



# **Efficacy and Cost Advantages are Driving Ion Implant Adoption in Commercial PV Cell Fabrication**

**NCCAVS JTG Meeting 14 July 2016**

**Babak Adibi Ph.D., Chris Smith, Paul Werbaneth  
Intevac, Inc.**

**Badibi@intevac.com**

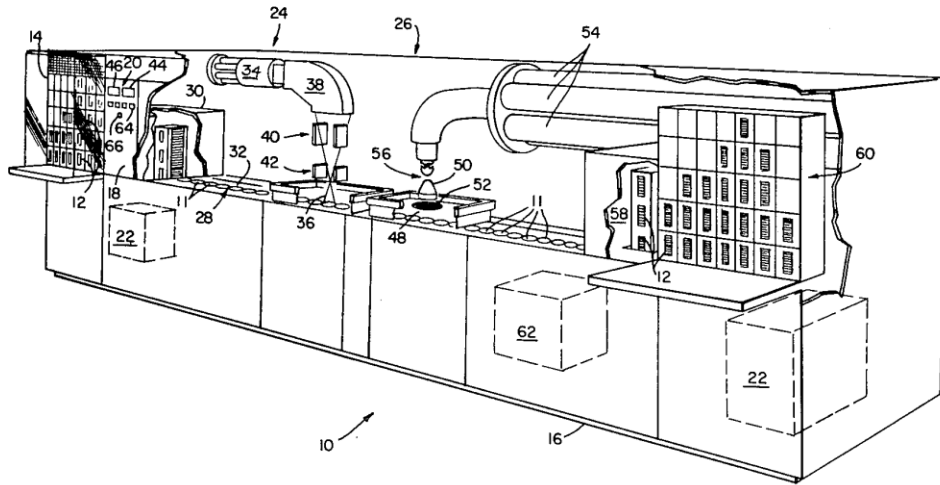
**POWERING INNOVATION. DELIVERING VALUE.**



- PV Implant Brief History – Crossing the Chasm
- PV market
  - Cost and Cell Efficiency
- Intevac Implant system at 3000 wph
  - How it works?
  - Benefits to customers
  - Cell results
- Patterning capability for advanced devices

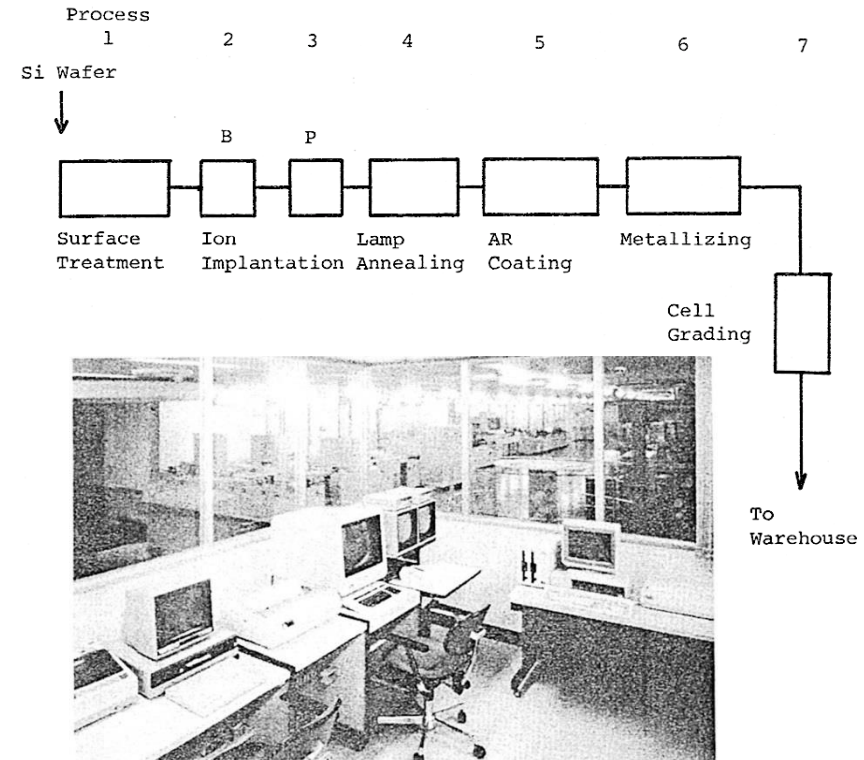


# 1980's Integrated Implant Solar Solutions



1982 - An integrated system: implant, e-beam annealer under common vacuum system with no wet chemistry for front contact cells

Armini and Little, Spire Corp (USA), patent 4,353,160  
"Solar cell Junction processing system"



1985 - Hoxan Corp (Japan ) Bifacial cell  
4" wafers, 9MW with 11% efficiency

Y, Tahara et. al., "High Throughput Automated Junction Formation by Ion Implantation and Halogen Lamp Anneal For 9MW Production" IEEE 1985 (4" wafers)



# Ion Implant in Solar PV: Recent History 2008+

“As of the end of August [2011], **over ten PV manufacturers** in the US, China, Taiwan, South Korea and Europe have received [Varian] Solion systems.” (Source: Varian)

