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Ion Implantation and Applications for Power Devices

Outline

- Introduction
- Silicon carbide doping challenges
  - Implant Species and Source Operation
  - High Temperature Implant for Implant Damage Control
- Silicon Carbide Structure and Implant Solutions
  - High Energy Implant for SiC Trench MOSFET
  - Purion XEmax High Energy System
- Summary

Axcelis at a Glance

- Global leader in technology development and manufacturing of ion implant systems and services for the semiconductor industry for 45 years
  - Serving the ~$2.7B ion implant systems market
  - Based in Beverly, MA with headcount greater than 1700 worldwide
  - Global customer support infrastructure
  - Growing installed base of greater than 3000 tools
  - Strong IP portfolio

- Supplier of record to leading semiconductor CAPEX spenders in all market segments including DRAM, NAND, Foundry, Logic, Power and Image Sensor

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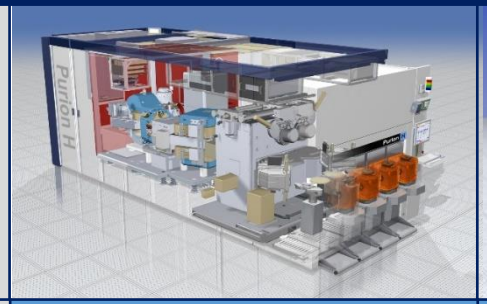
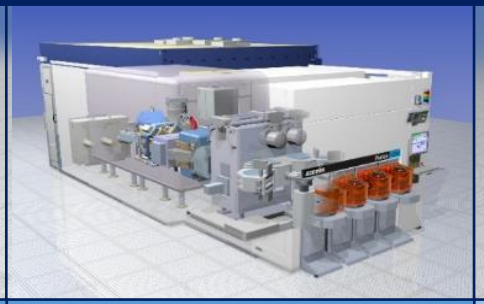
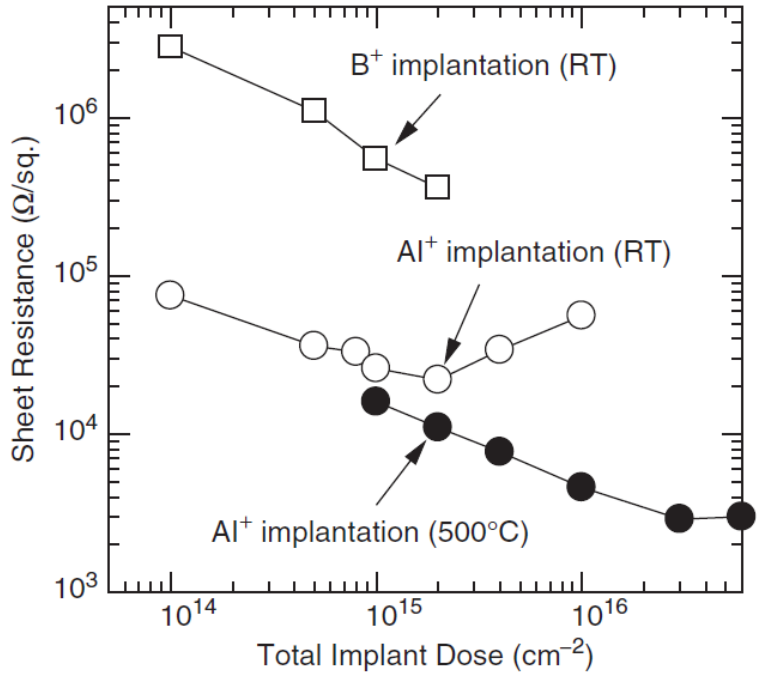
Product Overview - Common Purion Platform

Application Space	High Current	Medium Energy/ High Current	Medium Energy/ Medium Current	High Energy
				
Base Products/Model	Purion H Purion Dragon	Purion H200	Purion M	Purion XE/EXE/VXE Purion XEmax
Power Series™		Purion H200 SiC	Purion M SiC	Purion XE/EXE SiC
Customer Markets	Adv DRAM/NAND & Logic Material Modification	Power Device Mature Technologies	Power Device RF Mature Technologies Adv DRAM/NAND	Power Device Image Sensor Mature Technologies Adv DRAM/NAND

Silicon Carbide Doping Challenges

- Aluminium: P-type dopant
  - Solid source vaporizer like, AlI_3 , $AlCl_3$
  - Source operation control
    - — Beam tuning time
    - — Implant species change time
- Implant damage defects control
  - High temperature implant to reduce implant damages
  - Improve dopant activation
  - >500°C implant
- High temperature annealing for dopant activation
  - >1500°C
  - Surface capping layer for annealing

