KERF-FREE WAFERING: TECHNOLOGY OVERVIEW

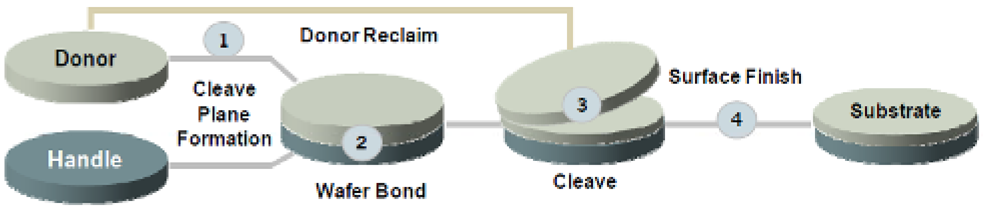
Adam A. Brailove, Ph.D.
Silicon Genesis Corporation
San Jose, California, USA

Outline

- About Silicon Genesis (SiGen)
- PV Market and Limits of Current Technology
- PolyMax™ Kerf-less Wafering Technology
- Manufacturing Equipment
- Material Characteristics of PolyMax™
- Conclusions

About Silicon Genesis

- **Founded in 1997**
- **Developed Layer-Transfer process and manufacturing equipment for semiconductor (SOI) and opto-electronic/display markets (SOQ)**

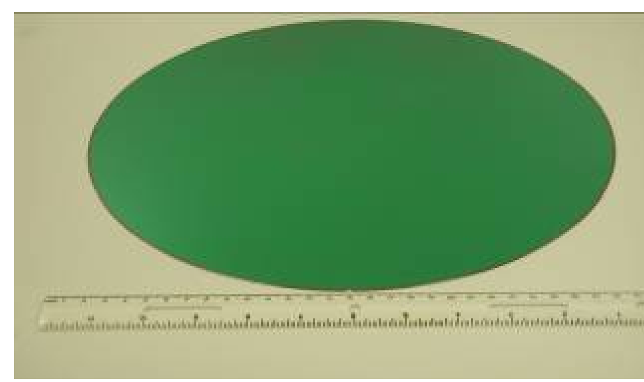


Plasma-Bond System

Cleave System

- **Recently focused technology on developing *PolyMax*™ system for solar wafering**

150mm Silicon-On-Quartz

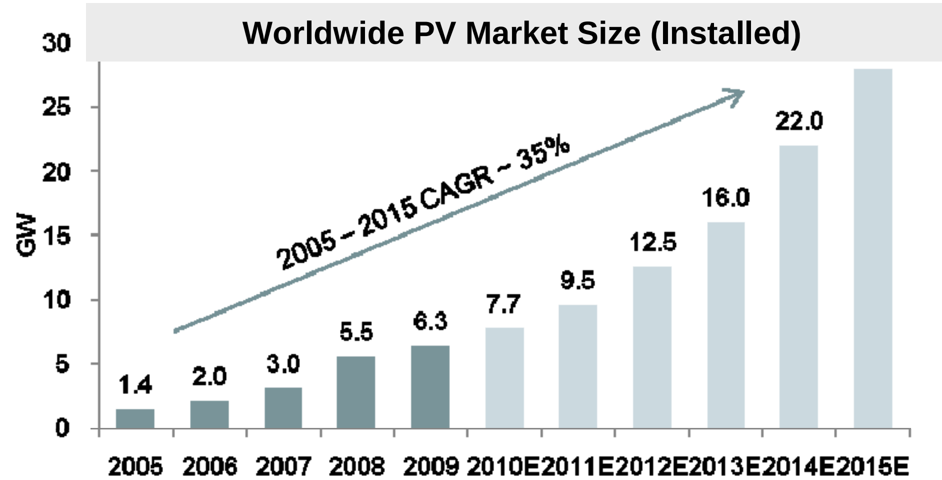


300mm 100nm SOI

Increasing Demand – PV Equipment

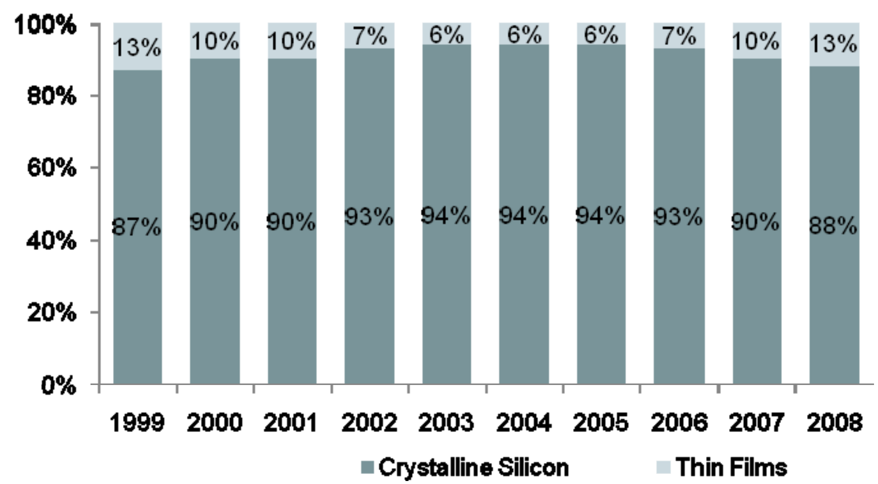
Solar installations are expected to continue to grow by 28% over the next five years

- This increase will continue driving demand for solar wafering equipment
  - Wafer capacity expected to expand by 5GW – 7.5GW per year for the next three years
- Federal RPS legislation is expected to increase demand for solar energy



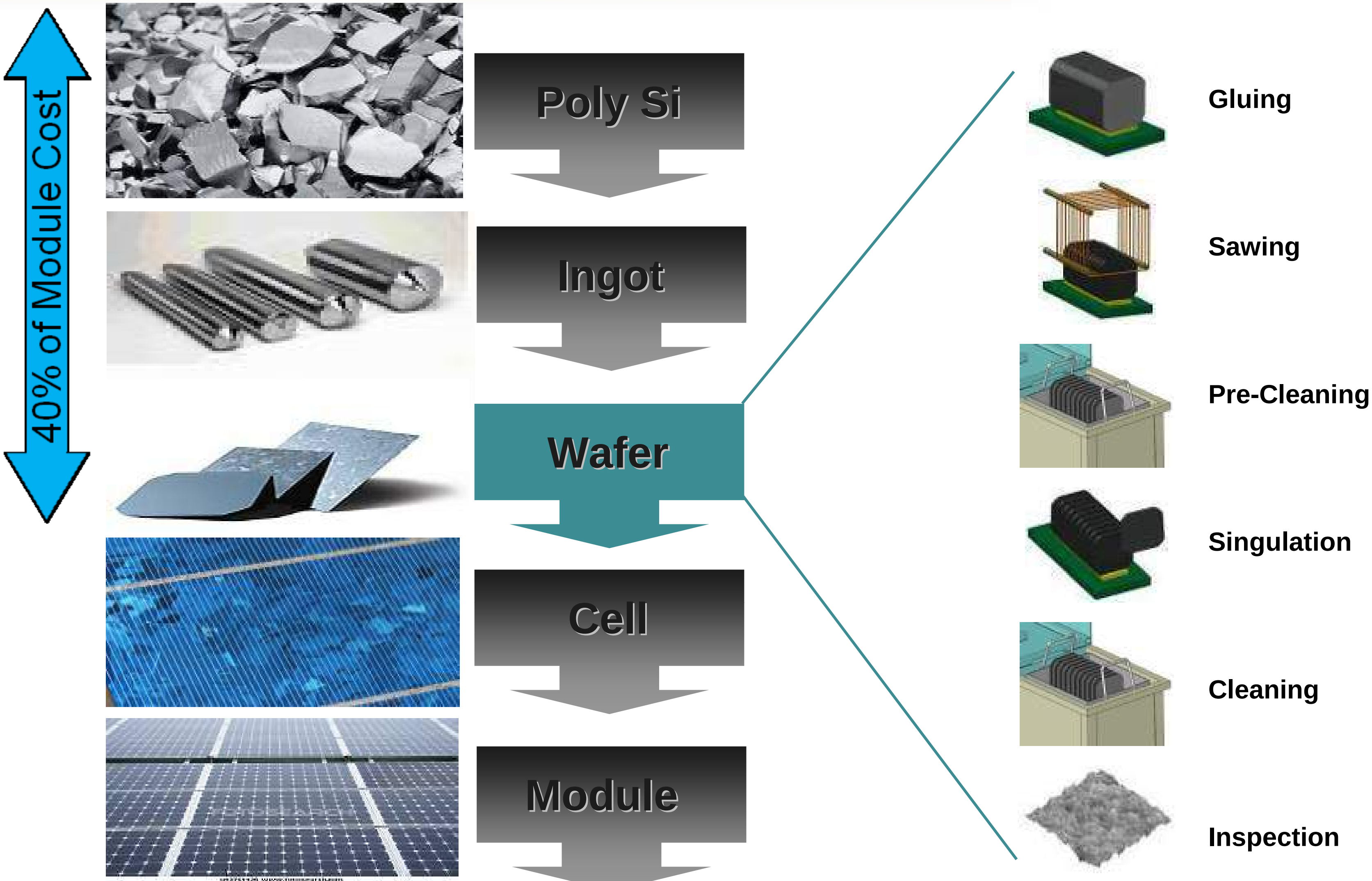
Crystalline silicon is the dominant solar technology representing ~90% of the market