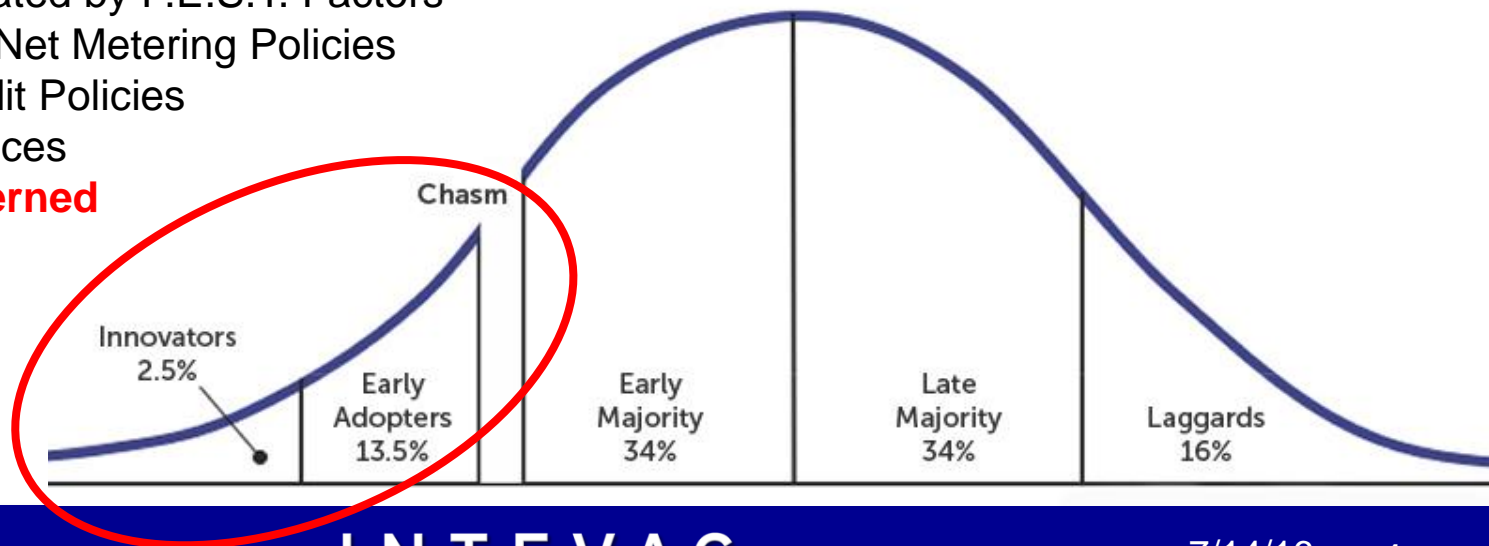
“**Amtech to sell majority stake in ion implant subsidiary Kingstone Technology.**”  
(Source: PV Tech, 24 July 2015)

“**Applied Materials Withdraws from Solar Ion Implant.**” (Source: PV Tech, 19 Aug 2015)

~100 Total PV Cell Manufacturers; Chasm Theory Suggests ~**16 Total Innovators / Early Adopters** in this Population

**Chasm Duration** Gated by P.E.S.T. Factors  
e.g. Feed-In Tariffs, Net Metering Policies  
Investment Tax Credit Policies  
Green Lifestyle Choices

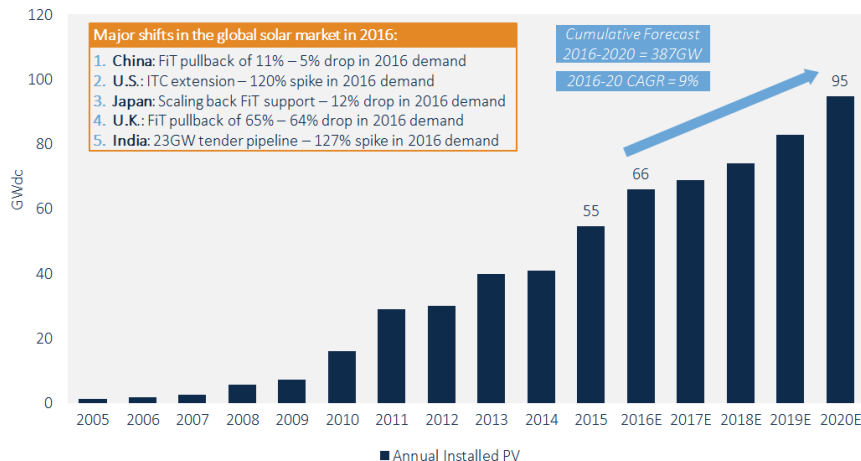
**Availability of Patterned  
Implant/Devices**



# PV Market Growth, Players and Flavors

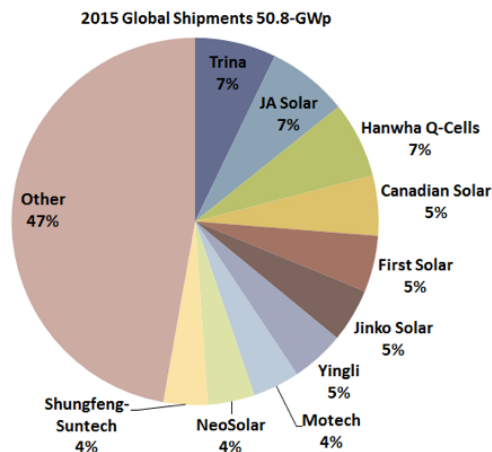


Global PV Demand 2005-2020E



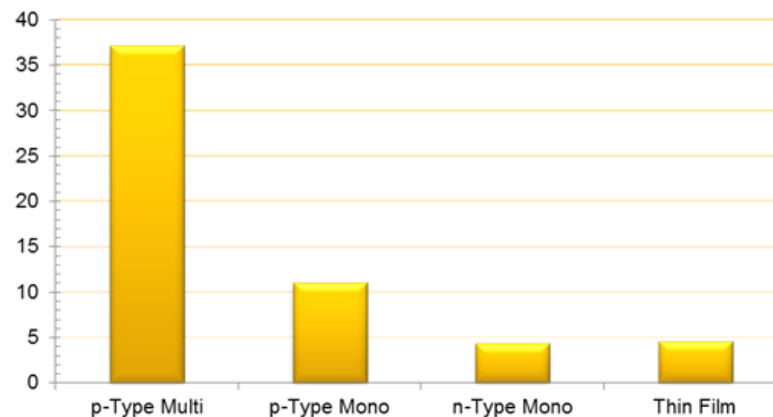
Source: Greentech Media 02 May 2016

- Fast Growth: 66 GW → 95 GW in 2020
- 100 PV manufacturers → ~11.7B cells/year
- p-type Multi → p and n Mono transition



