Novel Kerf-Free PV Wafering that Provides a Low-Cost Approach to Generate Wafers from 150 mm to 50 mm

DOE Agreement #DE-EE0000594

PROJECT TITLE:

Novel Kerf-Free PV Wafering that Provides a Low-Cost Approach to Generate Wafers from 150 µm to 50 µm

PV Program

Adam Brailove

Silicon Genesis Corp.
145 Baytech Drive
San Jose CA 95134
(408) 493-4158
May 25, 2010

Timeline

- Project start date: 8/1/2009
- Project end date: 7/31/2011
- Percent complete: 40%-50%

Barriers

- Barriers addressed
  - Materials Utilization & Cost
  - Manufacturing Processes
  - Efficiency

Budget

- Total project funding: $7.78 M
  - DOE Share: $3.0 M
  - SiGen Share: $4.867 M
- DOE Funding received in FY09
  - $1.5 M Plan ($1.437 M Actual)
- Funding for FY10
  - $ 1.5 M Plan

Partners

- REC Corp.
  - Factory automation
  - Bricking & grinding
  - Materials evaluation
- Project Lead
  - Silicon Genesis

Barriers / Problems Addressed

- Conventional wire saw approach to wafering is limited by:
- 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 slurry and associated production/recycle facility
  - Cost of ingot puller capacity to produce silicon lost to kerf
  - Cost of wafer washing and wet singulation

Source: Photon International

- Wafer thickness reduction
  - More efficient silicon usage driving need for thinner wafers
  - 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 increases probability of wafer breakage
  - Tradeoff: thinner = slower cutting speed
  - Thickness variation, wafer to wafer variability → wafer binning

Relevance of Kerf-less Wafering to DOE Objectives

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- Direct relevance to stated DOE SETP objectives
- 'First-order' impact on high-cost points in PV value chain: material usage and wafering
- Disruptive technology
- Potential for near-term commercialization
- Enabling technology for roadmap to very thin <100 micron wafers

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The US has an opportunity to lead with new technologies in c-Si

The US has the history and technical expertise

- Leverage long solar heritage and leading R&D system

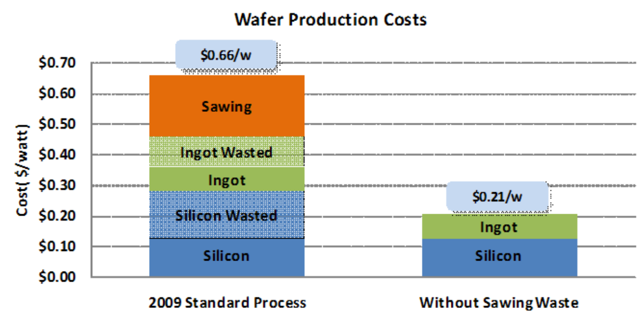
Different processes capture varying breadth of the PV value chain:

PolyMax →

- Ingots → Wafers (Ion implant with liftoff)
- Poly Si Feedstock → Wafers (direct solidification)
- Silane → Cells (Epi growth with release)

The most promising technology is kerfless wafering

- Wafer >40% of panel cost
- Sawing (including wasted materials) accounts for over 65% of the wafer cost
- >50% of polysilicon lost to kerf