- Achieve higher efficiencies from 15% to 20%+
- Lower risks and therefore higher bankability
- Thin film technology, though having an attractive cost structure, faces efficiency and scaling challenges
- Alternative solar technologies are many years away from gaining any significant market share



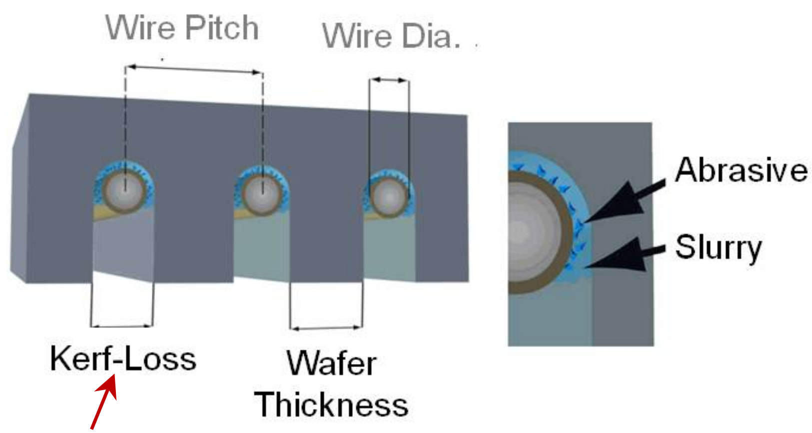
Source: Solar Vision Consulting, EUPD Research, Navigant, Photon International.

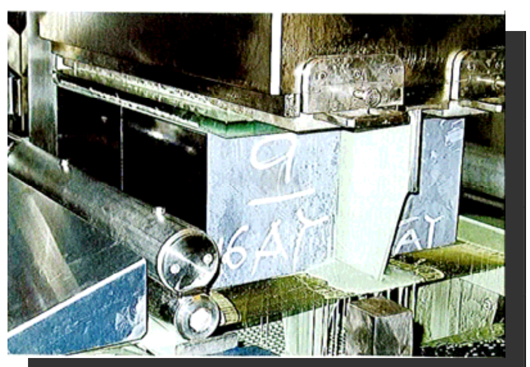
c-Si PV Value Chain



Wafering: Multi-Wire Sawing

Meyer Burger DS 271 Wire Saw





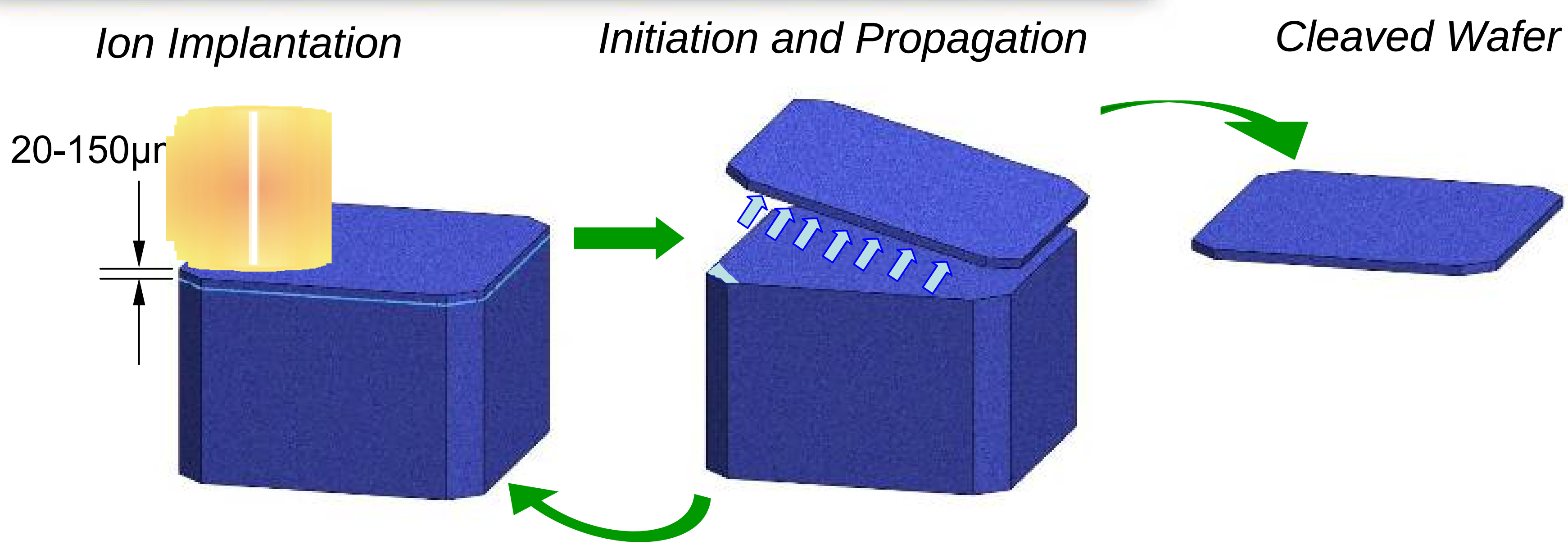
Source: Photon International

- Multiple parallel fine steel wires drawn across ingot at high speed
- SiC abrasive slurry entrained
- Slowly abrades through silicon

Limits of Wire-Saw Technology

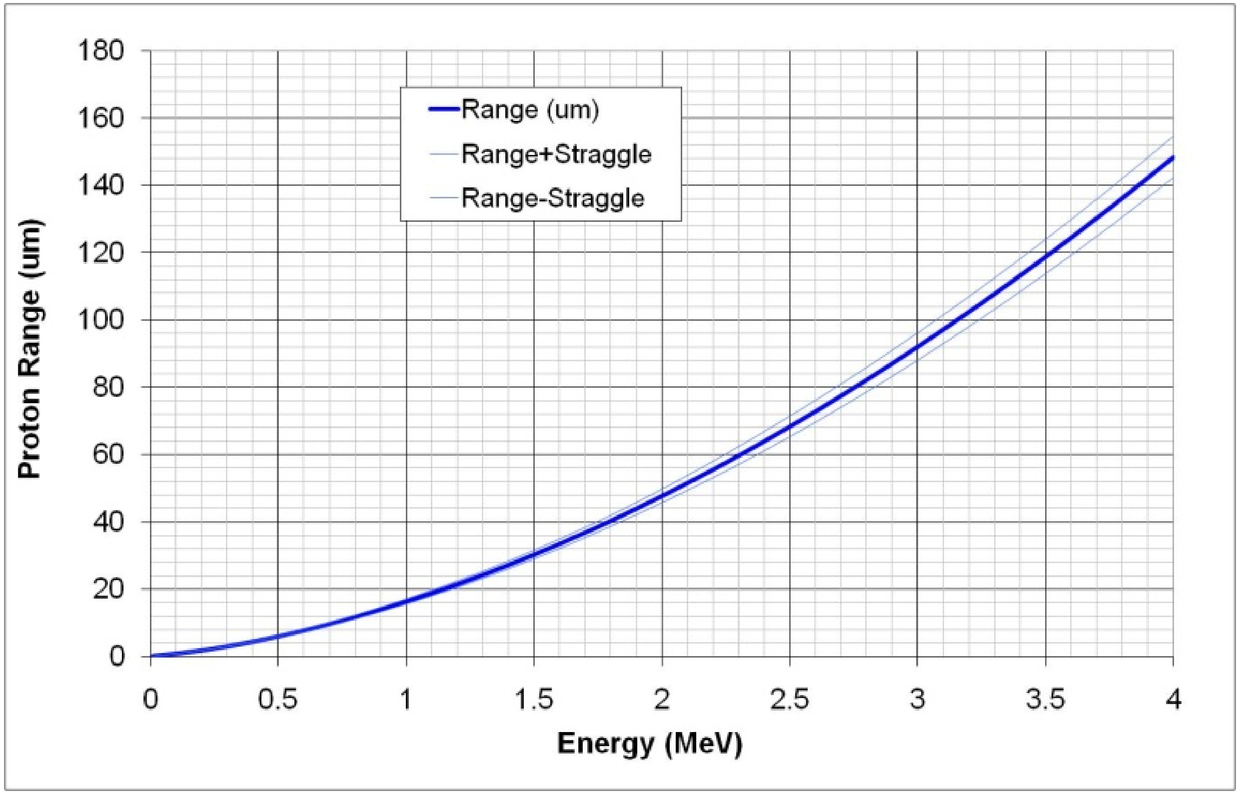
- Cost
  - Kerf-loss currently consumes > 50% of polysilicon
  - Silicon is turned into ‘sawdust’ mixed with abrasive slurry
  - Silicon recovery from slurry is costly, complex
  - Cost of wire, slurry and slurry production/recycle facility
  - Cost of ingot puller capacity to produce silicon lost to kerf
  - Cost of wafer washing and wet singulation
- Wafer Thickness Reduction
  - Need thinner wafers & more efficient silicon usage
  - Sawing is a rough mechanical process
  - Obviously not well suited for micron scale layers of silicon
  - Industry encountering difficulty scaling down wire-sawn wafer thickness
  - Saw damage/micro-cracks increases probability of wafer breakage
  - Tradeoff: thinner = slower cutting speed
  - Thickness variation, wafer to wafer variability → wafer binning
  - → No roadmap to < 100 micron thicknesses