Source: Paula Mints 08 April 2016

W-W Installed PV Cell Manufacturing Capacity 2016 (GW)

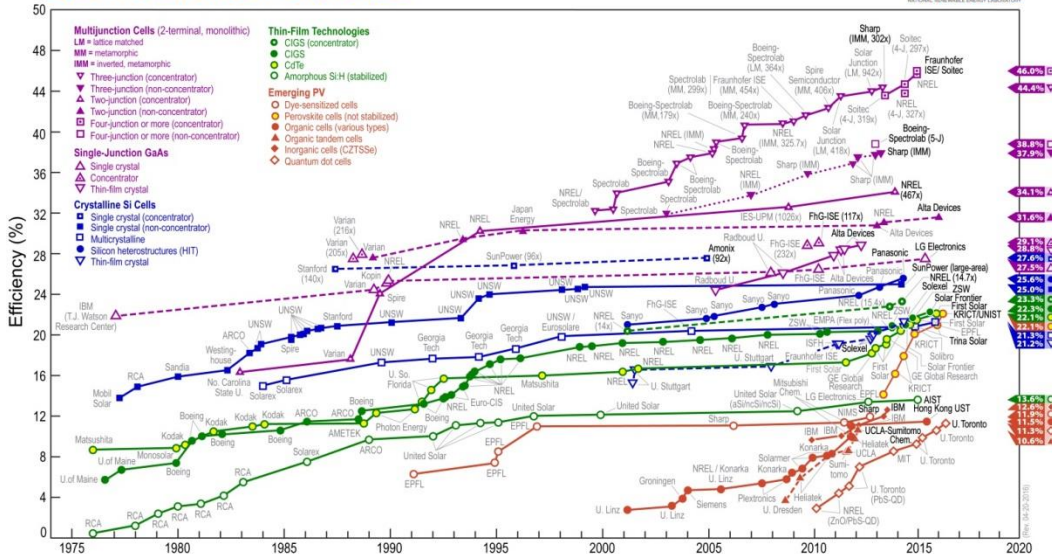


Source: Solar Media March 2016

# PV Cell Efficiencies and Cost Demands

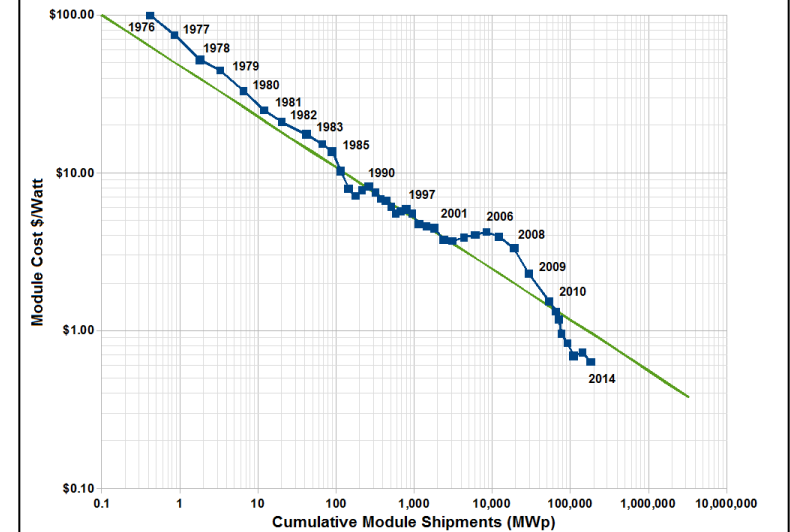


Best Research-Cell Efficiencies



Source: NREL April 2016

Swanson's Law



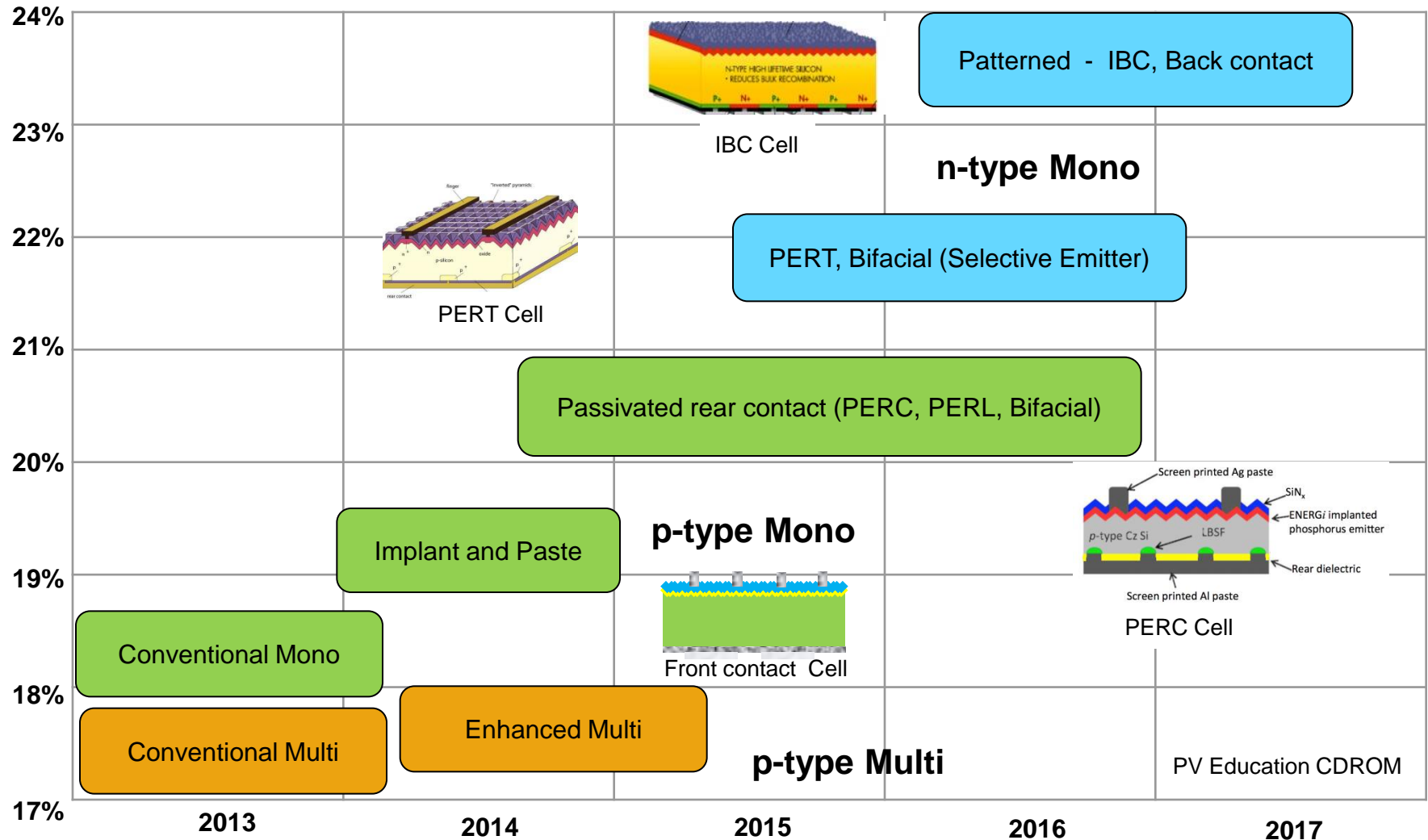
Source: Wikipedia

**SWANSON LAW:**

Cell cost falls by 20% with each doubling of manufacturing

**Δ 0.1% Efficiency Makes Headlines and Tenths of Pennies Count**  
**Cost of solar module now <\$1 per Watt**

# c-Si Solar Cell Roadmap: Efficiency is King



# c-Si Solar Cell Roadmap: Cost is also King

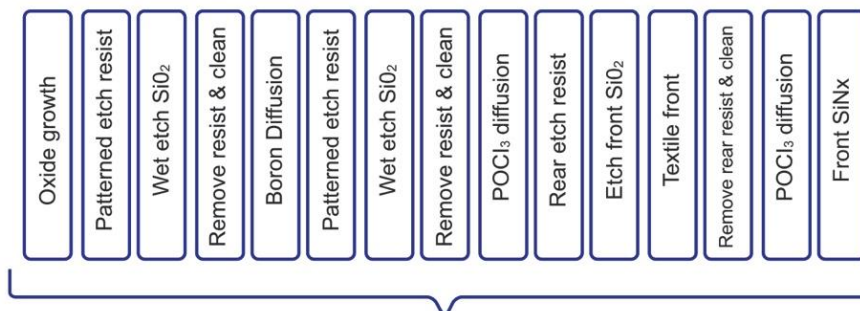


