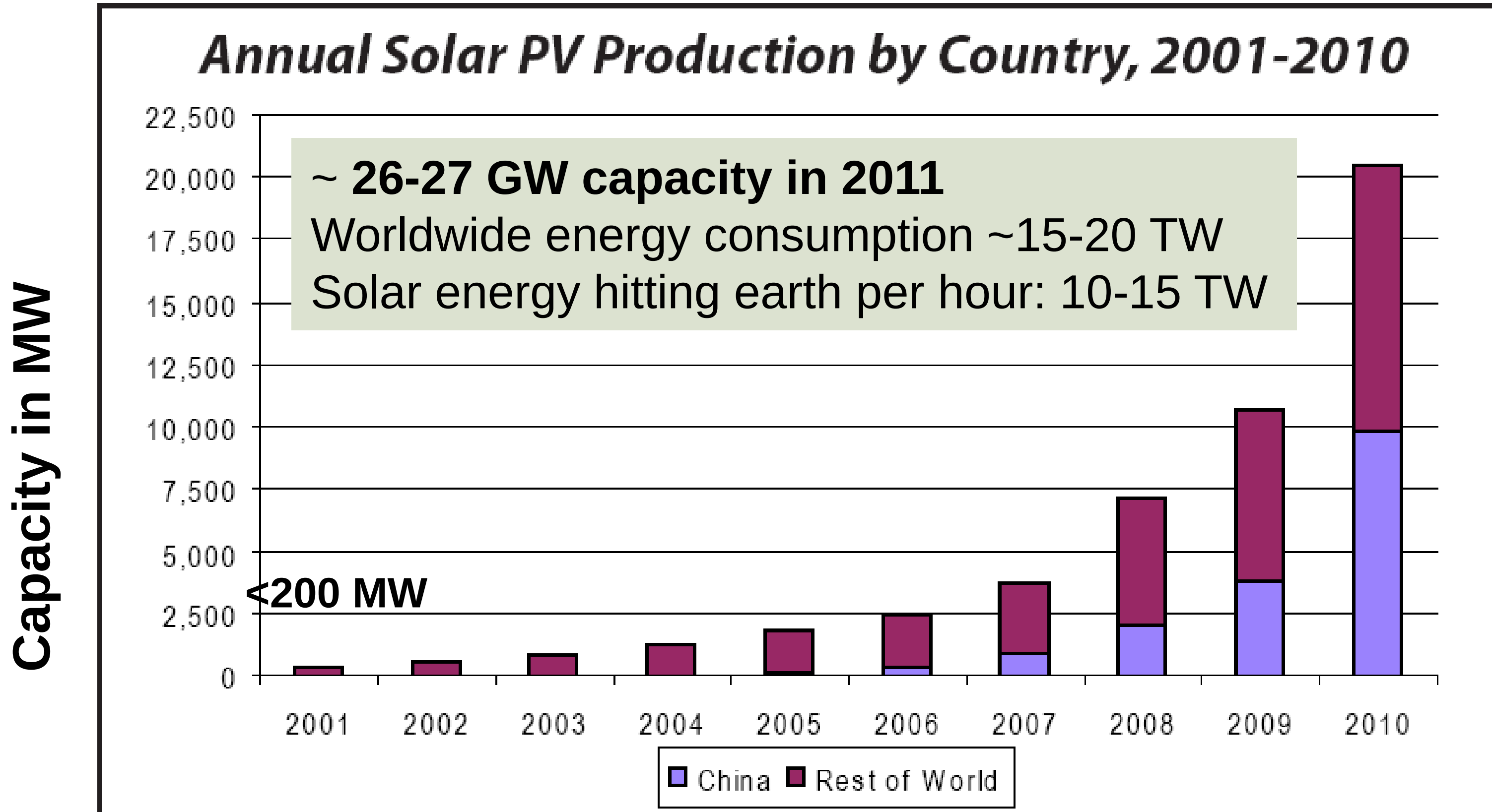
SiOnyx
black silicon

- SiOnyx is a Boston area startup founded in 2006
  - venture backed, materials based university spinout
    - laser modification of materials
  - high broadband quantum efficiency in thin layers of silicon
    - photodetectors and image sensors
    - photovoltaics
  - more later…

- photovoltaics industry
  - backdrop and barriers to entry
  - the role of technology/research in
    - evolutionary or revolutionary?

- lessons learned, challenges ahead
  - transitioning lab technology to product
  - entrepreneur or academic?