SiGen's Novel Solution: PolyMax™



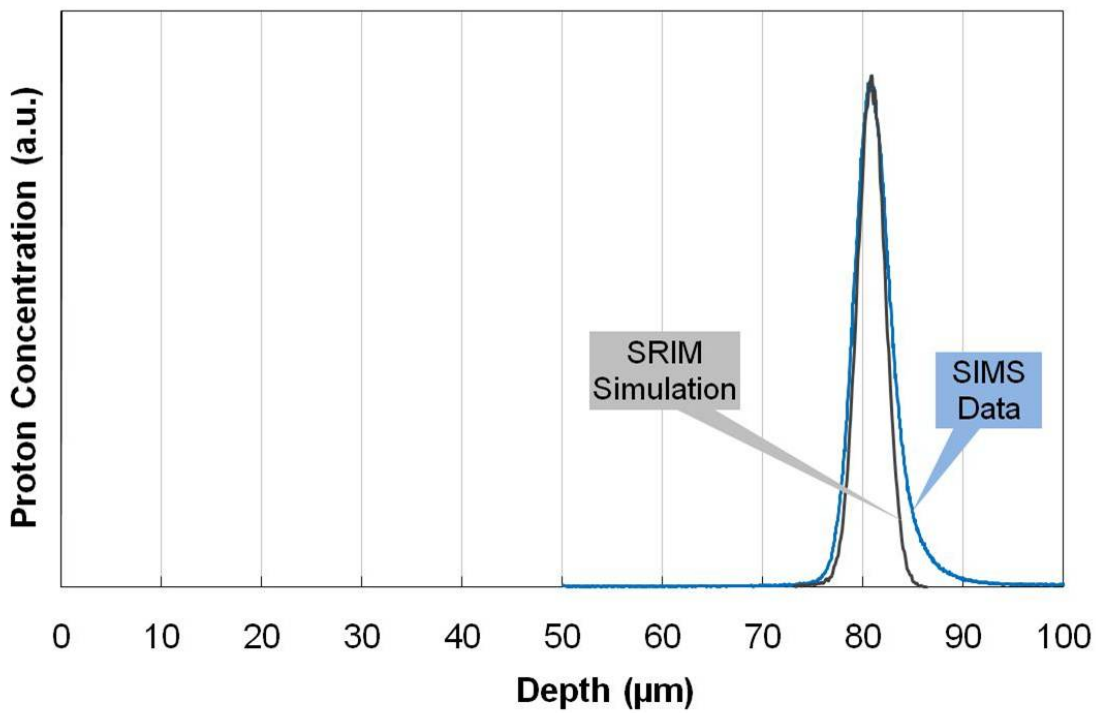
- A two-step process:
  1. Implant light ions into c-Si shaped brick
     - Form sub-surface cleave layer
     - Implant small initiation area with higher dose
  2. Controlled Cleave with energy beam
     - Initiate cleave in high dose area
     - Propagate crack across brick area to release wafer
- Repeat on newly exposed brick surface

Proton Range in Silicon



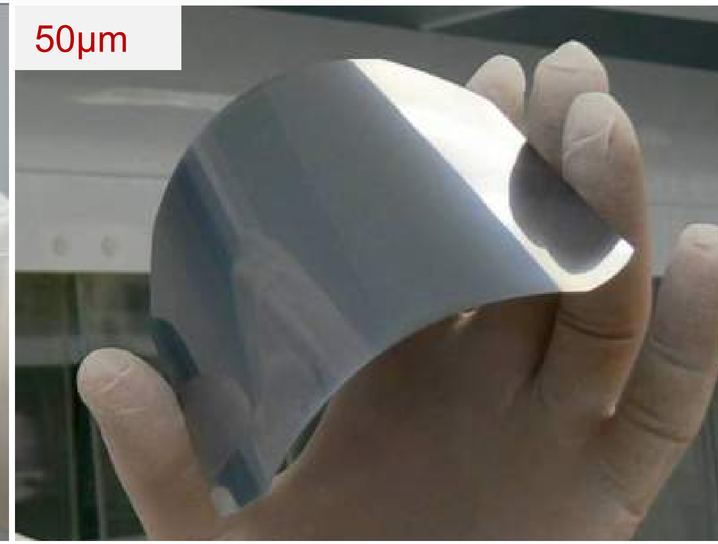
- 'Range' = average proton depth
- Proton energy sets wafer thickness
- 'Straggle' = variation in depth
- *Straggle scales down with lower energies, thinner wafers.*

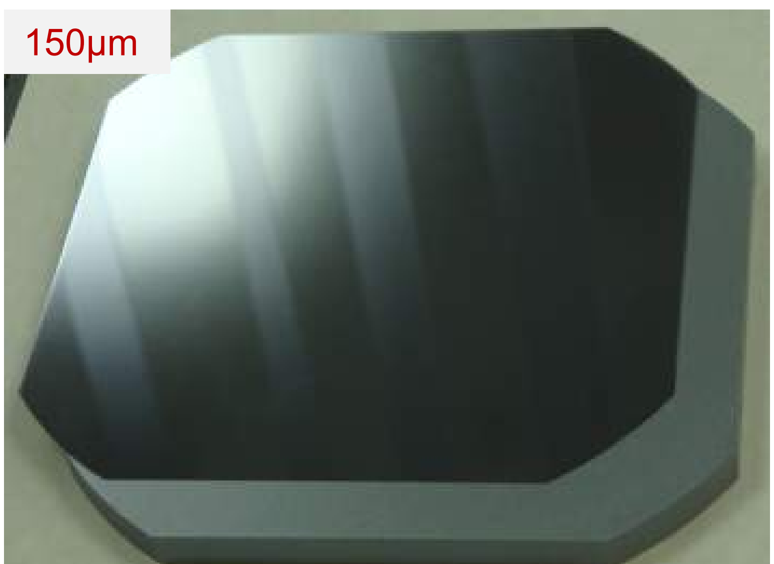
Typical Depth Profile



- Depth distribution is very narrow compared to depth
- Actual SIMS measurements agree well with SRIM simulations
- Depth (wafer thickness) is determined by highly repeatable physics
- Not determined by mechanical precision, as in sawing

PolyMax™ Wafers and Foils

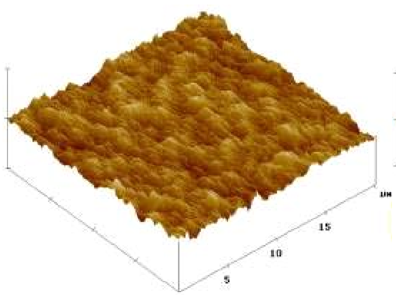




- Demonstrated kerf-less wafering
- Wide range of wafer thickness produced
- Proton energies: 1.1-4 MeV
- 20, 50, 85, 120, 150 microns
- 125 mm and 156 mm pseudo-squares
- High R&D yields
- No apparent problems due to progressive slicing
- <111> crystalline silicon

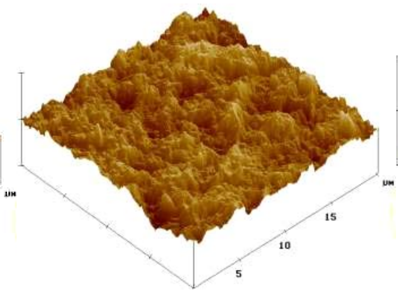
PolyMax™ SEM & AFM Results

X 5.00 µm/div
Z 1000.00 nm/div



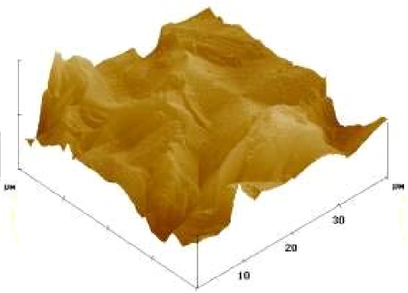
PolyMax™ 20µm thick wafer
RMS 59.1nm
Z range: 493.1nm

X 5.00 µm/div
Z 1000.00 nm/div

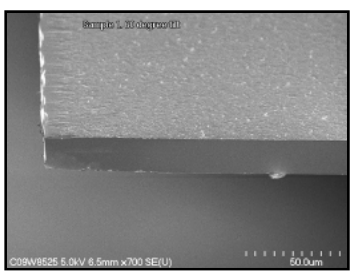


PolyMax™ 50µm thick wafer
RMS 97.6nm
Z range: 796.3nm

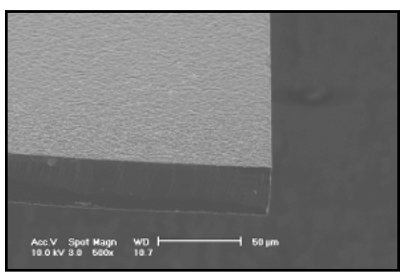
X 10.00 µm/div
Z 2000.00 nm/div



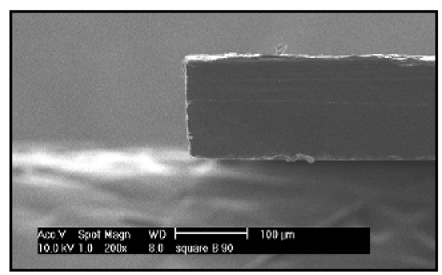
PolyMax™ 150µm thick wafer
RMS 386.8nm
Z range: 3.2µm