Dopant	Si/SiGe	SiC
N-type	P, As, Sb	N, P
P-type	B, Ga, In	**Al**
Non dopant	H, He, C, Si, F, Ge	H, He



Fundamentals of Silicon Carbide Technology, T. Kimoto, J. Cooper, Published 23 September 2014, Engineering, Materials Science, Physics

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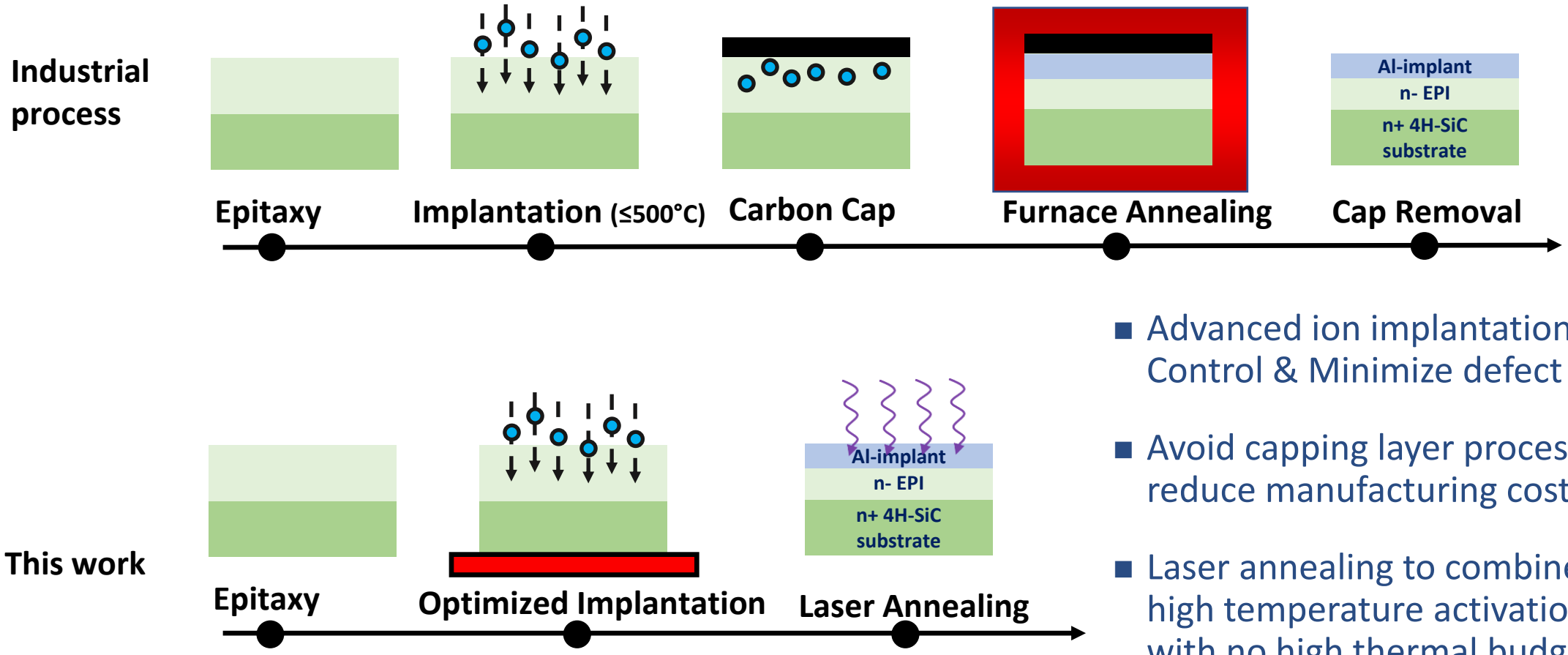
Implant and Annealing Strategy



- Advanced ion implantation Control & Minimize defect level
- Avoid capping layer process and to reduce manufacturing costs
- Laser annealing to combine high temperature activation efficiency with no high thermal budget-induced extending defects

Axcelis Internal Work, Presented by F. Mazzamuto at ISCREM 2023 Conference, Italy