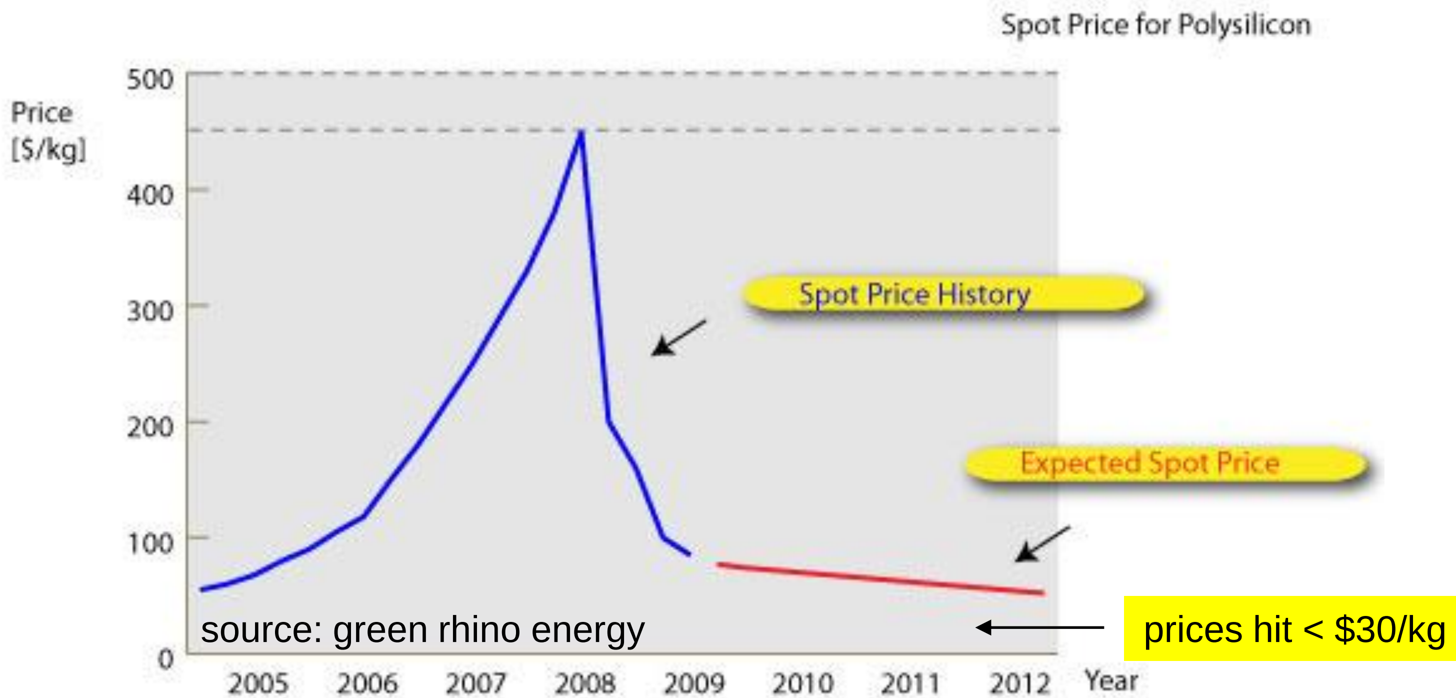
Photovoltaic industry - rapid growth



Source: CCBJ compiled from a variety of sources including Earth Policy Institute, Worldwatch Institute, Prometheus Institute, Greentech Media, PVNews, iSuppli, SolarBuzz and Photon International. China's annual share of PV cell production has gone from 0% in 2000 to 7% in 2005, and 14%, 23%, 28%, 35% and 47% in 2006-2010.

- solar photovoltaic industry is now over $80 **B** worldwide

Photovoltaic industry – poly feedstock prices



- rapid startup proliferation in 2006/07
- predicated on need for silicon alternatives
- silicon drops like a rock - economy and added capacity
  - China employs a low-tech brute force approach
  - proven technology hard to dislodge in commodity markets

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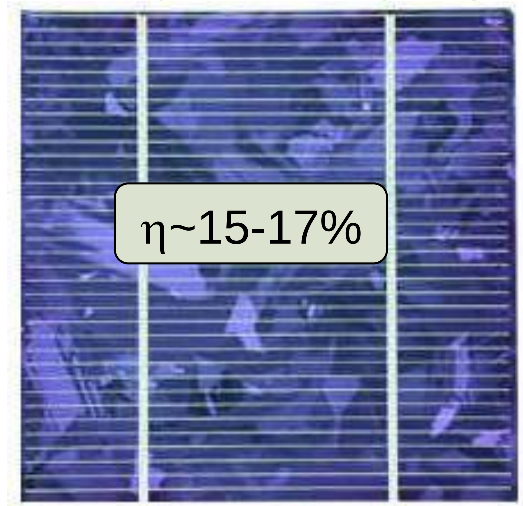
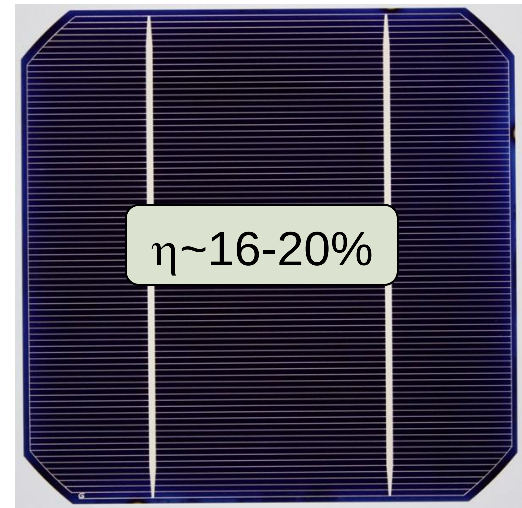
Photovoltaic industry - today

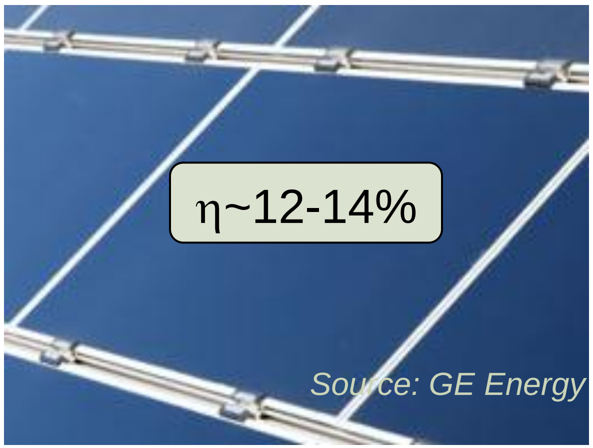
Multicrystalline Si (45%)



Monocrystalline Si (36%)



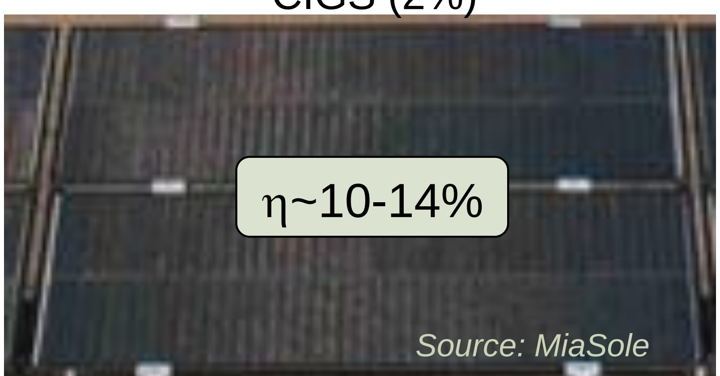
CdTe (10%)



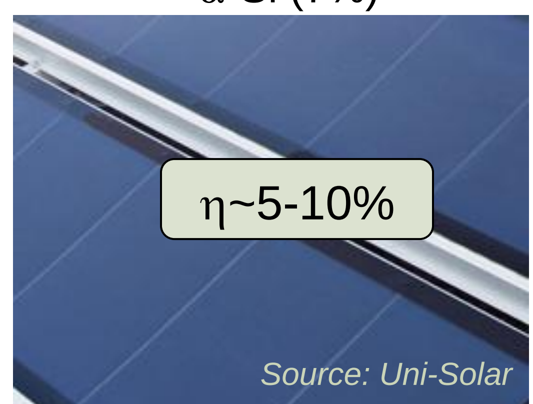
Typical cell efficiencies

(2009 market share)

