Infusion Doping for USJ Semicon 2005

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Infusion Fundamentals

Epion *n*Fusion™ System

300mm ***n*****Fusion™** System

- Epion is the only commercial developer of Gas Cluster Ion Beam (GCIB) technology with >30 tools manufactured and dominant IP with more than 110 patents issued or pending
- GCIB processes use a directional energetic chemical beam to produce surface effects which are not possible by other techniques

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Semiconductor Applications for "Infusion"

Semiconductor Applications

- USJ Doping
- Ge Infusion/ Deposition
- Si_xGe_{1-x} Deposition
- Other Deposition
- Etching Applications

•All of these applications involve chemical delivery by GCIB

•GCIB = Directed, energetic, chemical beam

•Unique qualities of GCIB lead to unique process capabilities

•"Infusion Processing": New name to set GCIB apart from other types of ion beam and plasma processing.

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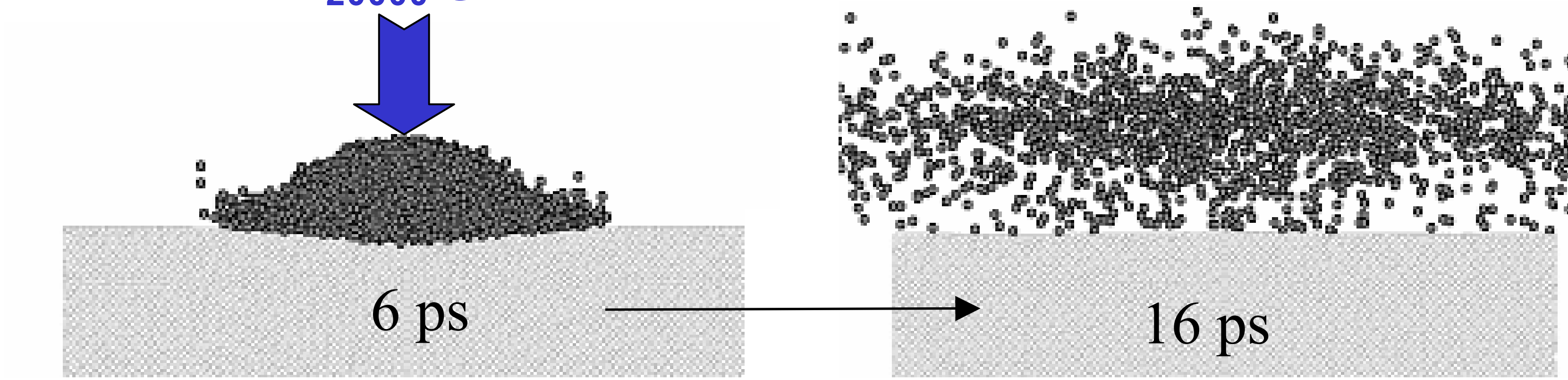
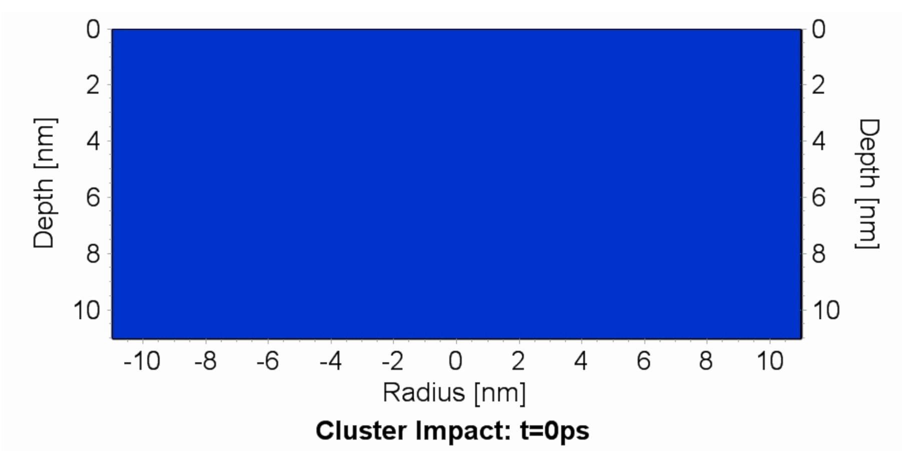
Infusion:
Transient Temperature and Pressure Spike (TTPS)

Ar_{20000} @20keV = 1eV/atom



(MD Simulation: Aoki-san, Laboratory of Advanced Science and Technology for Industry, Himeji Institute of Technology)



(FEA Simulation: M Gwinn, Epion corporation)

- Large Temperature Transient
- Large Pressure Transient
- Lasts on the order of picoseconds