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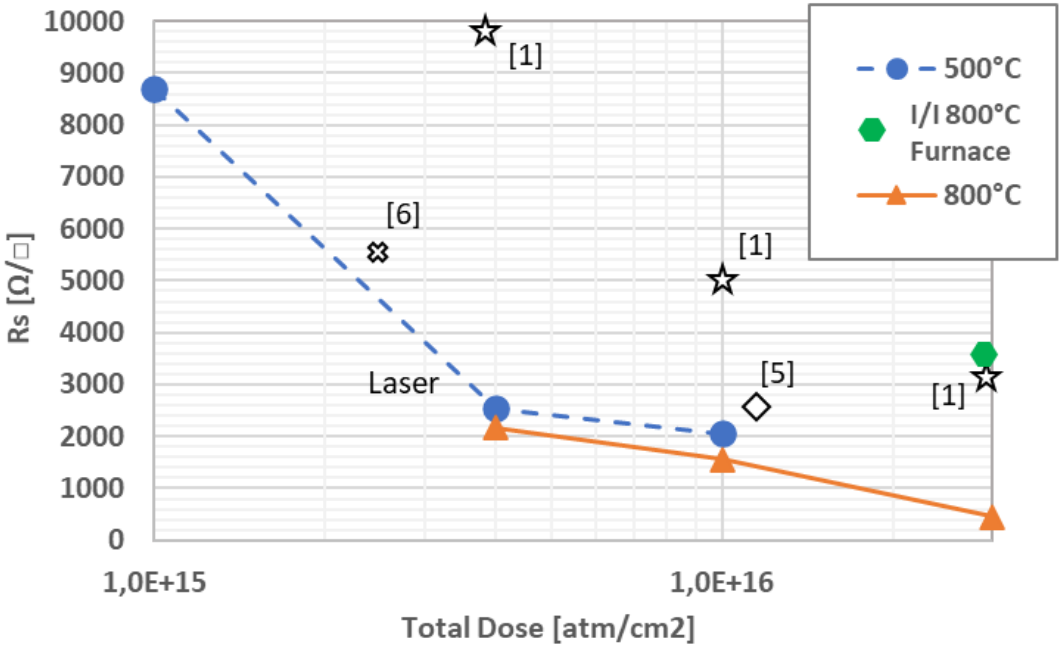
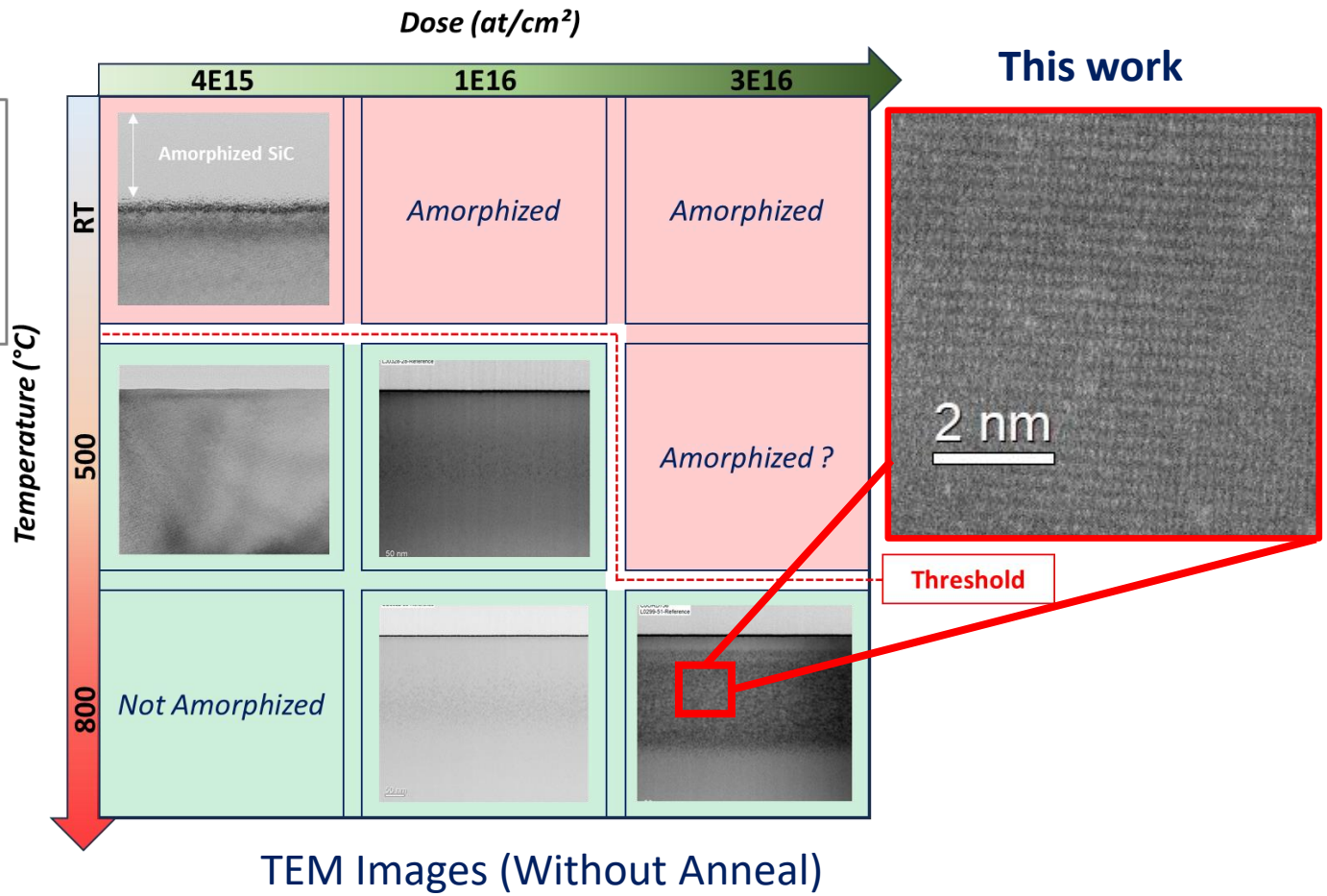
Hot Implant and Annealing Control to Implant Damages