CIGS (2%)



α-Si (7%)



Role of technology

- can university research help?
  - recent advancement of plain old vanilla silicon solar cells is entirely dependant on past academic work
    - UNSW, NREL, Georgia Tech, etc
  - just took some time for things to make it from the lab to the fab

- taking the long-view
  - technology improvements often require industry wide adoption
    - downstream supply chain compatibility
    - need to understand the requirements of the established infrastructure
  - well suited for academic/industrial collaboration
  - story for thin film technology isn't over but…
    - expectations need to be set correctly
    - this is a commodity market and evolution is historically more successful than revolution

- how you view the technology will impact the available capital

Advice and approach

- get connected with industry professionals
  - academia has a way of being insular and far reaching (timewise)
  - industry often does not know about available solutions
  - understand discrete pain points

- take advantage of the growing number of bridge institutions
  - ISC Konstanz, Fraunhofer, SVTC solar (coming online soon),centers of excellence

- consider collaboration or internship at a large corporation
  - sometimes difficult while in academia, but the experience is valuable
  - DO NOT worry about direct correlation to your research
  - getting a broader view is always a good thing

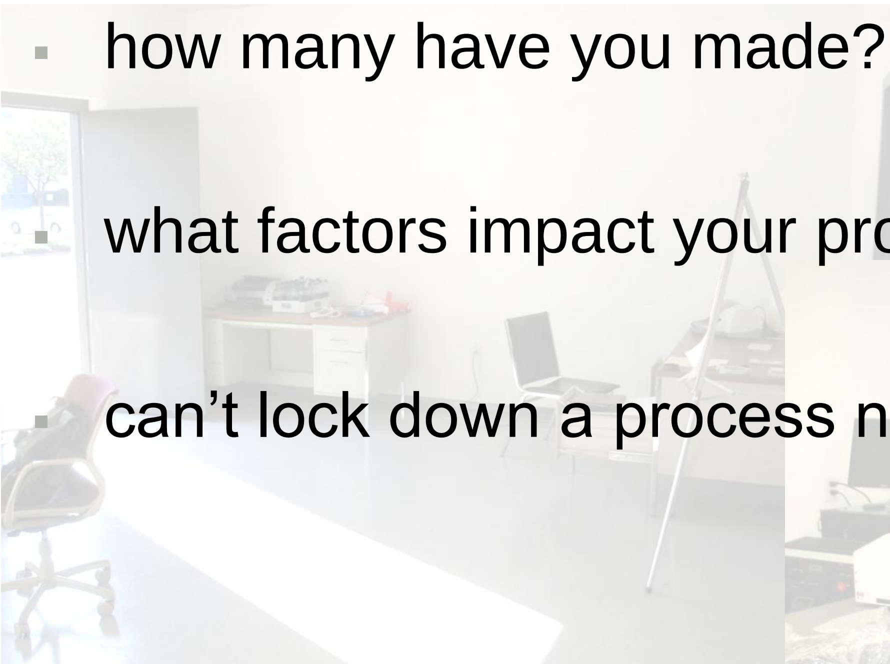
- process innovation is underappreciated
  - physics changes slowly, implementation changes rapidly

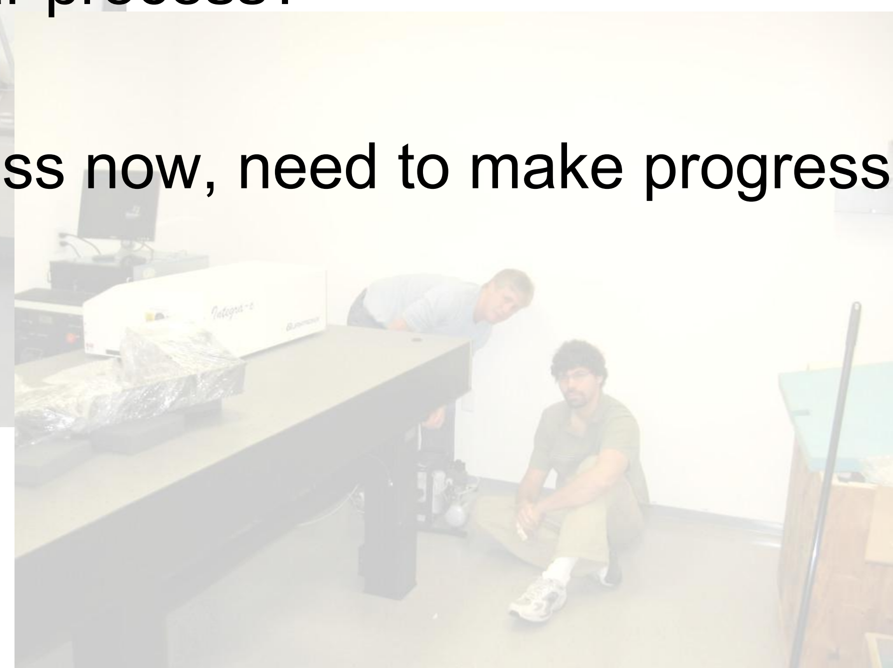
Going from lab to fab

- startups face all kinds of challenges
  - raising capital, hiring team, understanding opportunity…
- one of the most difficult for a young company is how to best mature a lab based technology
- where are we on the path to product, what market?
  - in all companies this is an evolving question, but in energy alternative applications it’s even more important
- when to invest in taking the next big step?