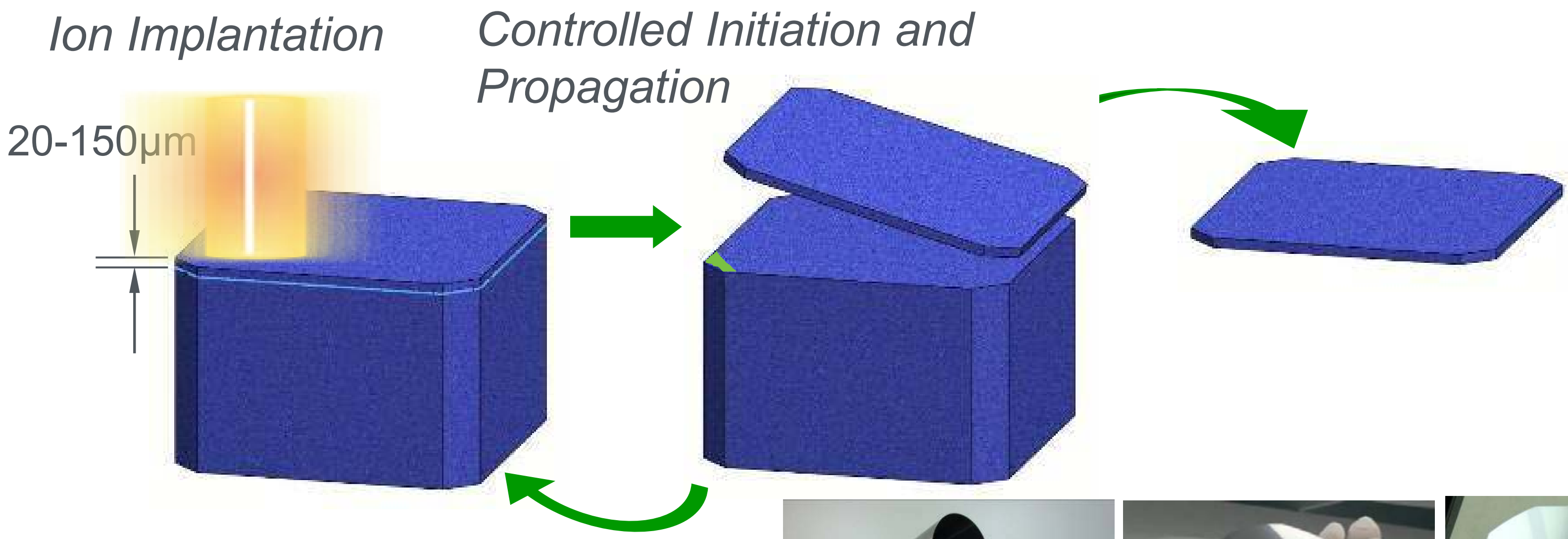


Source: Centrotherm, Photon International

U.S. Department of Energy Solar Energy Technologies Program Slide 6

Scott Stephens Presentation, DOE SETP

Silicon Genesis' Kerf-less Wafering (Approach)



- PolyMax is a two-step process
- Implant light ions into c-Si
  - Forms sub-surface cleave layer
- Controlled Cleave
  - Use a small high dose area to initiate a cleave
  - Propagate cleave through the lower dose area
  - Remove wafer
- Repeat on newly exposed brick surface

- SiGen has demonstrated kerf-less wafering on its R&D tools (previous work)
- Three thickness: 20, 50, 150 micron
- 125 mm and 156 mm square form factors
- High R&D yields
- No apparent problems due to progressive slicing
- <111> crystalline silicon

Goals and Project Objectives (Relevance & Approach)

- Overall Goals
  - Lab-to-fab: Drive SiGen's PolyMax wafering technology toward widespread commercialization
  - Achieve substantial reductions in cost and waste and across value chain at existing wafer thicknesses
  - Enable the development and commercialization of <100 micron wafers to drive PV roadmaps
  - Develop two key pieces of production-grade process equipment: Implant and Cleave, plus automation components to tie them together
- Project Objectives
  1. Complete the design and test of an 'alpha' implant tool (1st year)
  2. Develop improved low-dose cleaving process/prototype (1st year)
  3. Develop an 'alpha' cleave tool (2nd year)
  4. Integrate implant and cleave tools together in semi-automated system. Optimize process. Begin pilot wafering (2nd year)
  5. Gather throughput and machine performance from 'alpha' tools to drive 'beta' and production tool design and factory design (1st & 2nd year)
  6. Gather pilot cost and yield data to validate cost modeling (2nd year)

Technical Strategy: Implant (Approach)