[1] Y. Negoro et al. (2004).
[5] S. G. Sundaresan et al. (2007).
[6] R. Nipoti et al.(2018)



TEM Images (Without Anneal)

- High Temperature Implant for SiC Implant Defect Control
- "Warm" or Room Temperature Implants at Lower Lose for Productivity Consideration

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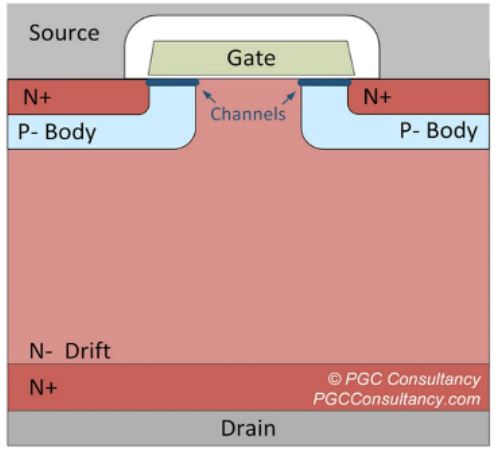
Silicon Carbide Structure and Implant Solutions

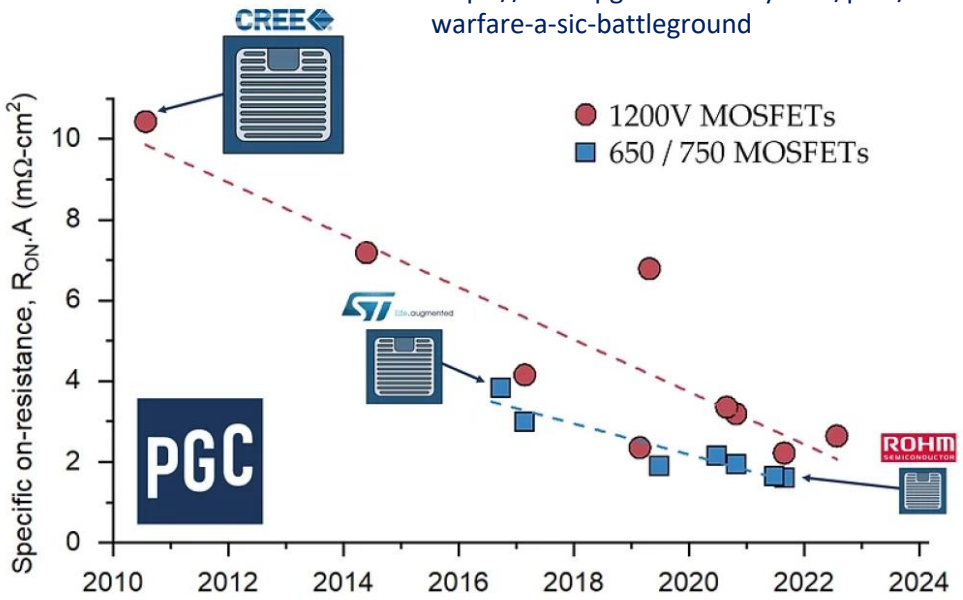


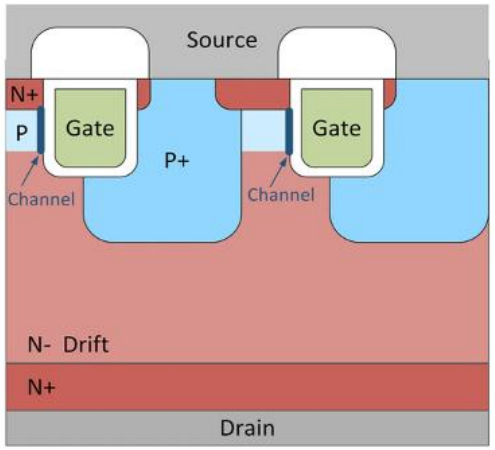
- **Planar MOSFET**
  - ~18-24 implants
  - Max E ~600keV
  - Max Dose ~ 2e15