20um



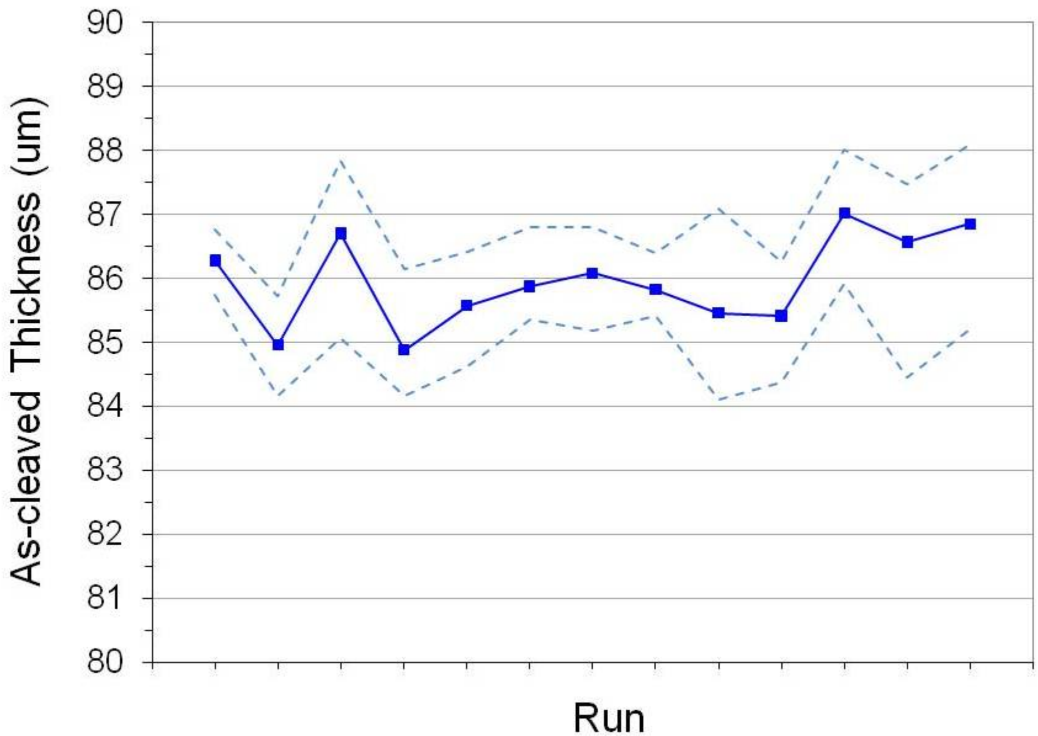
50um



150um

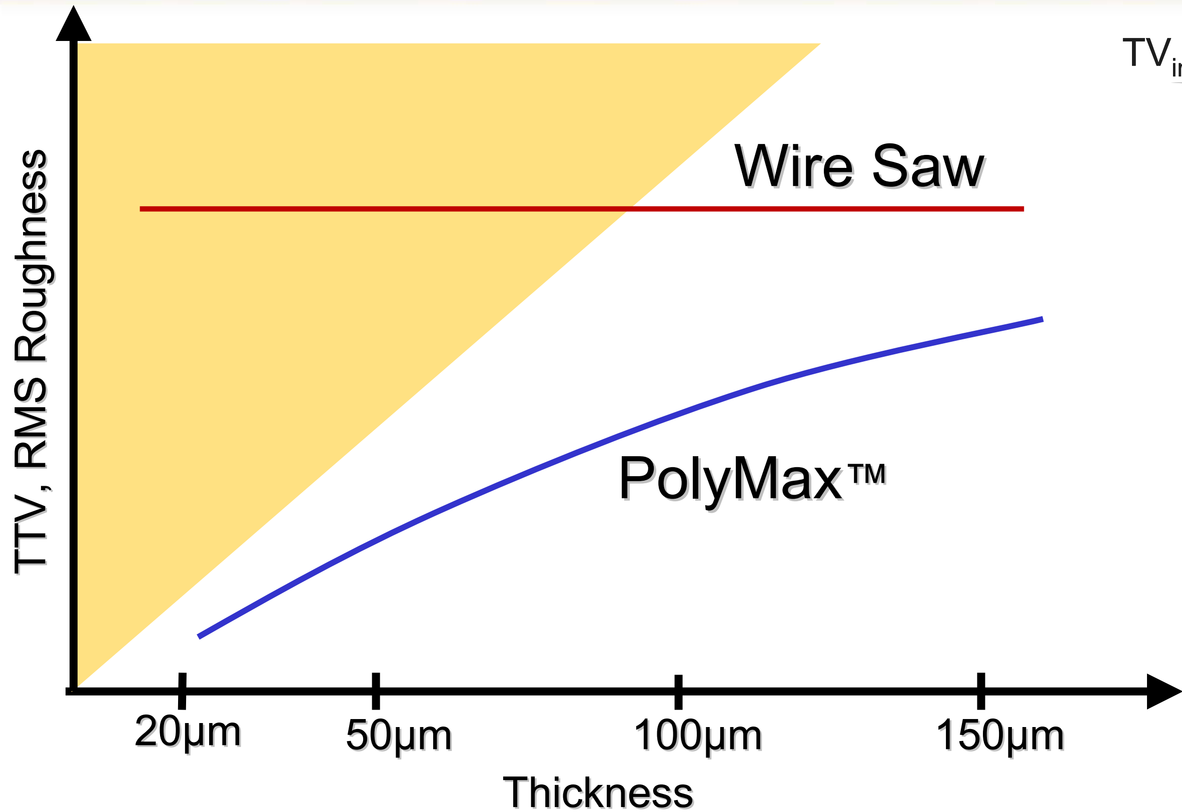
- Roughness scales down with thinner wafers
- Scaling is visually observable with naked eye
- SEM and AFM confirm
- No micro-scratches as in sawn wafers.

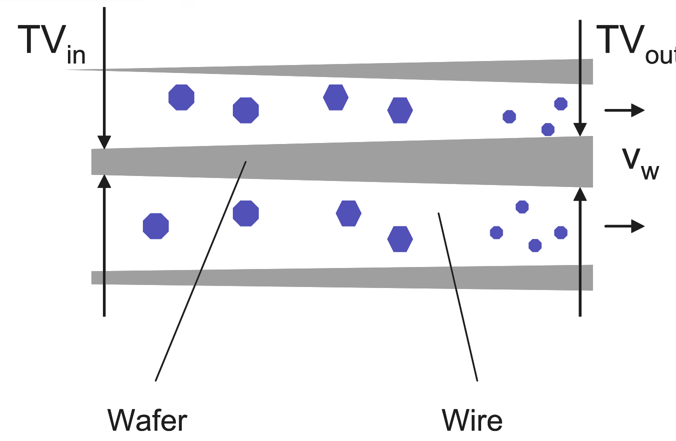
Wafer Thickness



- Wafer thickness distribution is very tight
- 9-points measured per wafer. Avg, Max, Min shown
- Wafer-to-wafer ~ +/- 1μm
- Within wafer ~ +/- 1μm
- 10x-20x better than wire saw