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- Implant: Most expensive process step
  - Minimize $/mA:
  - Scale up R&D tool currents >100x with *high current accelerator*.
  - *Implant many bricks in parallel*
  - Minimize dose required for cleave:
  - *Use patterned implant*: Concentrate high dose only in small area to initiate crack. Use lower average dose to propagate crack across brick.
  - *Use surface heating/temp control by ion beam for process optimization*
  - Develop high-speed ion beam scanner for maximum process flexibility: dose and thermal control
  - Develop efficient, low thermal resistance in-vacuum brick cooling technique

Alpha Implant Tool (Progress-1)

- Implanter design and parts fabrication & procurement is 100% complete.
  - All parts received at SiGen.
- Facility is 100% complete
  - Concrete radiation vault construction complete. Radiation safety system tested.
  - High initial gamma ray flux from accelerator mitigated with additional shielding
  - Coolant systems, gas delivery, electrical power in place and functional
- Ion Implant *System* Status
  - 4 phase integration *underway now*
    1. Get accelerator running stably at modest beam currents. (Completed)
    2. We are here → Couple accelerator to beamline; transport and scan beam
    3. Couple beamline to endstation; achieve first beam-on-silicon
    4. Scale-up beam current to spec current and energy
  - Expect first beam-on-silicon in 6 weeks. Will hit milestone for first implants by Aug 2010.
- Next steps
  - Equipment tuning and testing
  - Process development and optimization. High power implant capability will open new process capability/space for dose reduction. Increases availability of material for cleaving tests.
  - Wafer sampling to customers

Alpha Implant Tool (Progress-2)

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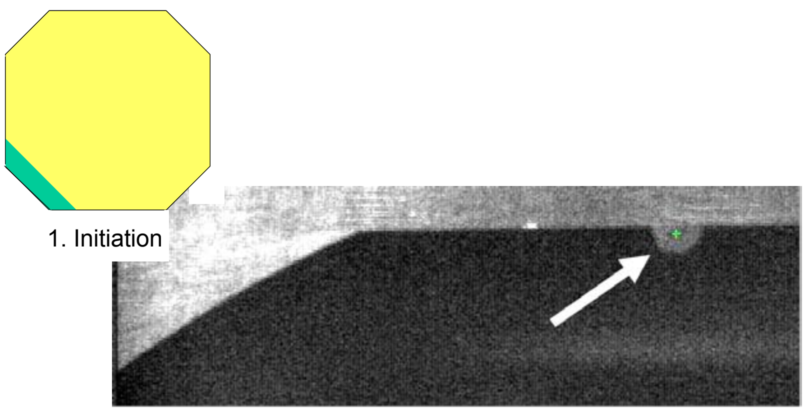
- Endstation – In-line, vacuum loadlocked process chamber. Handles and cools bricks during implant
  - Brick cooling: Tested on bench (in vacuum) Demonstrated to have acceptable heat transfer coefficients 61% of (somewhat arbitrary) design target.
  - Mechanical reliability: Several hundred trays of bricks 'dry processed' (no beam). No reliability issues.
  - Mechanical throughput: Measured on actual endstation. Exceeds targets. Beam current limited, NOT mechanical/pump limited
- Accelerator – Generates ion beam and accelerates it to high energy
  - Alpha beam energy spec: 2-4 MeV (50-150 micron wafers)
    - Max energy achieved to date 3.5 MeV
  - Beam current scale up:
    - Alpha specification: ~ 50% of Production tool spec
    - Achieved to date: ~10% of Production tool spec
    - Scale-up goal: 2x Production spec within 2 years
- Beamline – Transports beam to Endstation
  - All parts assembled, leak tight
  - Bench tests of scanner system passed 100%. Scanner speed meets spec.
  - Beam transport, debugging, testing and firming up software controls are underway
- Key Equipment Testing Planned
  - Brick cooling & temperature
  - Tray temperature
  - Longevity of consumables (parts struck by beam)
  - Measurements of radiation (activation) of silicon and machine parts
  - Any reliability issues due to thermal expansion