## Ion Implant Process Flow Advantage

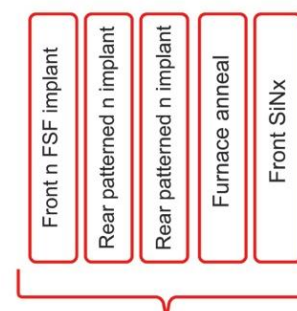
Cell Type	Diffusion process steps	Ion Implant process steps
Front Contact	3	2
Front Contact (with Ox)	4	2
Front Contact	5	2
Bi-Facial	6	2
IBC	~6	2



## Low cost of ownership Bi-Facial cell solution



IBC by multiple diffusion masks and furnace diffusions



IBC by patterned implant



# Intevac Equipment Products



**200 Lean®  
PVD System for Hard Disk**



**Solar**

**ENERGi™ Ion Implant**



**MATRIX™ PVD**



- Intevac is a leader in high productivity equipment
- Capabilities to address multiple advanced solar applications
- Focus on higher cell efficiency and lower cost / Watt

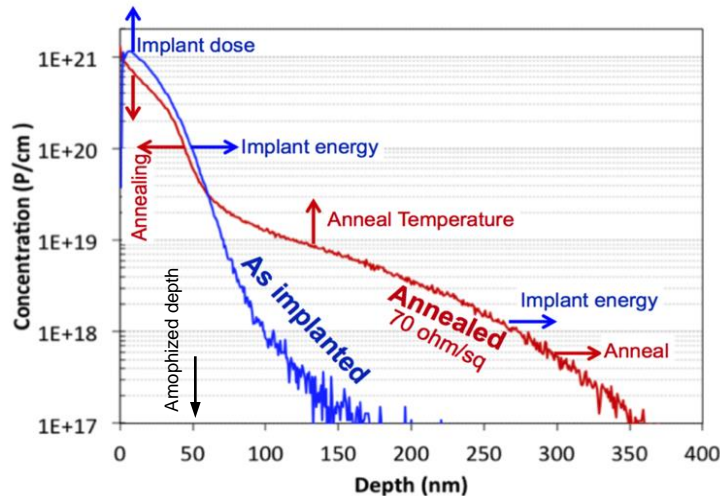
# ENERGi™ - Implant System Specifically for Solar