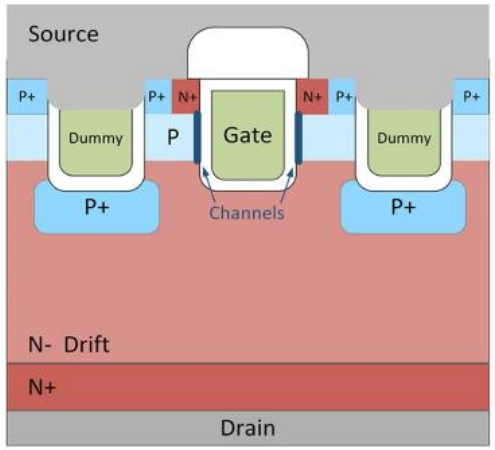
MC + HC/HE

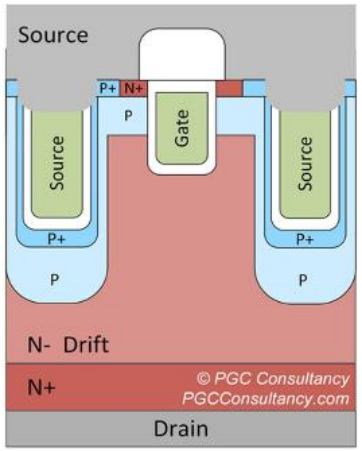
https://www.pgcconsultancy.com/post/rohm-gen-4-a-technical-review

https://www.pgcconsultancy.com/post/trench-warfare-a-sic-battleground









- **Trench MOSFET**
  - ~ 30 implants
  - Max E ~ 2MeV
  - Max Dose ~ 5e15

HE + MC/HC

MC = Medium Current

HC = High Current

HE = High Energy

Device structures are driving "different" implant solutions to optimize High Volume Manufacturing

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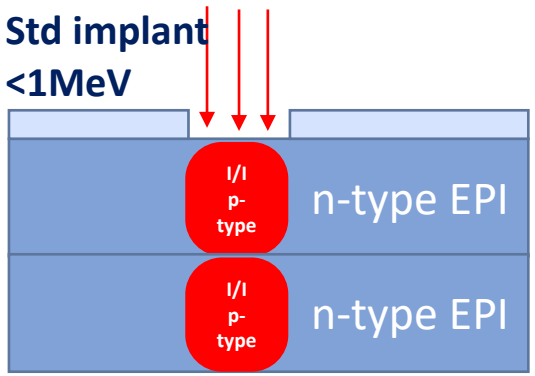
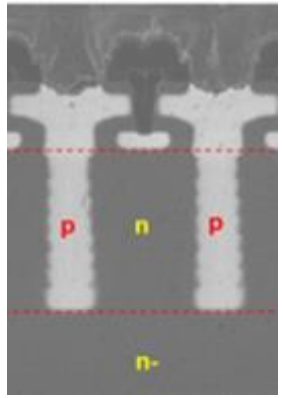
Super Junction Formation and High Energy Implant

(Multi-step) n-EPI/p-type implant



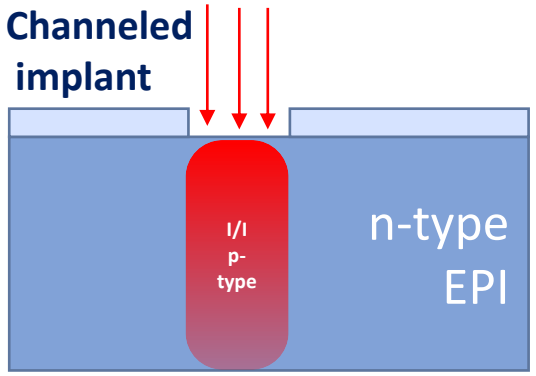
Process (Multi Epi/Implant Step):

- Each n-type EPI (literature 0.7-0.8um)
- Masking and opening at p-type pillar
- Compensating implant
- Repeat



Kobayashi, Y. et al. (2019). *(ISPSD)* (pp. 31-34). IEEE.