Endstation

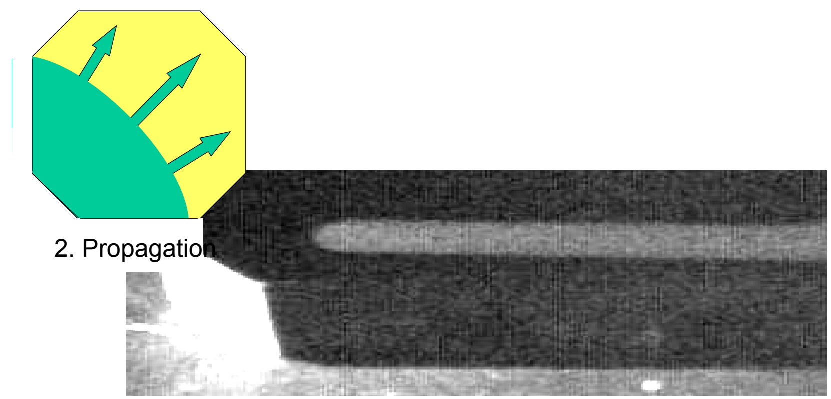
Process Tray

Technical Strategy: Cleave (Approach)

- Cleave: Improve and optimize for lower doses. Reduce thermal budget
  - Conventional approaches require ion doses which are high, limiting productivity
  - To achieve cost and productivity targets, reduce ion dose needed for cleaving
  - SiGen’s strategy is to apply a source of external stress or energy to *drive* the crack
  - Implanted layer serves to *guide* the crack at lower doses
  - Develop benchtop prototypes to evaluate several different novel approaches to applying external energy and select
  - Existing iso-thermal cleaving approach is currently used



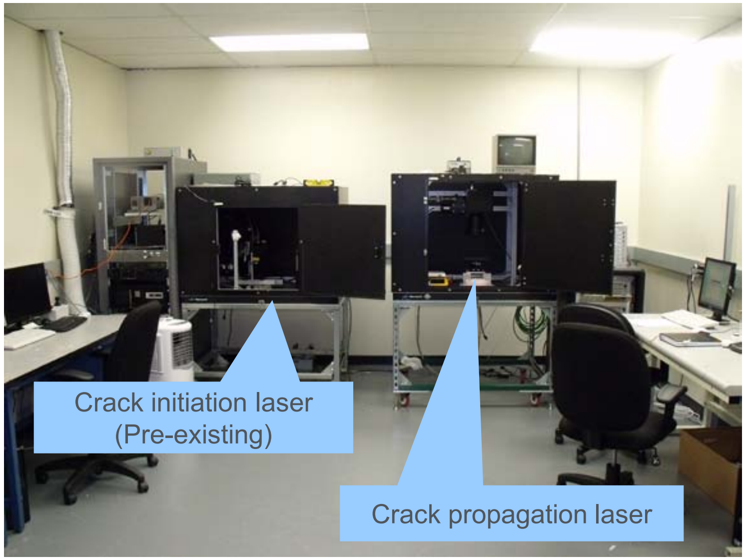
IR Image of a post-initiated area (pre-existing work)



IR Image of a propagation path (pre-existing work)

Cleave (Progress-1)

- Developed scanned laser cleaving test-beds for crack initiation (pre-existing) and propagation
- Developed repeatable laser crack-initiation recipes for 20 micron and 50 micron thick wafers
- Demonstrated first laser initiation of 150 micron thick wafer
- Controlled-depth cleaves have been successfully propagated starting from these initiation points, to form silicon films of moderate (centimeter-scale) size.