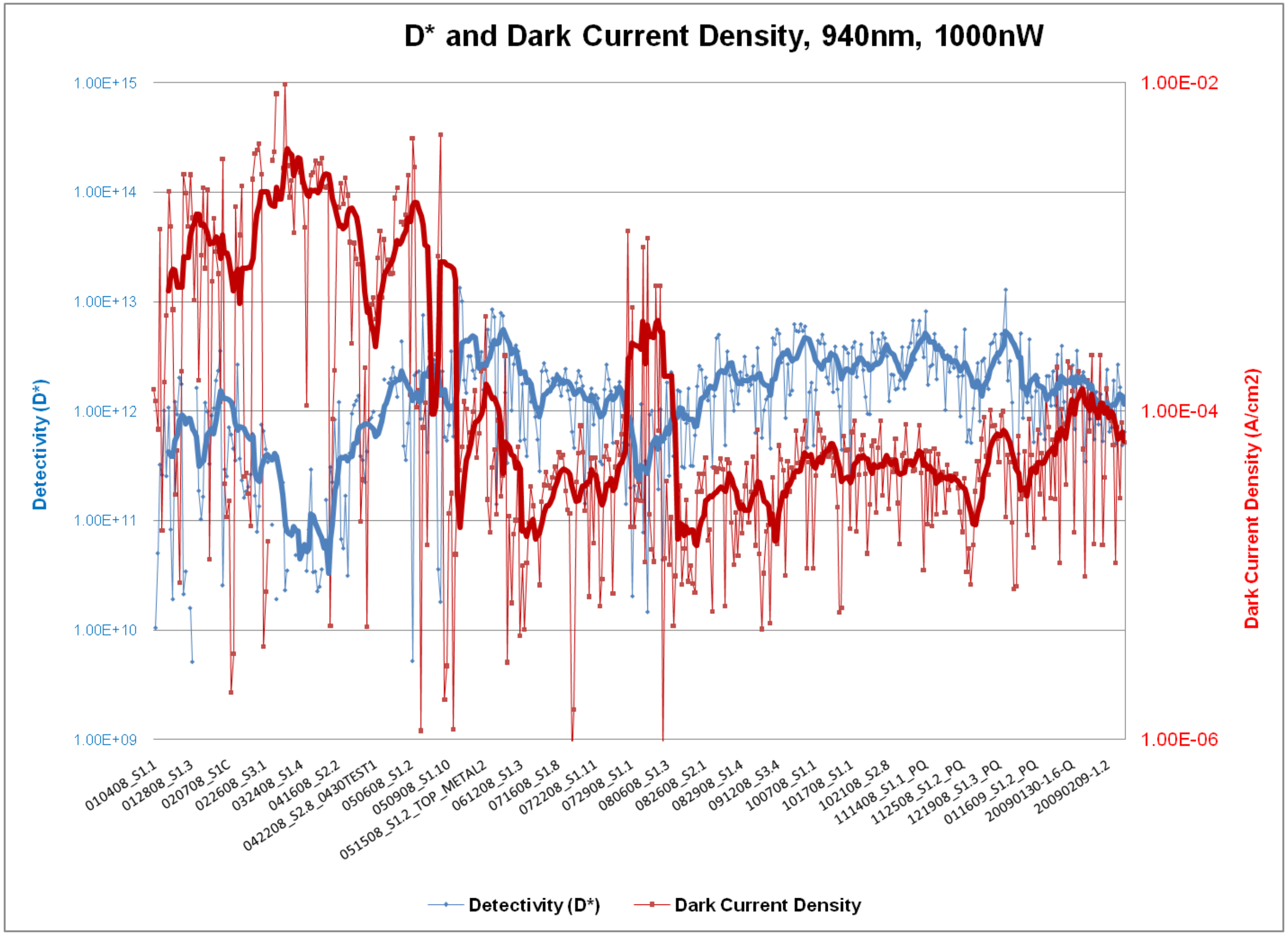
Common questions

- how many have you made?
- what factors impact your process?
- can't lock down a process now, need to make progress!





Transition example - trended device performance



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A controlled environment

statistical process control: maintain a program providing maximum control with minimum investment of time & money; focus on upstream control of material, equipment & processes and establish predictive measures correlated to device performance.

elements:

- supply chain established; substrate specification & tier1 supplier; semiconductor grade materials from qualified suppliers; batch qualification procedures; outsourced elements of device fabrication
- laser equipment monitoring
- cleanroom environment for all process steps
- in-line analytical analysis and metrology
- database for inline and device test data
- controlled documentation system
- **development of correlations of inline measurements to device performance**

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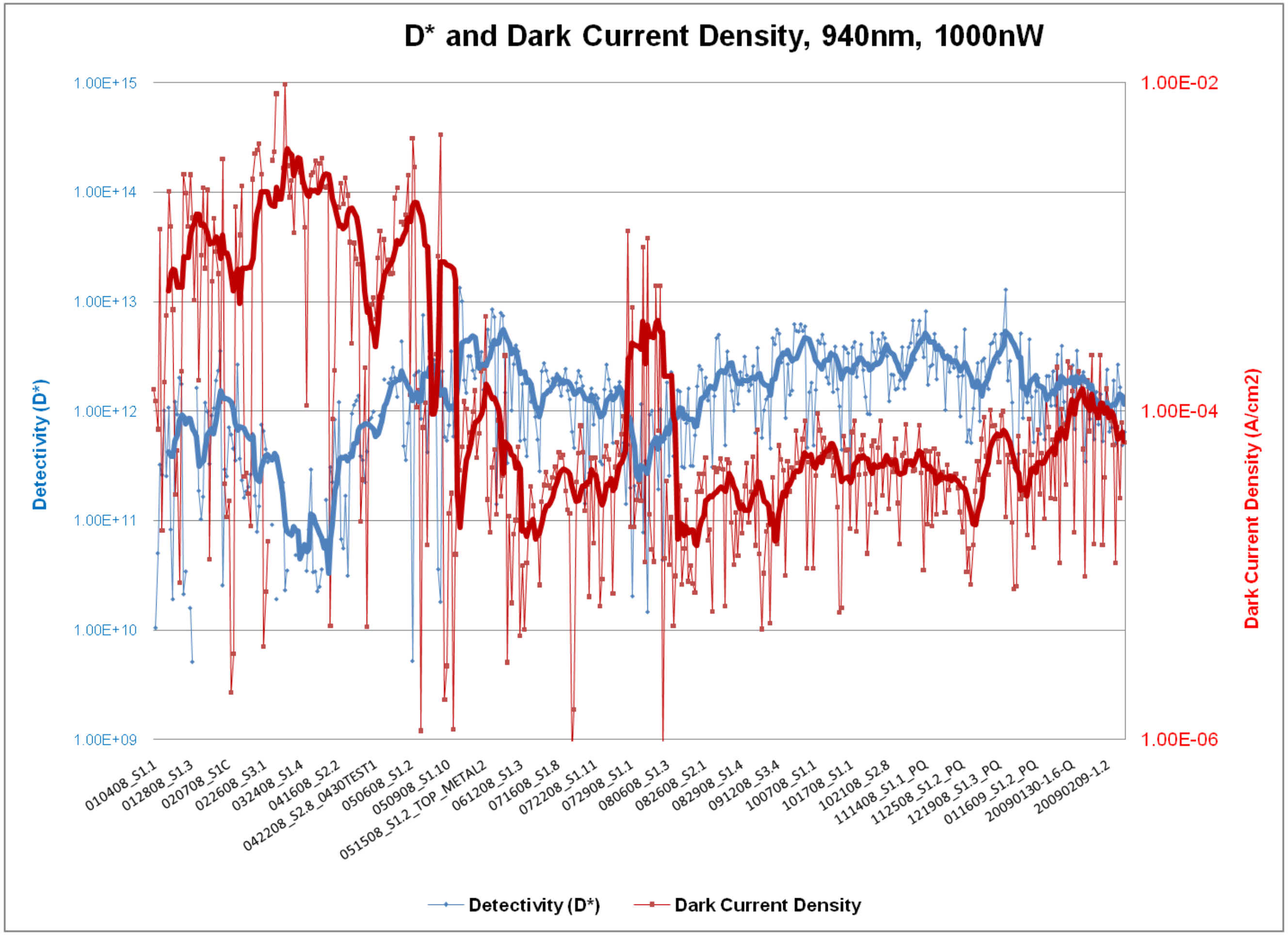
Transition example - trended device performance