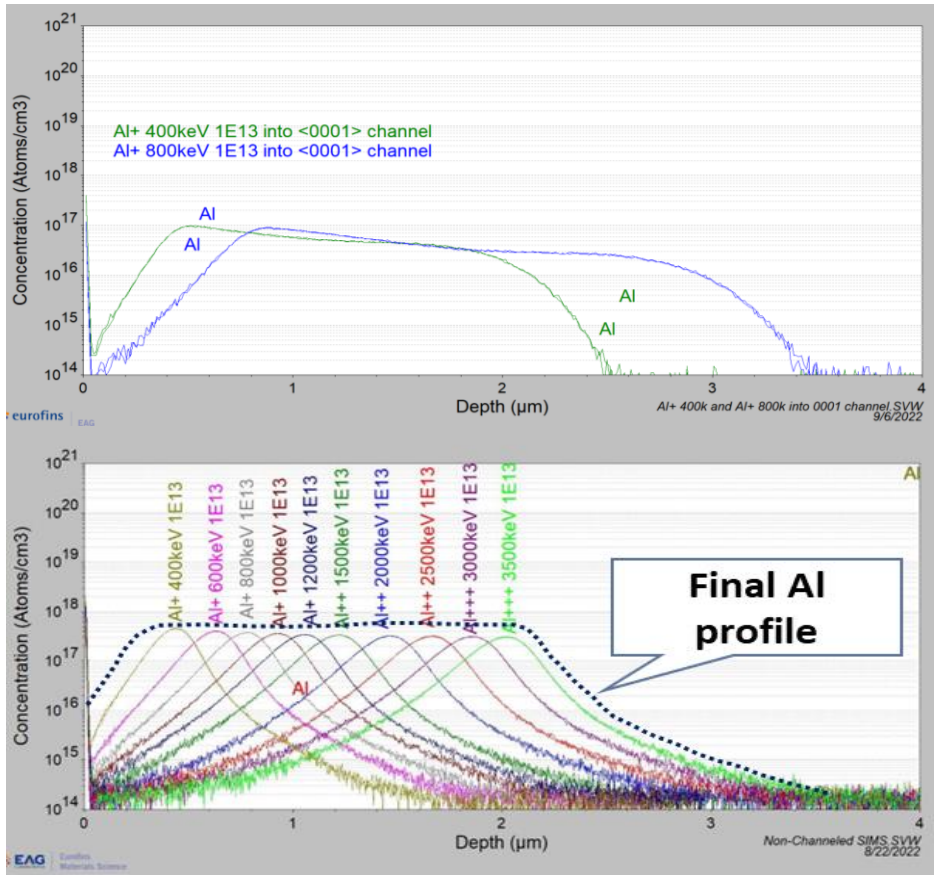
n-type (EPI) + p-type implant



Process (Single Epi Step):

- n-type EPI (final thickness)
- Masking and opening at p-type pillar
- Multiple implants or channeling implants

- Channeling Implant Profiles



- Enable deeper profiles with fewer and lower energy implants
- Implant angle accuracy for channeling profile control

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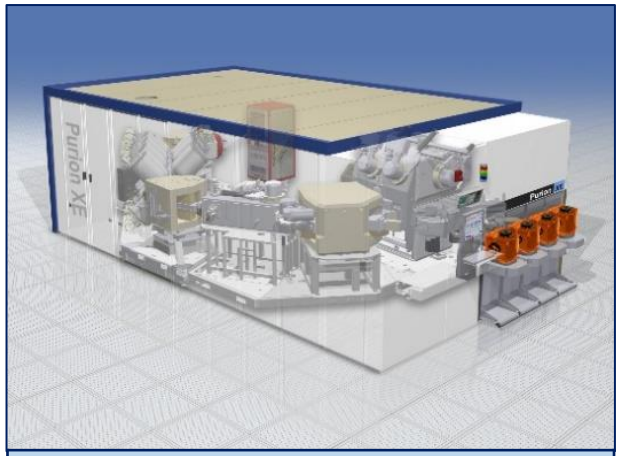
Axcelis High Energy Implant Systems



Purion XE/EXE/VXE
Purion XEmax

Purion XE/EXE SiC

Power Device
Image Sensor
Mature Technologies
Adv DRAM/NAND

- Linear acceleration (LINAC) technology
  - Market leader
  - High productivity
  - Reliable and cost effective
- High temperature implant for SiC
  - Purion XE
  - Purion EXE
- New developed systems:
  - Purion XEmax
    - Ultra high energy system (15MeV)
    - To satisfy implant roadmap requirement