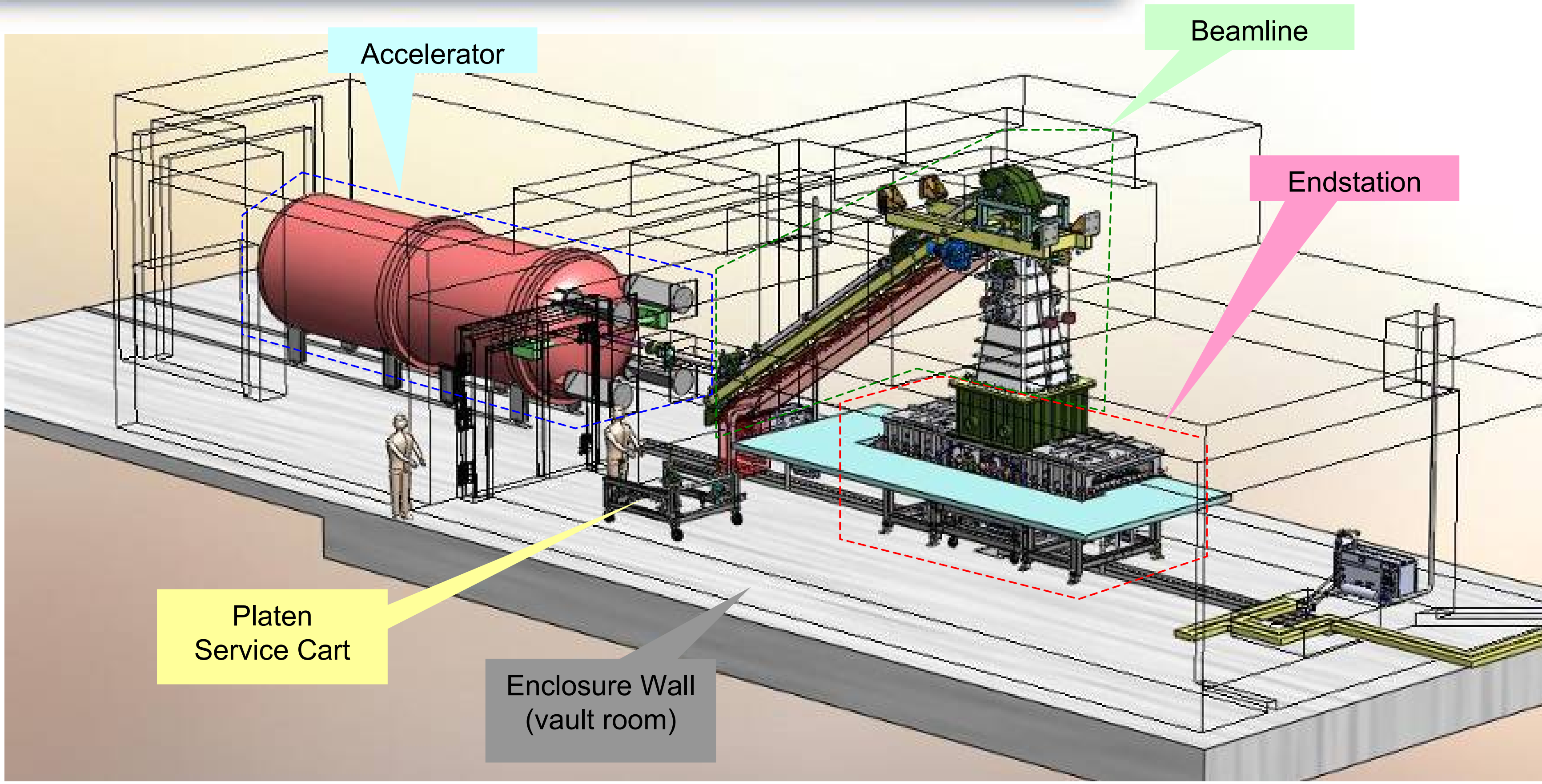
Scalability to Thin Wafers





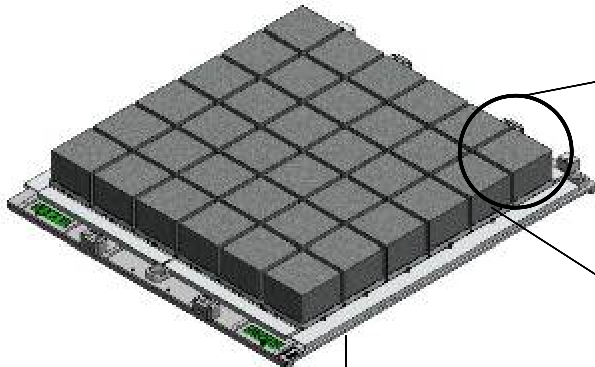
- Wire saw process has thickness variations and roughness driven by mechanical effects. Eg. Wire wear, grit size
  - Variations do not scale down. Limits minimum thickness of wafer
- PolyMax thickness variations and roughness driven by physics
  - Variations scale down. Enables roadmap to thin wafers

Equipment – Alpha Implanter

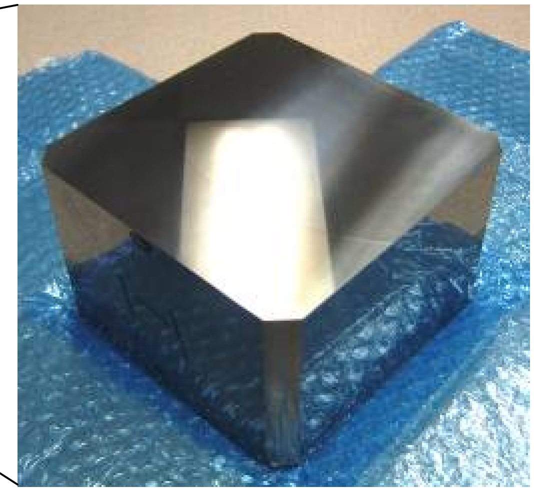


- 3 major components: Accelerator, Beamline, Endstation
- 4MeV (150 um) max energy
- Enclosure (vault room) constructed of standard concrete. Shields prompt gammas.
- Designed for Serviceability: Cart, Horn, Accelerator
- Currently operating at SiGen facility, San Jose