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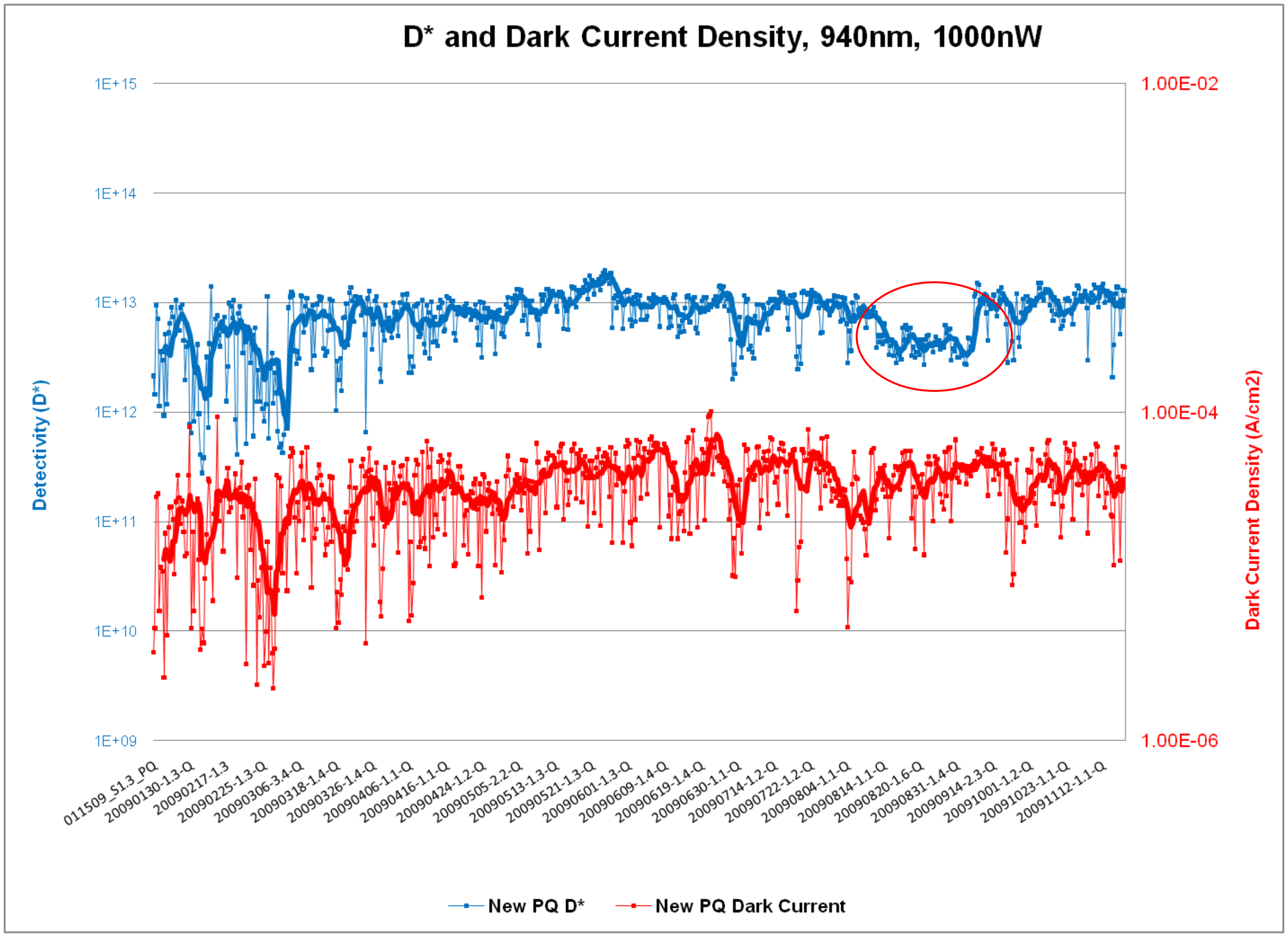