Axcelis Offers Complete Set of High Energy Systems for IC Manufacturing

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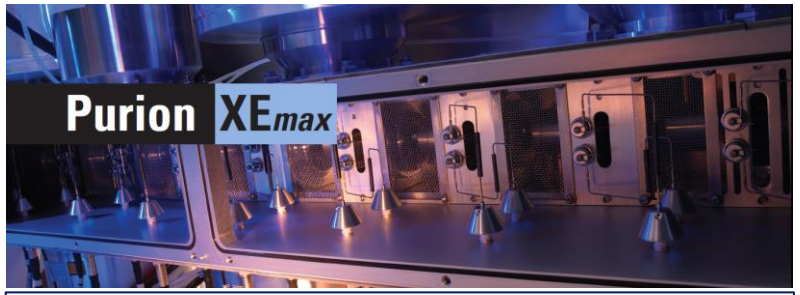
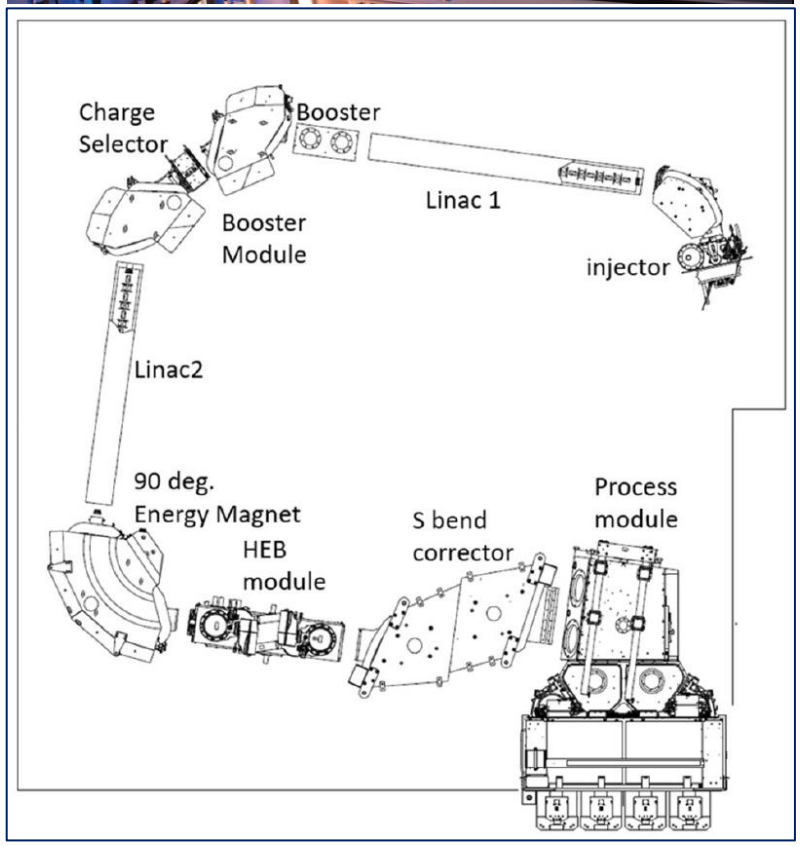
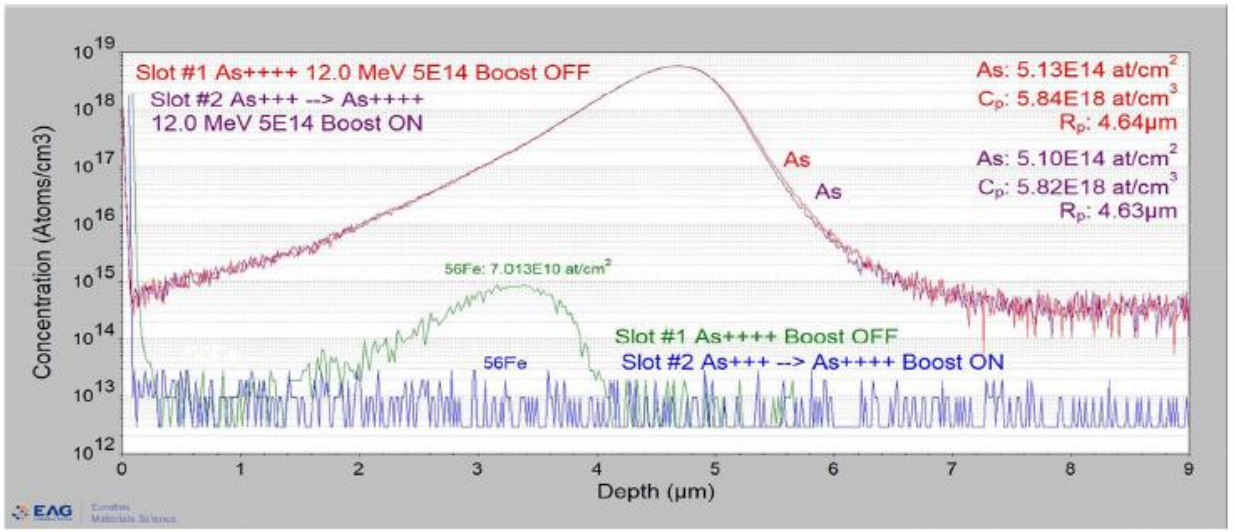
Purion XEmax High Energy System