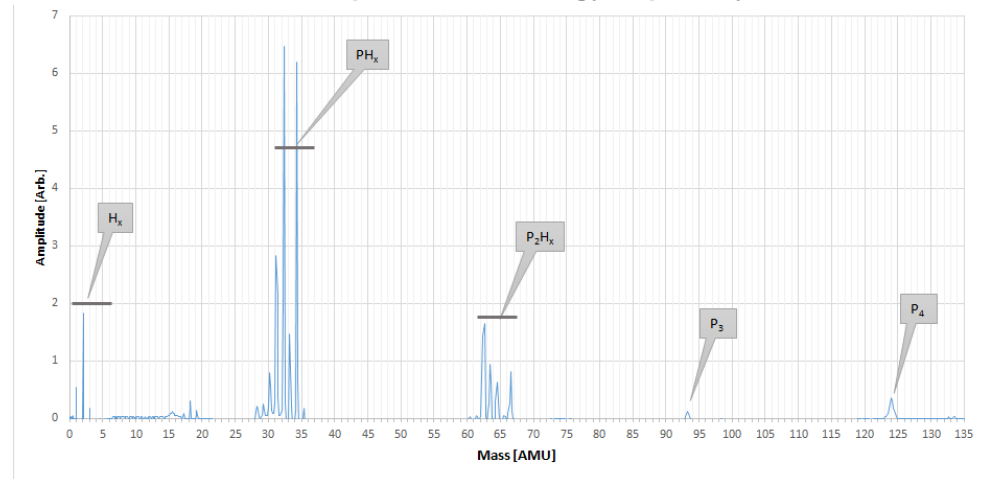
**ENERGi Ion Implant System**  
**Fully automated**

- Lower in cost than diffusion process flow
- Higher cell efficiency than diffusion flow
- Running millions of cells in full production
  - Highest throughput of 3000 wph
- Demonstrated advanced cell design
  - Front contact cell
  - PERC
  - N-PERT
  - Bifacial cell
  - IBC
  - Unique Patterning (Selective Emitter and IBC)  
Patent Pending

# Non-Mass Analyzed Atomic Profile Advantages



Mixed species and energy capability

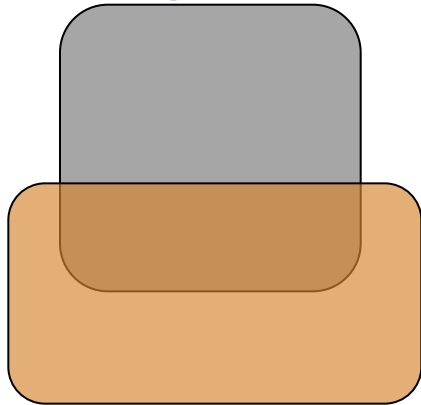


- Implant all precursor bi-products very near surface (Similar to Diffusion)
  - Annealing only impacts the diffused parts
- High dose rate → Full Amorphization:
  - Leading to complete anneal and activation – Solid Phase Epitaxial Regrowth (SPER)
- Near surface profile tailoring is important to optimize cell parameters
  - For Ag pastes, optimize contact resistance vs Voc

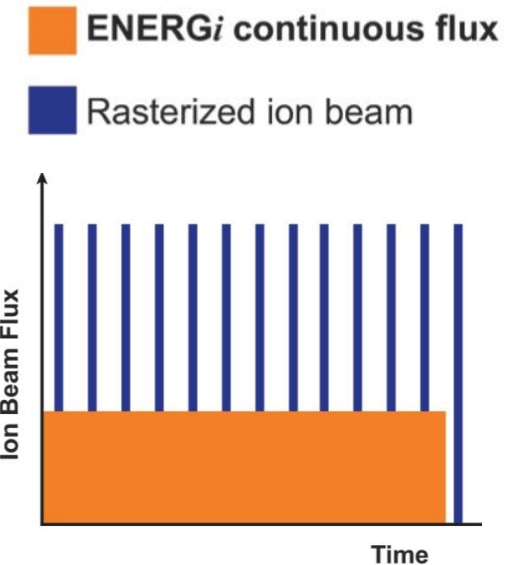
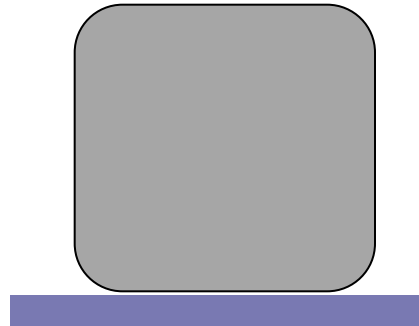
# ENERGi™ Continuous Flux Implant