Cleave (Progress-2)

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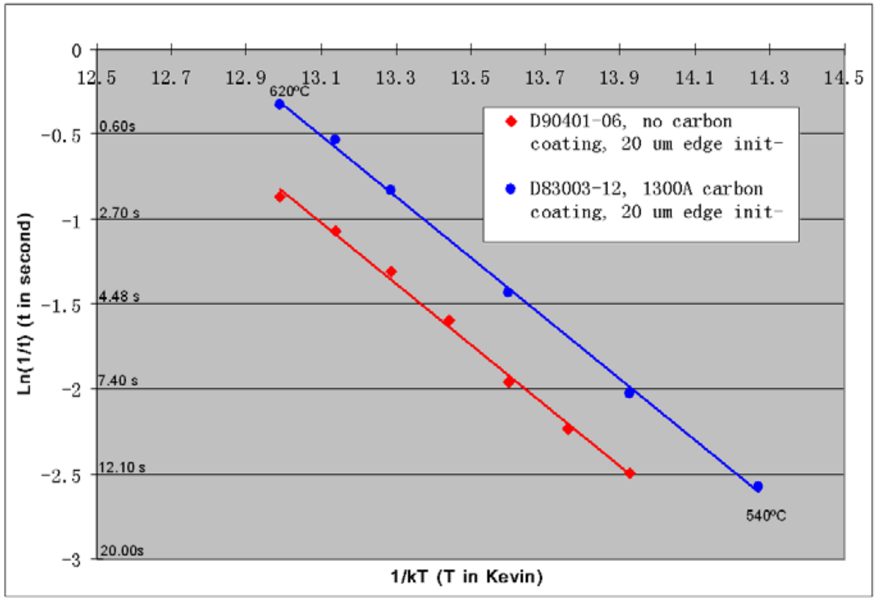
- Confirmed laser crack propagation theory in numerous experiments using two low thermal budget propagation techniques.
- Laser Initiation described by first-order kinetics, characterized by an activation energy
- Scanned-beam pyrometry system calibrated using known-emissivity surface. Temperature accuracy on bare silicon improved.
- Increased area of beam-cleaved film



Future Plans (FY 2010 and beyond)

- Implant
  - Assess hardware results from initial alpha implanter operation (2010/2011)
  - Assess life of components struck by beam and develop improvement plan (2010)
  - Kickoff of beta tool design (2010)
  - Continue scale-up of beam current to spec and beyond if possible (2010, 2011)
  - Make improvements in equipment reliability, uptime etc (2010, 2011)
  - Kickoff factory automation design (2010)
- Cleave:
  - Complete cleave prototype evaluation tools (2010)
  - Select and develop alpha cleave tool (2011)
  - Ongoing process optimization and dose reduction (2010, 2011)

Collaborations

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- REC Corporation (Norway)
  - Customer/Industrial Partner. Not in DOE Solar Program.
  - SiGen & REC collaboration is extensive:
    - Commercial relationship with tool supply agreement
    - Wafer samples supplied by SiGen, evaluated by REC
    - Development of cell process technologies for thin wafers, <111> texturization by REC
    - Inputs by REC into design of equipment
    - Factory layout and automation
    - Testing and evaluation of alpha machines at SiGen
    - Planned Beta site at REC
- Company A (name withheld due to confidentiality)
  - Potential Customer, Not in DOE Solar Program.
  - Company A has received and evaluated SiGen wafer samples
  - Material quality, lifetime evaluated
  - Cells fabricated, efficiency comparable to CZ reference wafer
- NorSun Corp (Norway)
  - Customer/Industrial Partner.
  - Commercial agreements
  - Not in DOE Solar Program.

Summary

- Integration of alpha Implanter tool is progressing well and on track to achieve first implants by Aug. 2010. No show-stoppers.
- Availability of high-power alpha Implanter will
  - Open new areas of process space for dose reduction
  - Dramatically increase rate at which SiGen can perform process optimization experiments
  - Increase supply of early samples to partners/customers
  - Provide a lot of practical ‘learnings’ about the equipment that will be used for the beta
- Cleave theory is now well-developed
- Several new cleave modes and possible techniques were developed
- Prototype test-fixtures covering these techniques are being fabricated now