- Designed to achieve high energy implant capability
  - Higher extraction current
  - Longer source life
- Booster module acceleration
  - Select higher charge state ion after booster
  - Eliminate energetic contaminants generated from ion source



- S bend corrector magnet
  - Provide accurate ion beam angle control

Purion XEmax, Axcelis ultra-high energy implanter with Boost™ technology, Shu Satoh, IIT 2022

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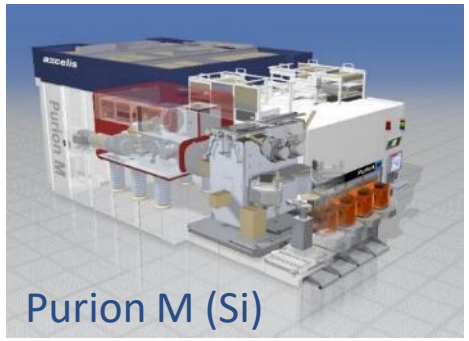
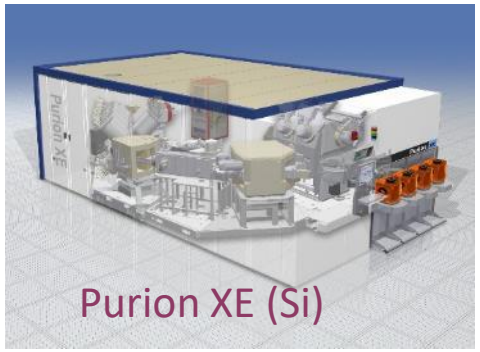
Axcelis Purion Power Series for SiC
Highest Productivity Solution for ALL Implants in SiC HVM

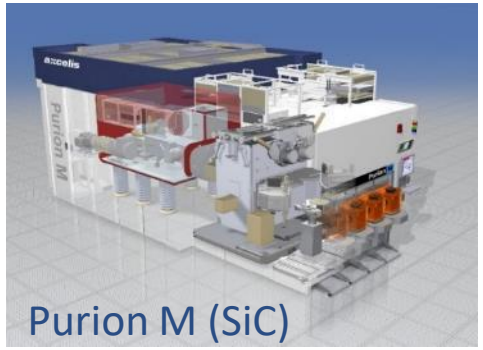


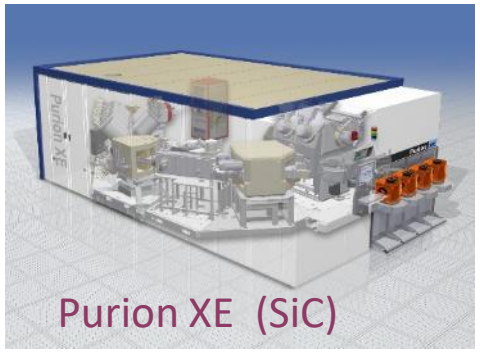


Al+ Source

150/200mm SiC Wafer Handling

Heated Implant Capability (650°C)





Energy Range (keV)

Species	M	XE	H200
+	335	1200	200
++	670	2700	400
+++	1000	3500	--

Highest Productivity Tool Set for SiC Manufacturing

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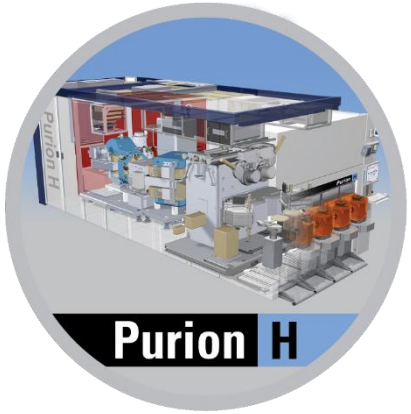
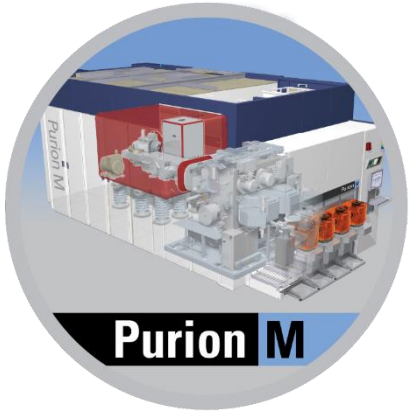
Summary

- Axcelis makes critical R&D investments to fuel continued innovation that further differentiates our products
- Axcelis tools provide a variety of competitive advantages across all customer segments
- Axcelis provides SiC implantation solutions
  - Medium energy with high current implant capability
  - Provide high temperature implant capability with high productivity
  - Provide high energy system for profile optimization/engineering



Purion H200 SiC

Purion XE SiC



Purion M SiC

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