**ENERGi  
Continuous Flux  
Single Pass**



**Competitor's  
Multiple Pass  
Systems (6 - 7 times)**



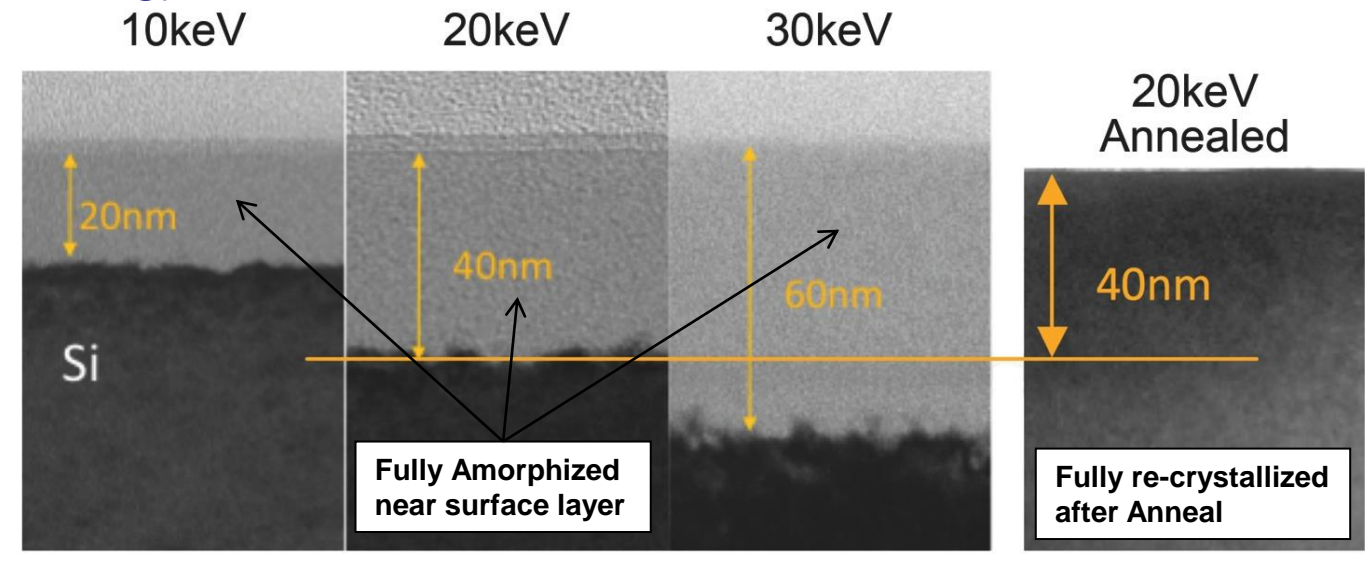
- Dynamic annealing occurs between passes (no beam)
- Single pass helps to fully amorphize and fully anneal

# Near Surface Amorphization and Regrowth

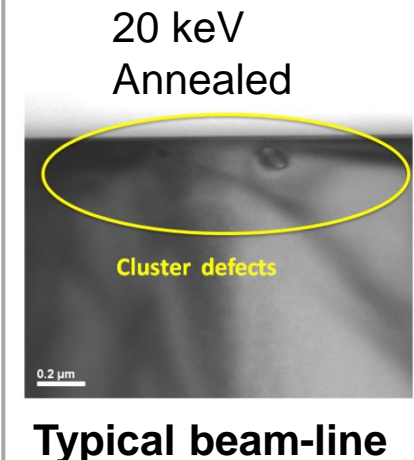


- ENERGi generates fully amorphized near surface layer
  - Due to high dose rate and single pass
  - Good/complete amorphization is desired for best annealing
- This layer will fully re-crystallize during anneal
  - Solid Phase Epitaxial Recrystallization (SPER)

## ENERGi



## Competitor



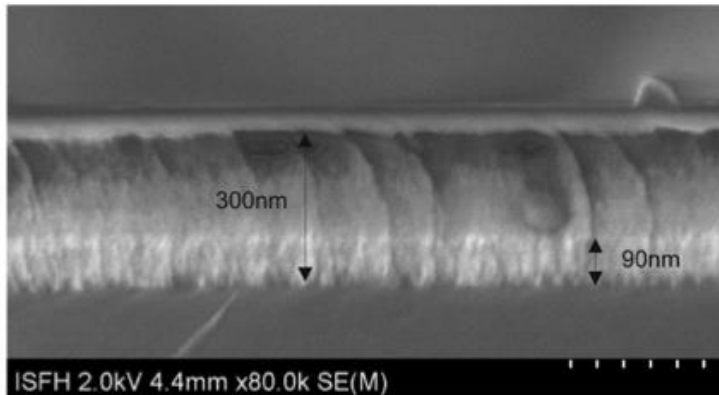
**ENERGi ion implant enables high quality epitaxial regrowth**

# Boron Implant Advantages



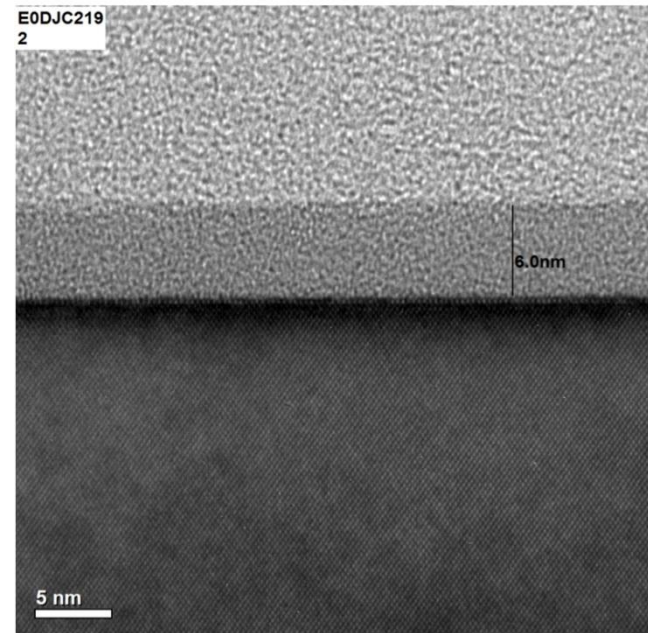
## Diffusion

- Boron Rich Layer (BRL) impact minority carrier life time
- BSG removal is difficult
- More process steps
- Higher CoO