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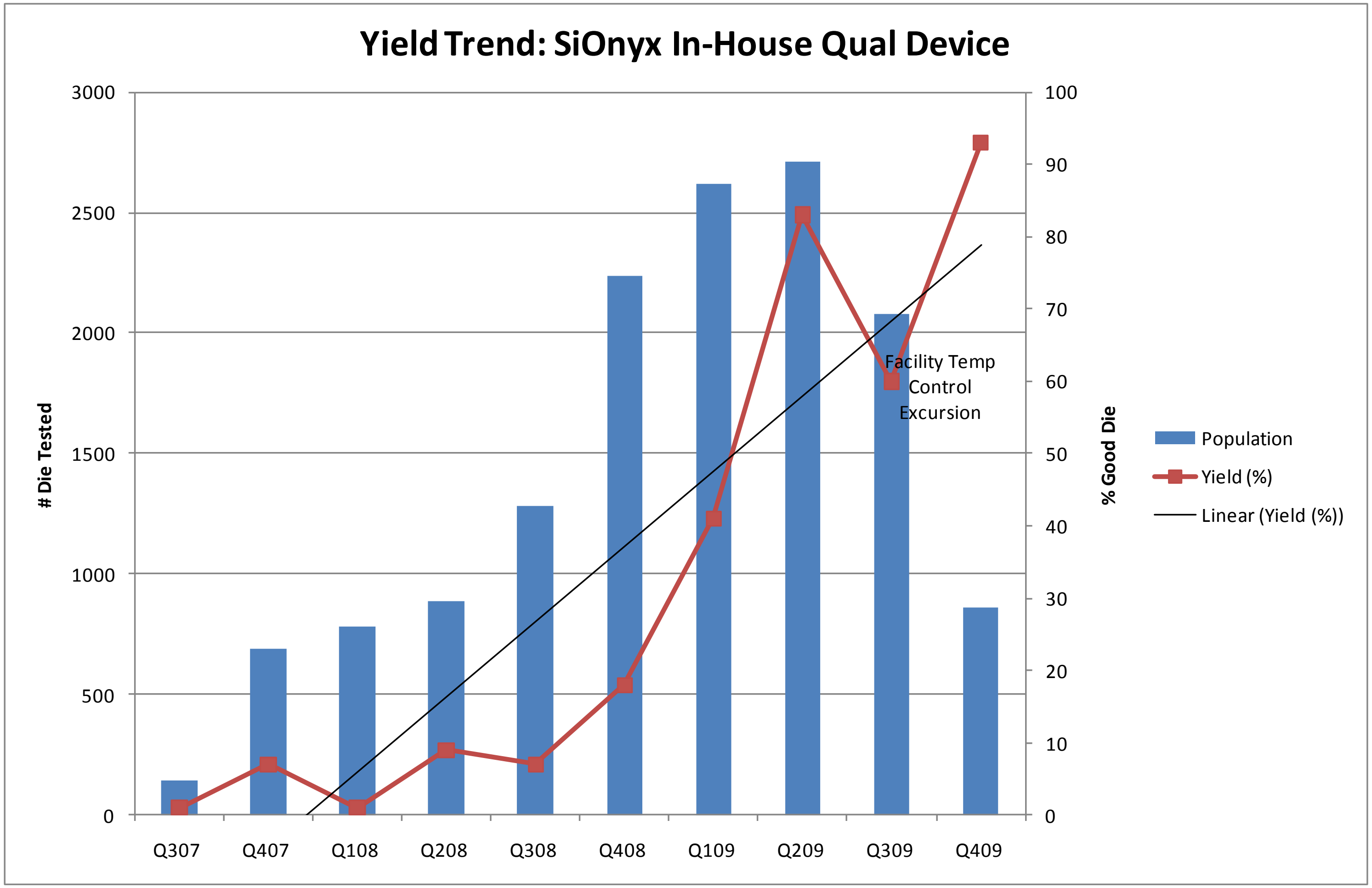
Transition example - trended device performance



Stepping up to manufacturing maturity

- often hard to understand the benefits for an early process
  - increased expense
  - "we need to finish development on a smaller scale"

- increased speed of learning is invaluable

- need to know your limitations early
  - process integration challenges
  - 90 percent of your development challenges are ahead of you

- getting into the true manufacturing environment will illuminate your strengths and weaknesses

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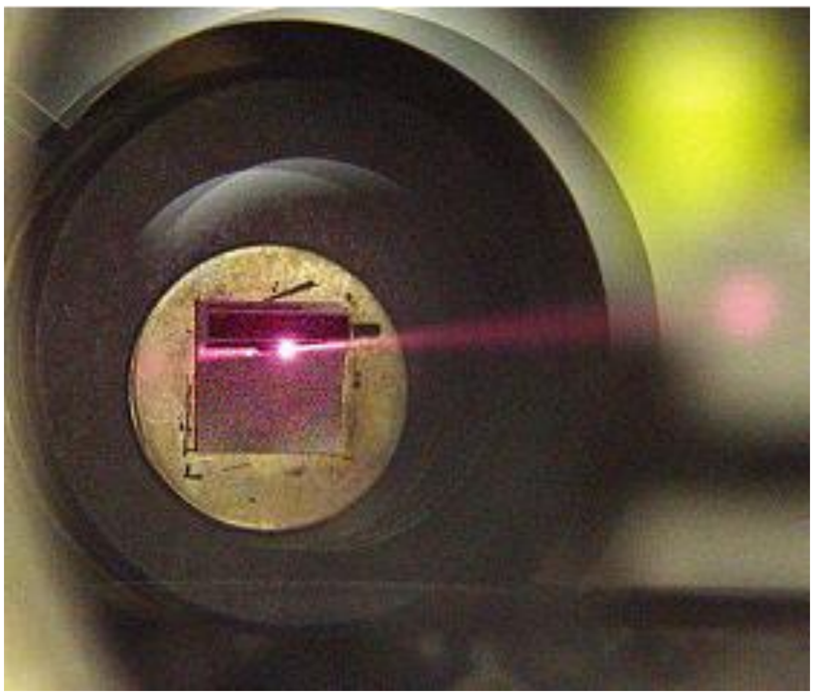
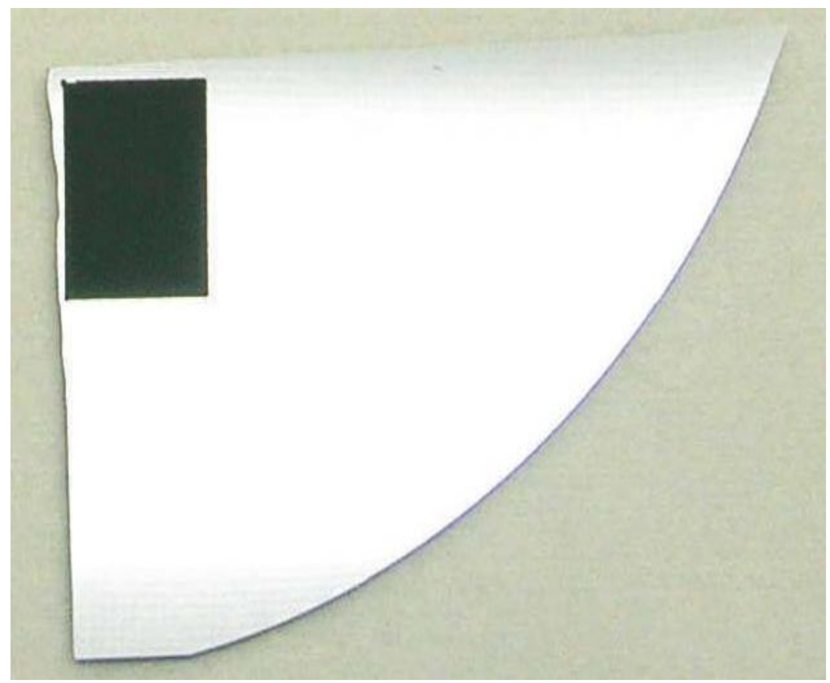
SiOnyx beginnings and black silicon