Brick Transport Tray



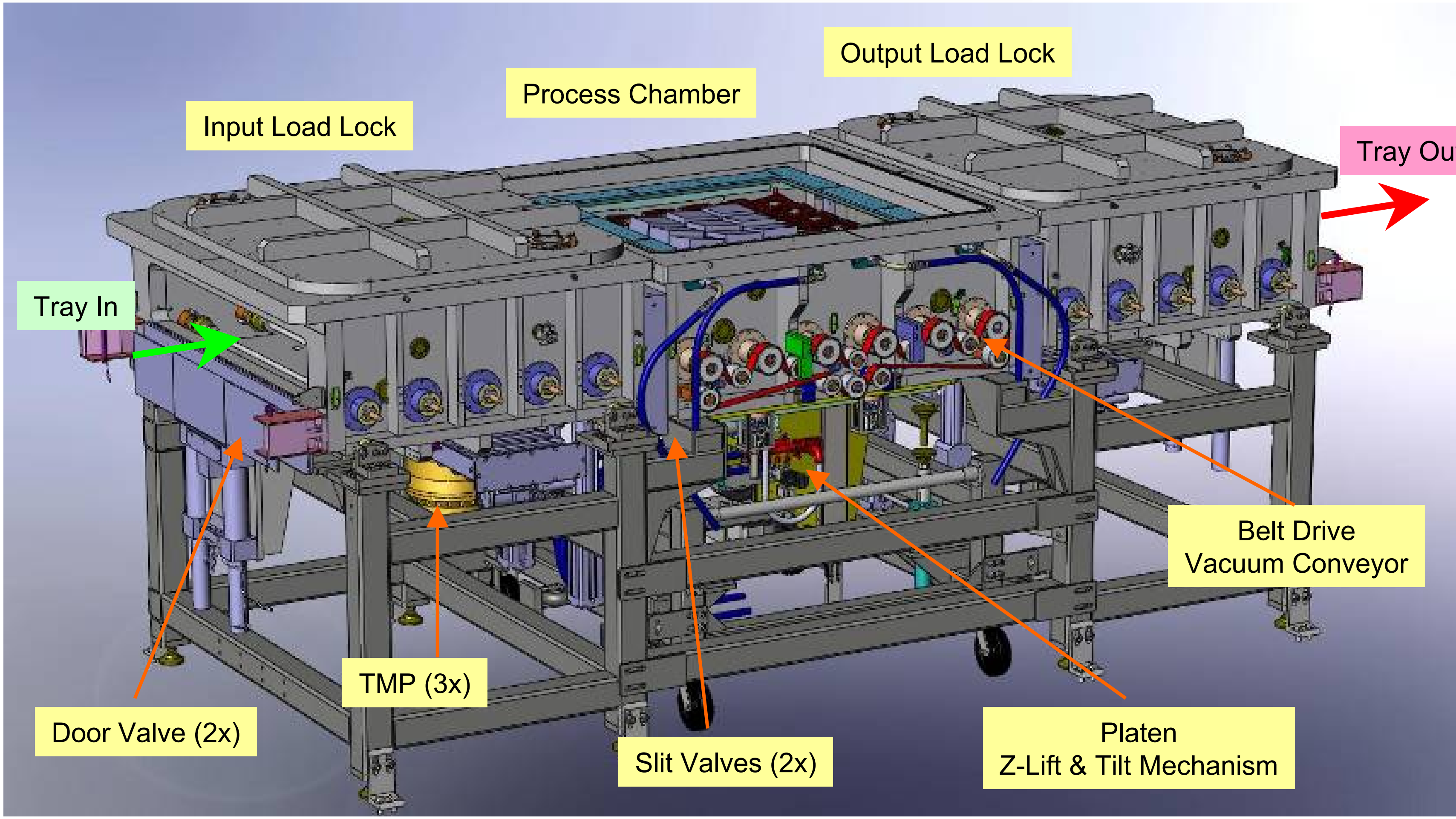
Silicon brick



Tray

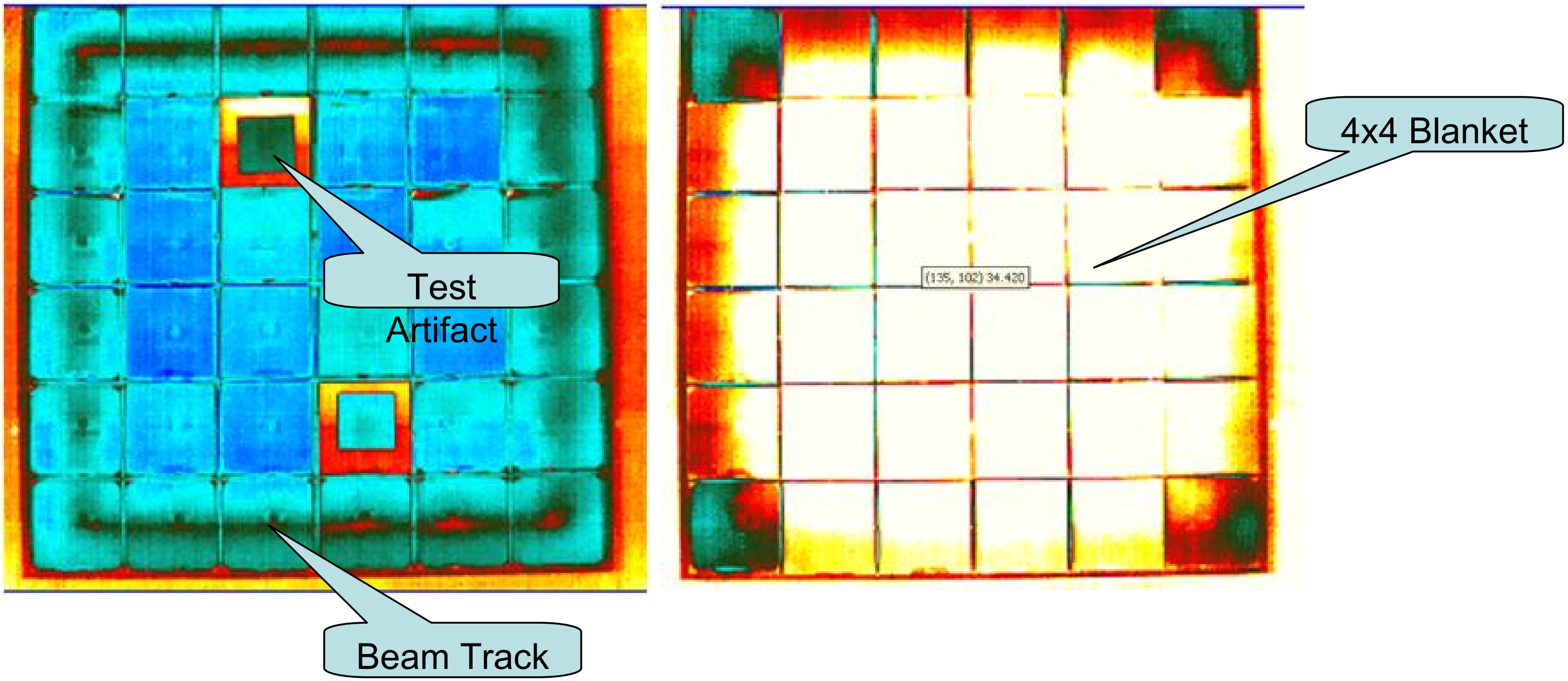
- Aluminum brick transport tray
- 36 bricks per tray (156 mm size)
- 100 mm max brick thickness

Endstation



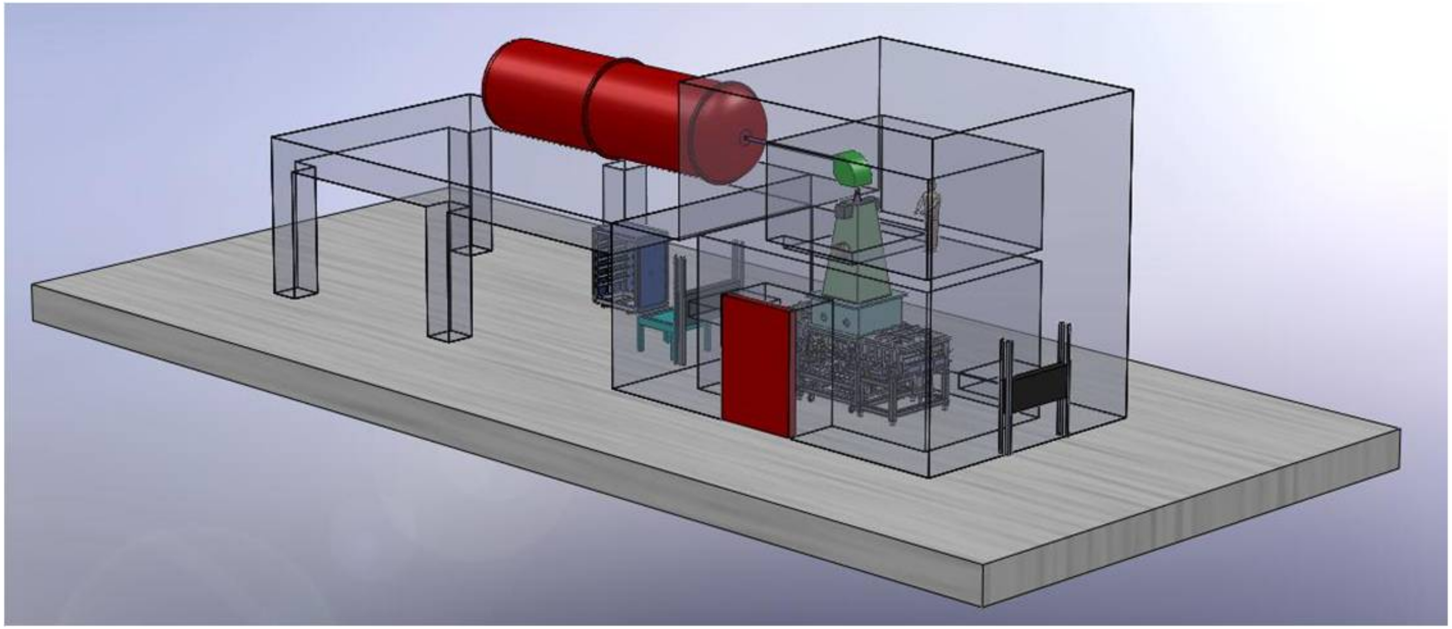
- Pipelined, In-line system
- Dual high speed load locks
- Proprietary brick clamping and cooling system to handle high beam power

2D Magnetically-Scanned Beam



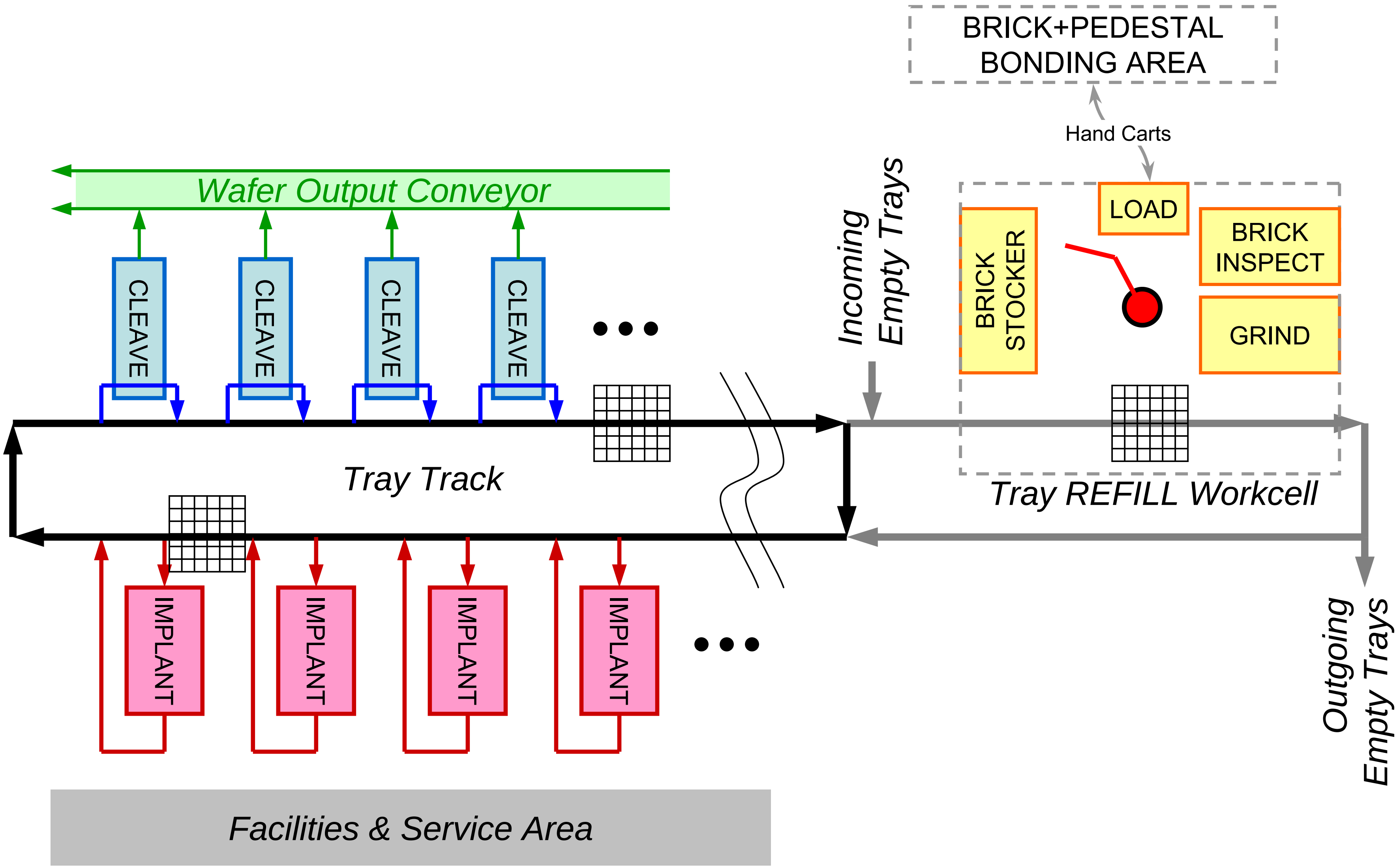
- IR camera images of system *under test*
- High speed scanning
- 2D patterning of dose and thermal budget
- Put high proton doses *only where needed for crack initiation*