## Ion Implant

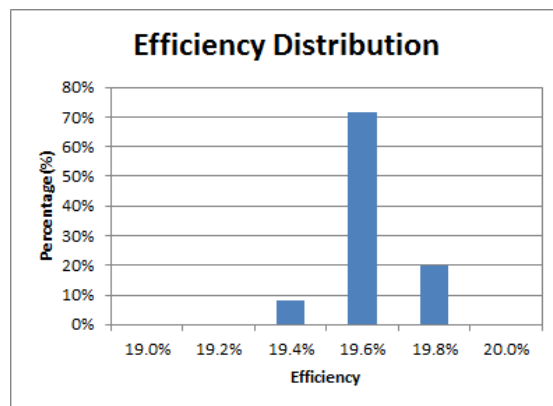
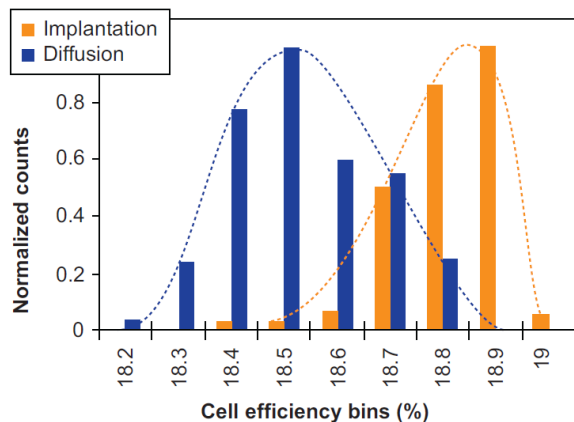
- No Boron rich layer or BSG
- Precise Boron dose and single sided doping
- Superior surface interface & emitter
- Excellent uniformity and repeatability
- Low cost of ownership



# ENERGi in Production – Front Contact Cell



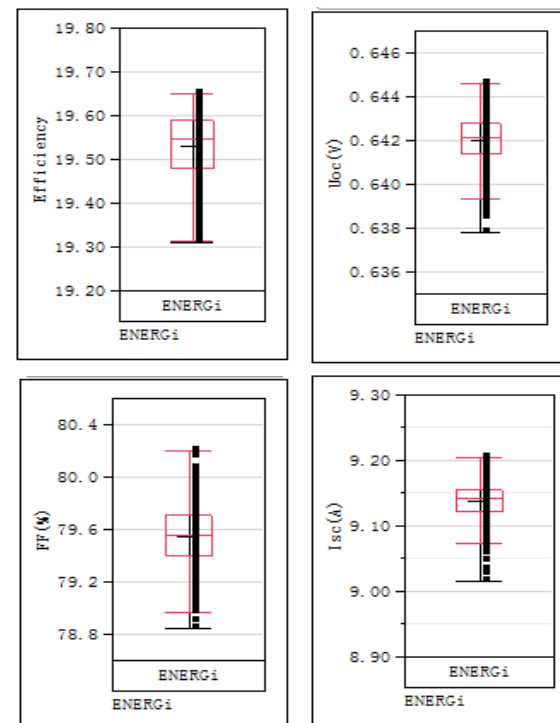
- Millions of cells processed - (50+k wafer per day)
  - Higher Cell efficiencies and  $V_{oc}$  than diffusion
  - Narrow efficiency distribution



Narrow distribution → Module matching

NCell	$U_{oc}(V)$	$I_{sc}(A)$	FF(%)
19.95%	0.6461	9.3264	80.19

Champion data from customers



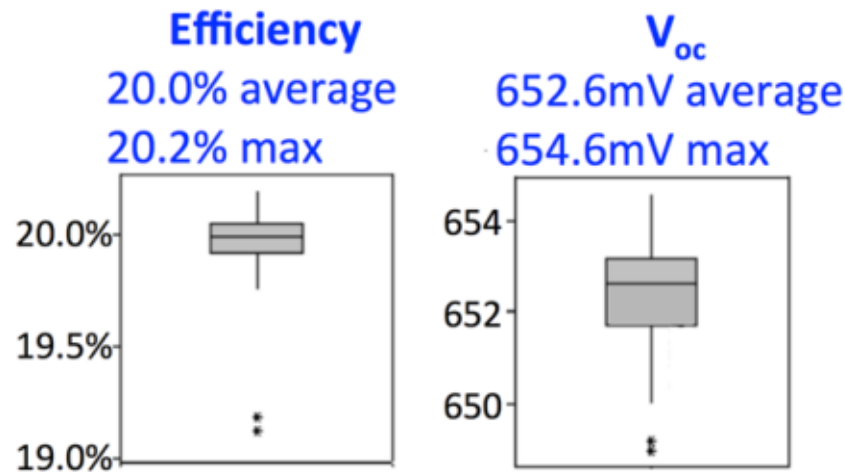
Industrial data from customers

Data shown with customer's permission

# ENERGi in Production – PERC cells



- Rear passivated cells such as PERC are a challenge for diffusion
- Implant demonstrated good results (With oxy-nitride passivation only)
  - 0.4% gain over POCL3
  - 0.2% over competitor next generation system