- femtosecond laser processing of silicon (Harvard)
  - enhanced and extended absorption
  - doping with ambient chemical species





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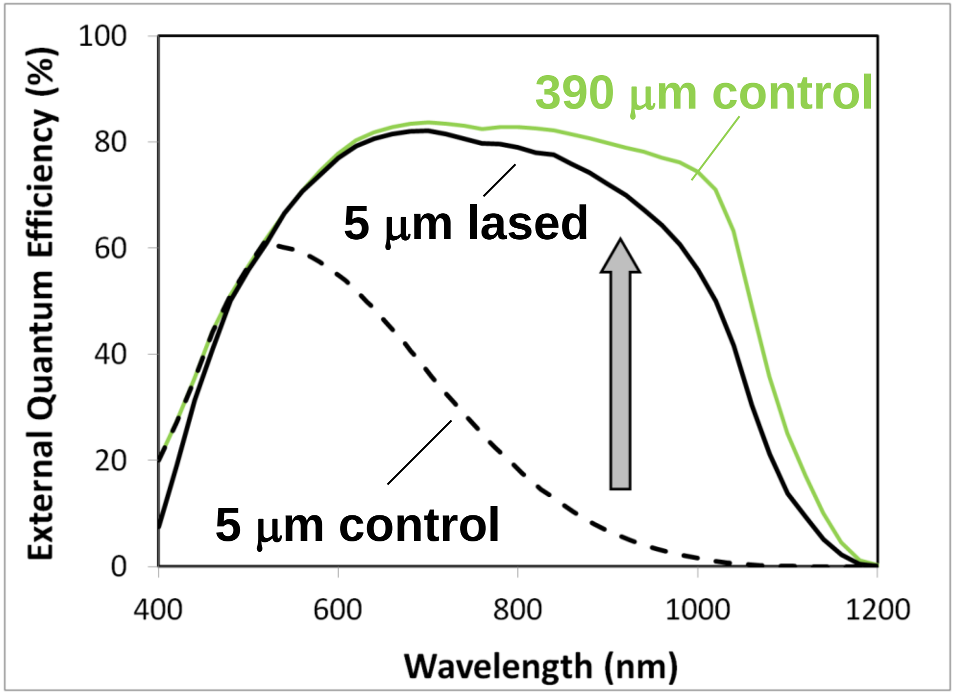
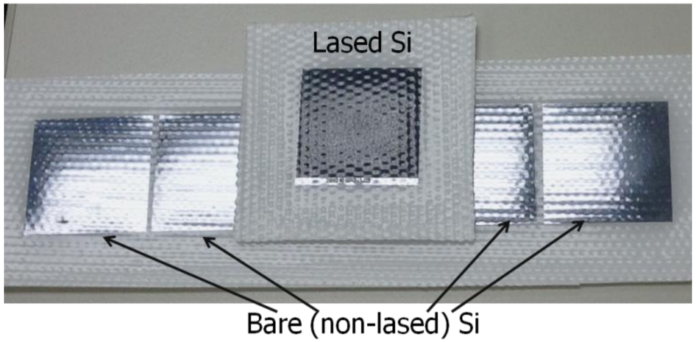
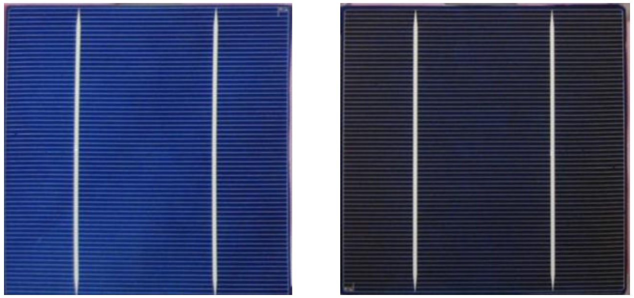
SiOnyx technology

QE Boost in Crystalline Si



Lower Reflectance





Standard cell

Laser textured

- improves QE, not just absorptance
  - outstanding light trapping and ability to usefully extract carriers
  - make very thin Si (cheap, fast response time, low noise) appear optically thick
- dramatically reduce surface reflectance to couple more light in
  - minimal material removal and shallow topography, critical for thin Si devices
  - independent of crystal orientation

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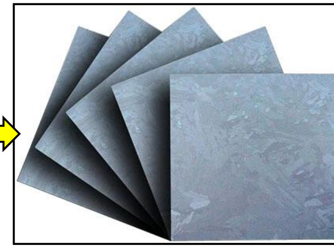
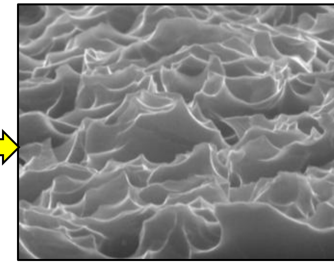
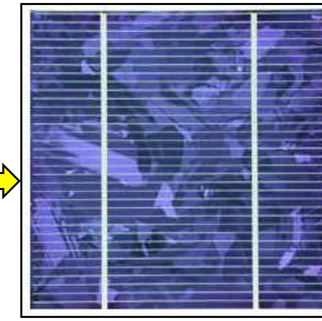
Multicrystalline Si PV Cell Process Flow







Poly-Si
- Raw material
- Melted to form ingot

Bricking
- Ingot is sliced into bricks (156 mm)

Wafering
- Bricks are sliced into individual wafers

Texturing
- Chemical saw damage removal and surface texturing

Cell Processing
- Remaining steps (emitter, ARC, metal, etc.)