PolyMax 2nd Generation Tool

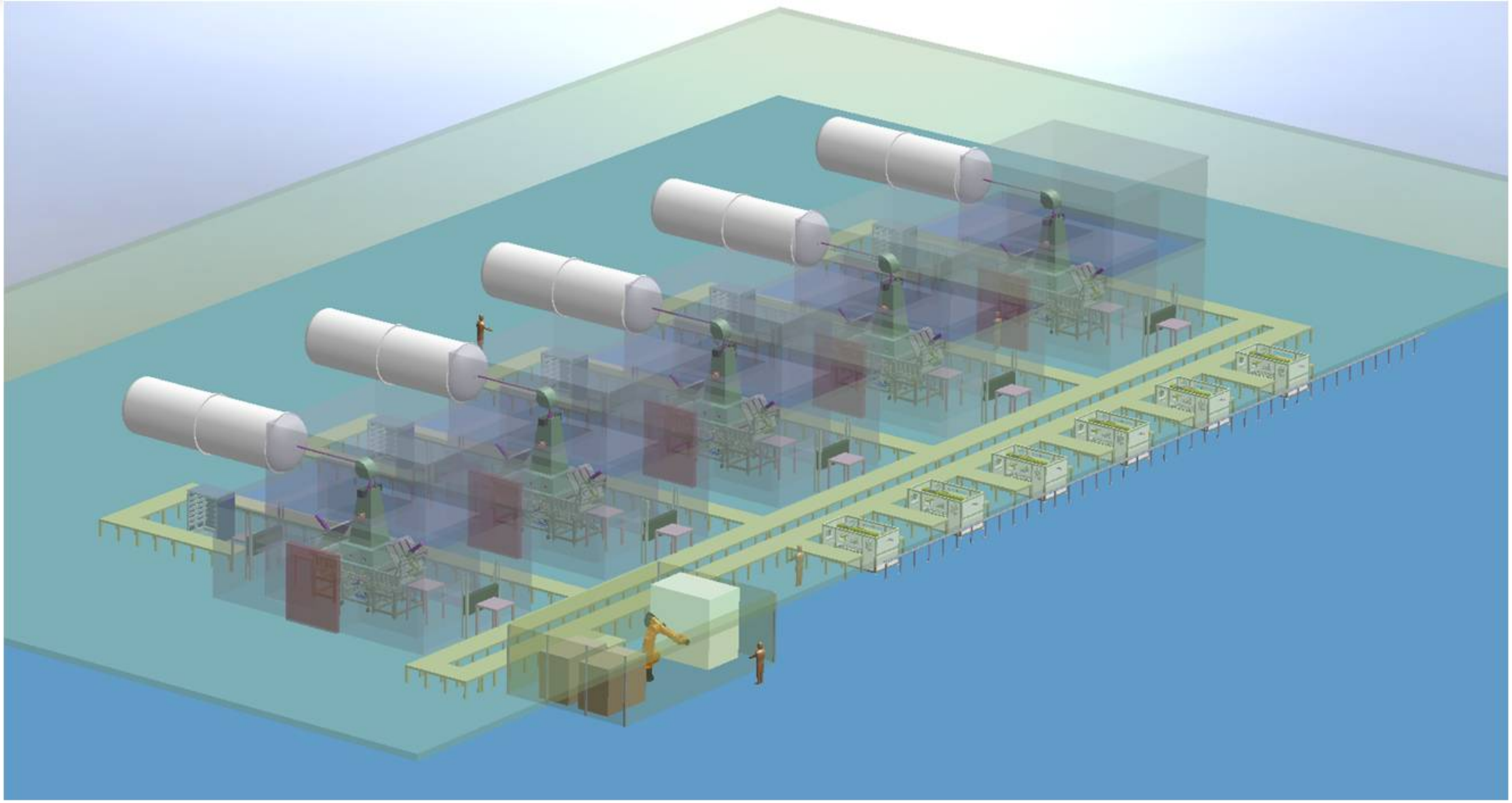


- More compact production implanter tool design
- Two floors
- Short beamline
- Less concrete

PolyMax Manufacturing Layout

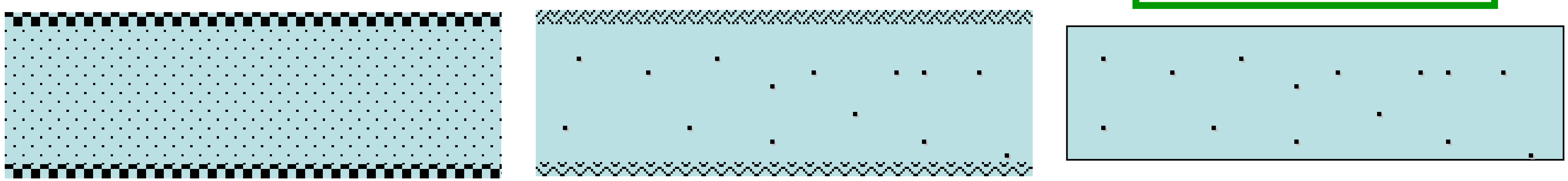


PolyMax Manufacturing Plant



Effective Lifetime Recovery

<10 µsec → 150-300 µsec Typical



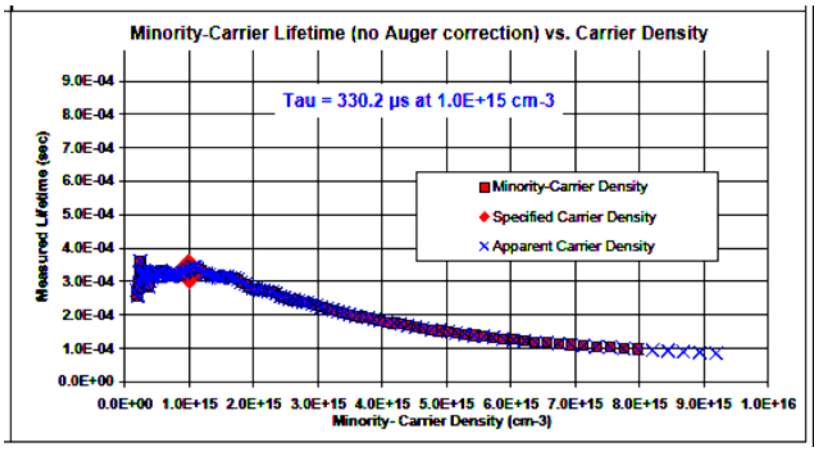
As-Cleaved Wafer
Bulk defects + End-of range damage

Post-Implant Anneal ~ 400-800 C
Crystal bulk defects healed

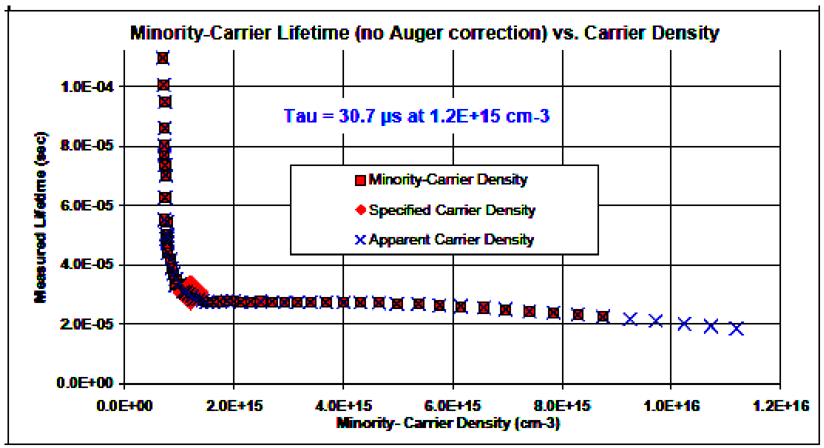
Etch ~ 5-10% per side
EOR surface damage removed