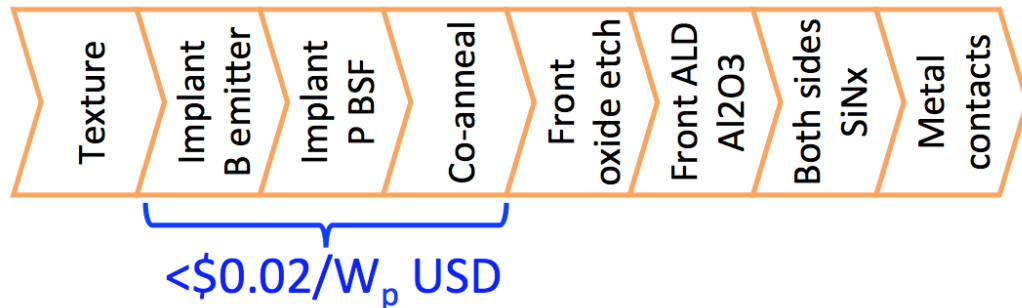
Data shown with customer's permission



# ENERGi Boron Data (N-PERT & Bifacial)



Low cost of ownership Bi-Facial cell solution



- ENERGi recipes developed for both N-PERT and Bi-facial
- ENERGi (P+ B) and Co-anneal simplifies flow and lowers cost of ownership

Rsheet B Emitter (Ω / □)	Rsheet P-BSF (Ω / □)	J <sub>OE</sub> (fA/cm <sup>2</sup> )	MCL (0.1 sun) (μsecs)	Implied V <sub>oc</sub> (mV)
88	56	65	131	650

N-type Si, 156mm 1.4 Ω-cm Cz, textured  
 ENERGi Boron + ENERGi Phosphorous with Co-anneal  
 Passivation B-Emitter Plasma ALD Al<sub>2</sub>O<sub>3</sub>, SiNx  
 Passivation P-BSF, insitu thermal oxide + SiNx

Data shown with customer's permission



# Ion Implant in Solar PV: Today

**“Tool Order: Intevac to supply ion implant tool to solar cell producer.”**

(Source: PV Tech, 29 Sept 2015)

**“Intevac wins ion implant systems orders from Chinese solar cell producer.”**

(Source: PV Tech, 25 May 2016)

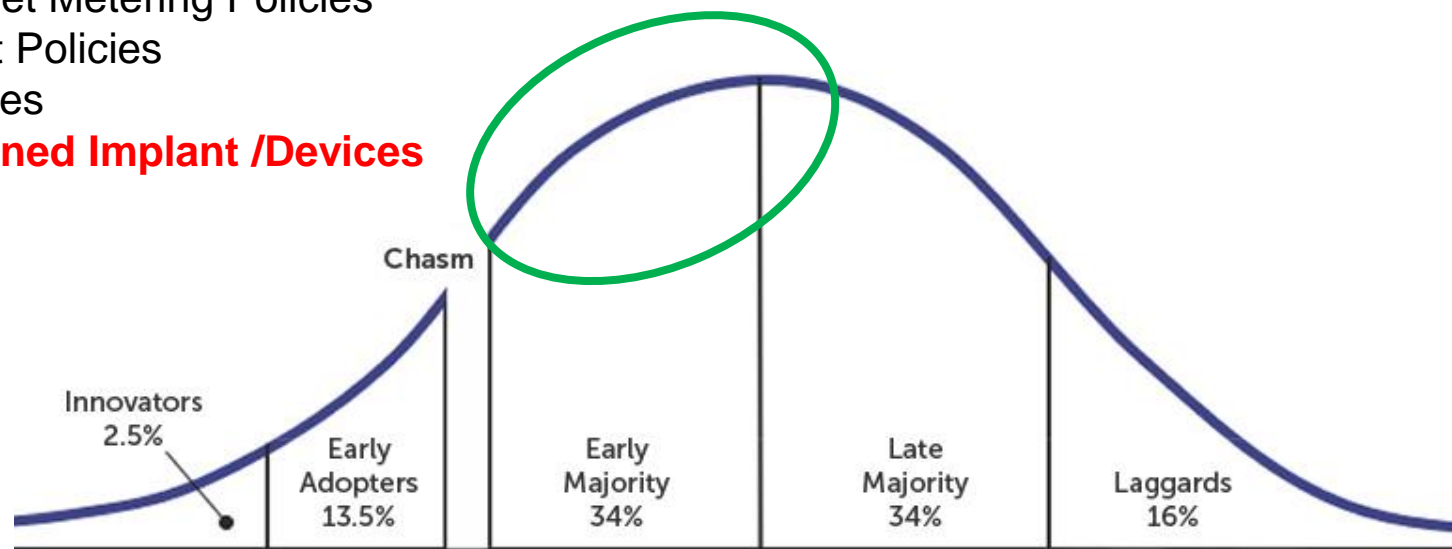
**Chasm Crossing** Gated by P.E.S.T. Factors

e.g. Feed-In Tariffs, Net Metering Policies

Investment Tax Credit Policies

Green Lifestyle Choices

**Availability of Patterned Implant /Devices**



# ENERGi - Implant System Specifically for Solar



**ENERGi Ion Implant System**  
**Fully automated**

- Lower in cost than diffusion emitter flow
- Higher cell efficiency than diffusion emitter flow
  - N-type doping - front contact at 20+% efficiency
- Running millions of cells in full production
- Highest throughput of 3000 wph
- Demonstrated advanced cell design
  - Front contact
  - PERC
  - N-PERT
  - Bifacial
  - IBC
  - Patented Unique patterning (Selective and IBC)



# INTEVAC

**POWERING INNOVATION. DELIVERING VALUE.**