- silicon PV wafers require surface texture for good light absorption
- multicrystalline PV wafers combine saw damage removal and surface texturing steps = “isotexture”
  - HF/HNO_3-based etch that forms texture as it etches saw damage
  - process is not optimized for either step: leaves some residual saw damage (lowers efficiency) and texture reflectance is not good (high)
  - isotropic etch required due to multiple crystal grain orientations
- better solution: separate saw damage removal (etch) and texture (laser)

Benefits of laser texture

	Isotexture	Alkaline texture	SiOnyx laser texture
Decouple saw damage removal and texture processes to maximize V_{oc} and J_{sc}?	**Not separable**	✓	✓
Low reflectance?	**22+% refl. pre-ARC**	✓	✓
Fast / inline?	✓	**Too slow for inline**	✓
Robust features, <1 μm height?	**Deep saw damage holes**	**Pyramids 3-10 μm**	✓
Consume <2 μm of Si to form texture?	**Consumes 4+ μm**	**Consumes 10+ μm**	✓
Independent of grain orientation?	✓	**Only suitable for (001) surfaces**	✓

- open-air, high-throughput ultrashort pulse laser process
- compatible with p-type and n-type Si
- complementary to all other efficiency boosts (selective emitter, advanced metal pastes, backside passivation / local contacts, etc.)
- superior light trapping enables thinner wafers with high efficiency
- minimal material removal – key for ultra-thin films

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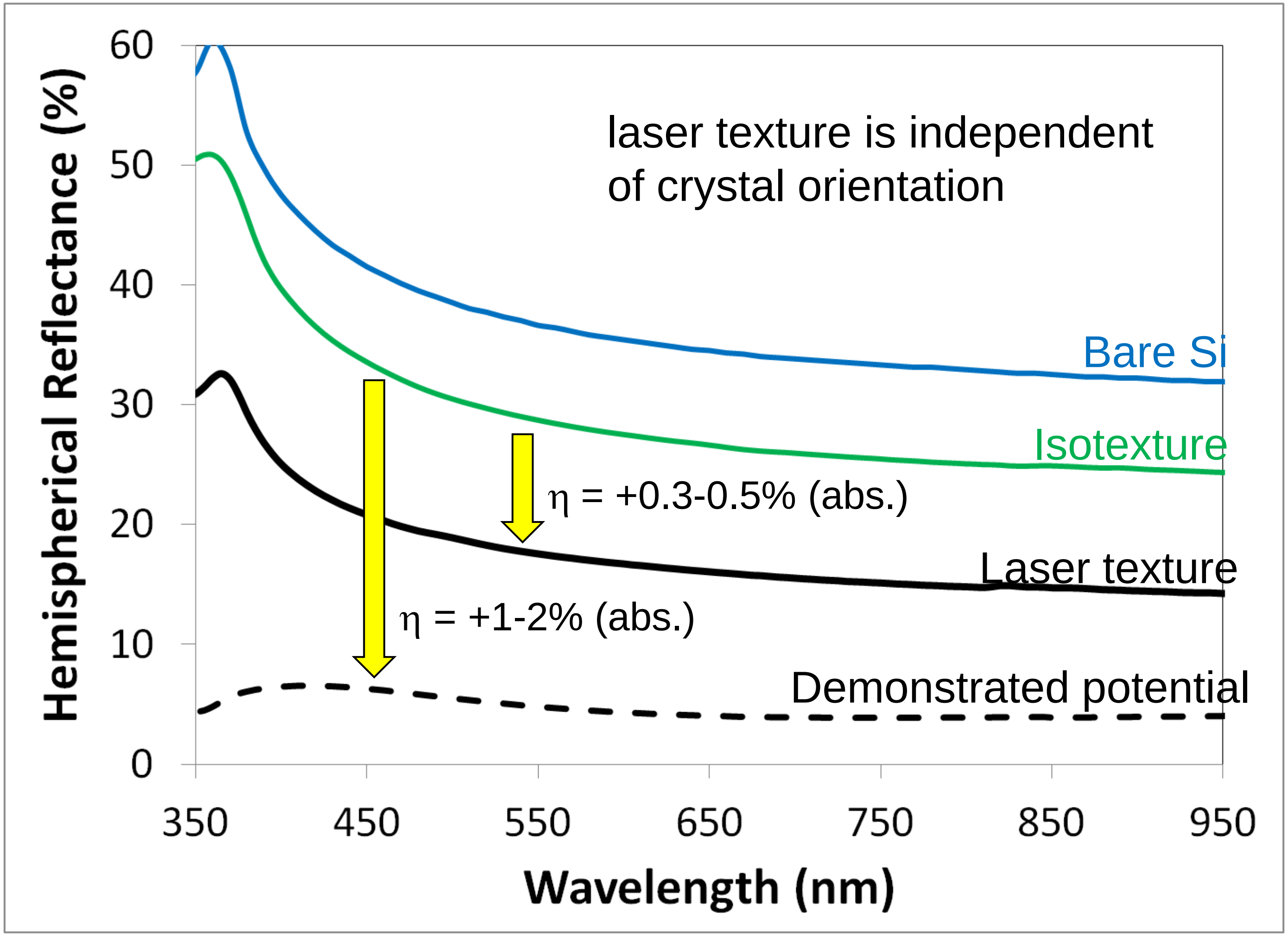
Spectral reflectance



- lower surface reflectance boosts PV cell current and efficiency

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Enhanced thin layer quantum efficiency

- silicon is an indirect bandgap semiconductor
  - necessitates a thick layer for absorption of NIR wavelengths

- thin, flexible or BIPV applications enabled with high efficiency
  - reduced material costs, weight, balance of system costs

- monolithic silicon sensors have low response at wavelengths greater than 850 nm (CMOS or CCD)
  - device layer is typically thin epi layer (< 10 um)
  - pixel designs limit applied bias and depletion width
    - thicker layers are difficult to deplete
    - electrical cross talk increases with thickness
  - hybrid solutions cannot take advantage of 4T architectures
    - leads to higher dark current

black silicon imagers – security and DoD apps

- image sensor in typical security/surveillence conditions
  - black silicon enhanced QE provides 4x SNR in NIR

standard CMOS

SiOnyx imager

Summary – Thank you!

- SiOnyx has been able to grow with VC funding AND organic growth with government funding in PV

- PV ante is huge
  - > $200M to get started with a run-of-the-mill multicrystalline fab
  - margins are extremely difficult to come by
  - if you are startup minded – not so bad to target a smaller company

- successful alternative technology companies are “old” by startup standards
  - First solar was doing CdTe in the 80’s – used to be a glass company

- however
  - market is still growing and is not going to go away
    - socially or economically
  - current market dynamics driving consolidation are healthy
  - differentiation is hard to come by and will be valued in a mature market
  - you never know…

- stay motivated and involved and take the long-view