Minority Carrier Lifetime Recovery Processes
Is Similar to Standard Cell Process

Recovered Lifetime Raw Data



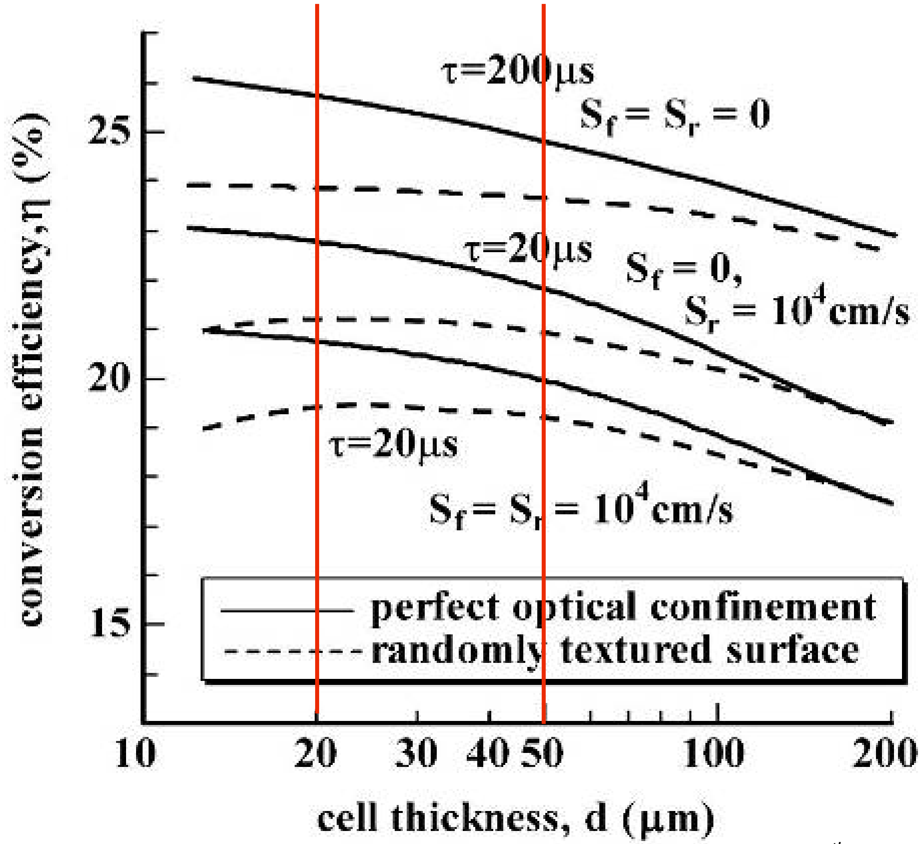
Effective lifetime (35µm PolyMax™ wafer)



Effective lifetime (17µm PolyMax™ foil)

- Sinton WCT120 system
- QSS (Quasi Steady State) measurement mode
- Chemical passivation

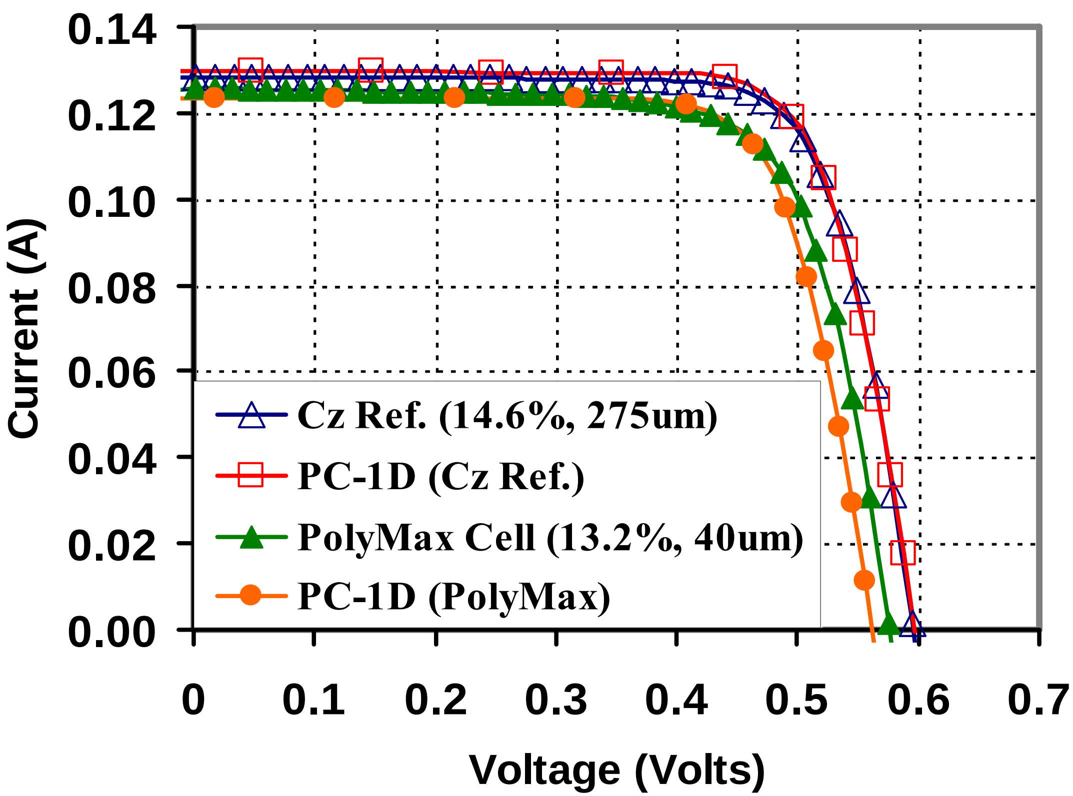
Cell Thickness and Cell Efficiency



Hayashi et al, *Proceedings of the 10th European Photovoltaic Solar Energy Conference*

- With >20us bulk lifetime, 20-50um cells can achieve over 20% conversion efficiency
  - Front and back surface recombination are low
  - Optical confinement must be optimized

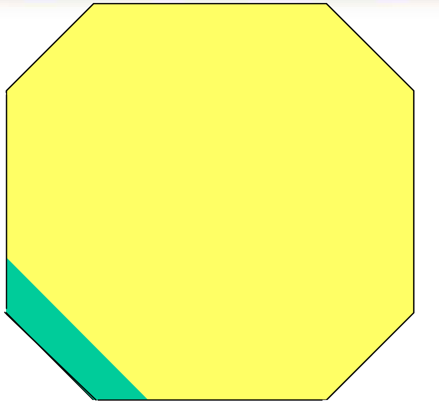
PV Test Cell Efficiency



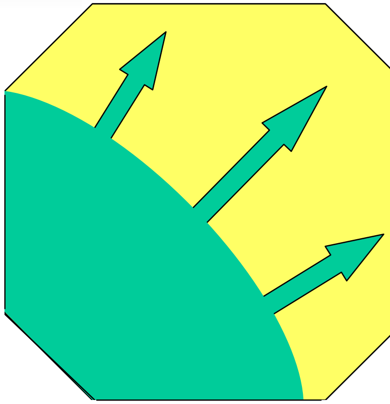
PolyMax™ 50µm and CZ reference cell efficiency test

- Georgia Tech
  - Preliminary effort at thin cell fabrication in the lab
  - 40 um thickness
  - Non-optimized: No texturing, light trapping etc.
  - Results very close PC-1D simulations
- Major PV manufacturer
  - Initial run of SiGen thin wafers in production line
  - Non-optimized cell process
  - Performance similar to thinned wafers

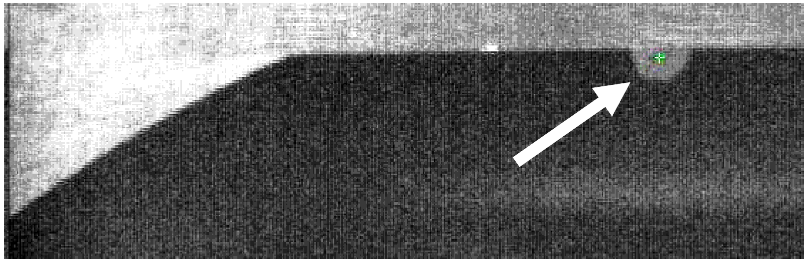
Controlled Initiation and Propagation



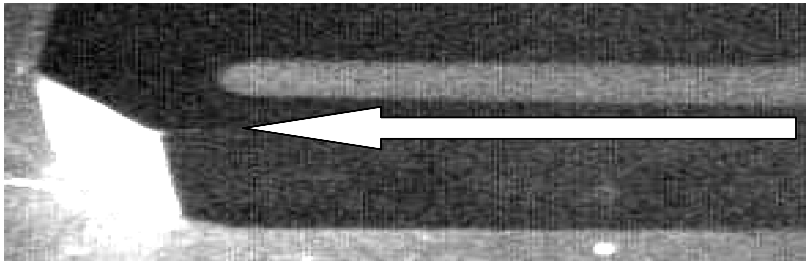
1. Initiation



2. Propagation



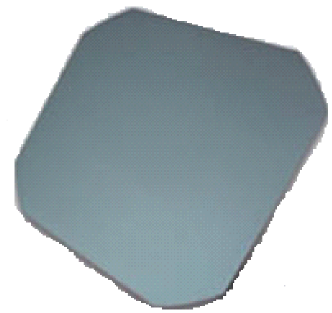
IR Image of a post-initiated area



IR Image of a propagation path

- Controlled Cleave with Scanned Energy Beam
  - Cleave **Initiation** – high dose area (mm^2 to cm^2) to initiate a starting crack
  - Controlled **Propagation** – crack propagates along the cleave plane

Advantages of Kerf-Free Wafering



Silicon / Ingot

- Improved poly-silicon utilization
- Reduces upstream capital expenditures utilizing less poly feedstock
- Lower cost per wafer

Wafering

- Low/zero kerf-loss
- Avoid slurry recycling
- Ability to slice down to < 50µm
- Improved thickness consistency. Lower TTV
- Less micro-fractures

Cells/Module

- Superior mechanical strength
- Less wafer breakage
- Low surface roughness
- Higher efficiency due to greater wafer uniformity
- No lifetime degradation

← Upstream

Downstream →

Summary

- Disruptive PolyMax™ wafering technology introduced
- Demonstrated full size wafers 150um to 20um thick
- First production-grade implanter running.
- Excellent material properties
- Substantial cost reductions from elimination of kerf-loss
- Scalable to thinner wafers for ongoing cost reduction
- *An enabling technology for reaching grid-parity*

Thank you!

For more information visit

www.sigen.com