1eV atoms can not penetrate surface

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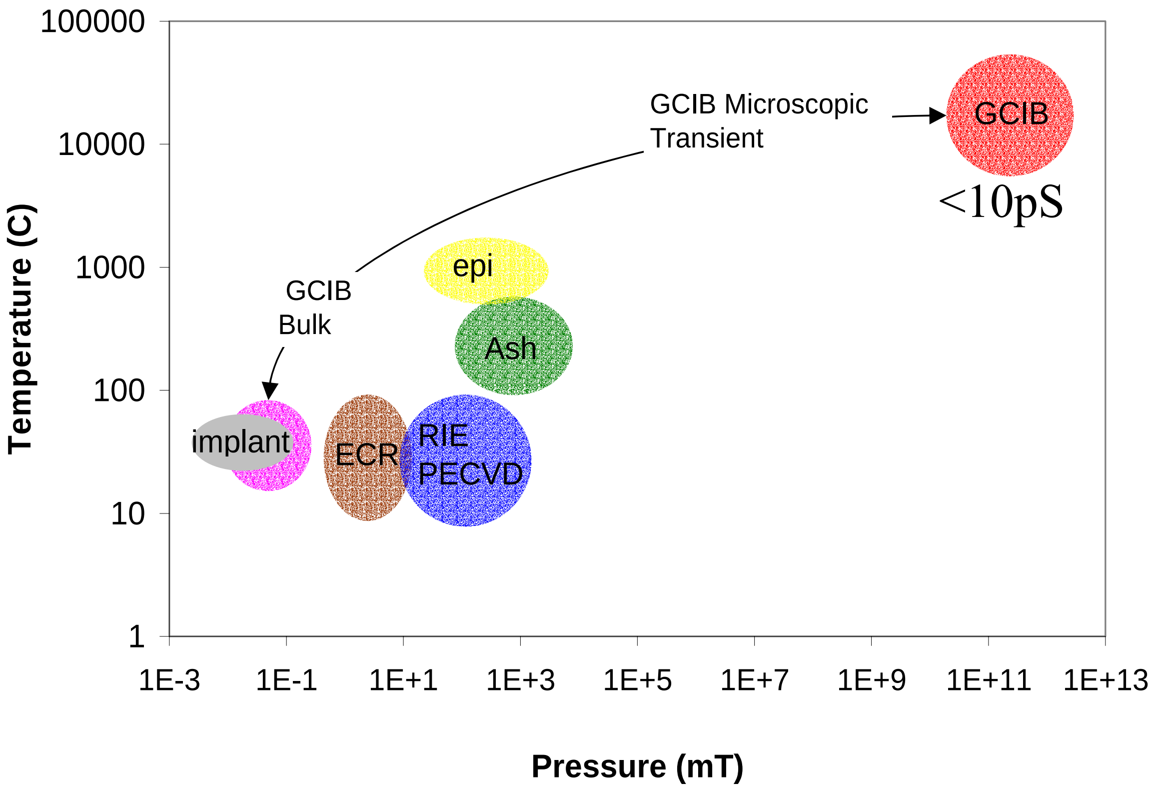
Processing Conditions Comparison



- The extreme high pressure and thermal spike produced locally (10-20 nm diameter) during the cluster impact enables unique processing capabilities.
- The bulk wafer remains at room temperature and in 10^{-5} Torr which prohibits any gas phase reactions.
- All chemical and physical effects take place locally during the 10^{-12} seconds the gas atoms infuse into the substrate.
- The heated volume is quenched in 3 dimensions in $<10^{-11}$ seconds producing a uniform amorphous layer.

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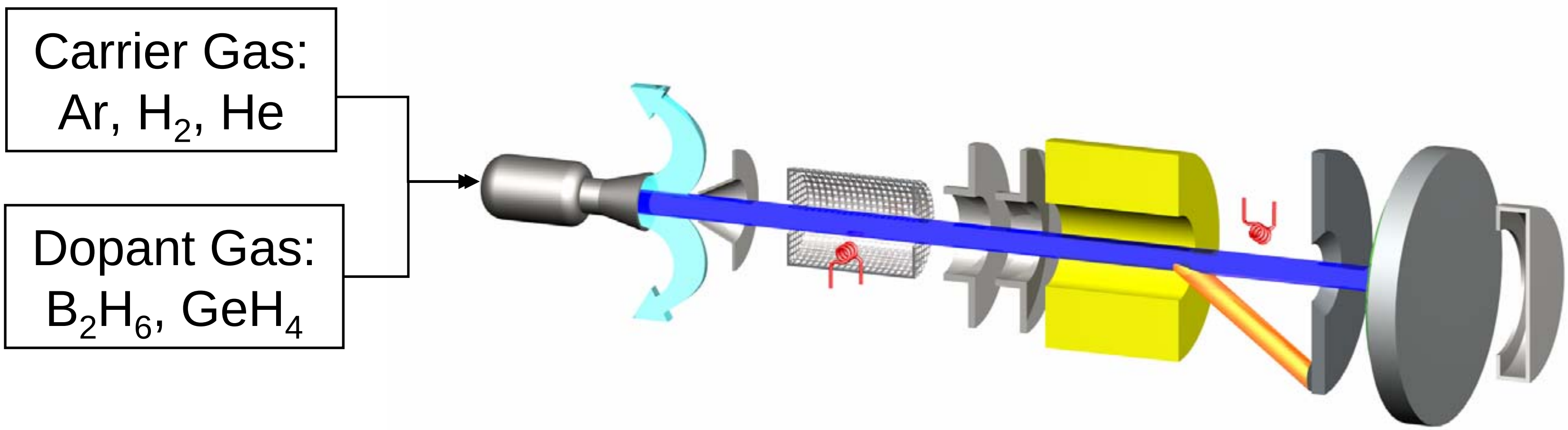
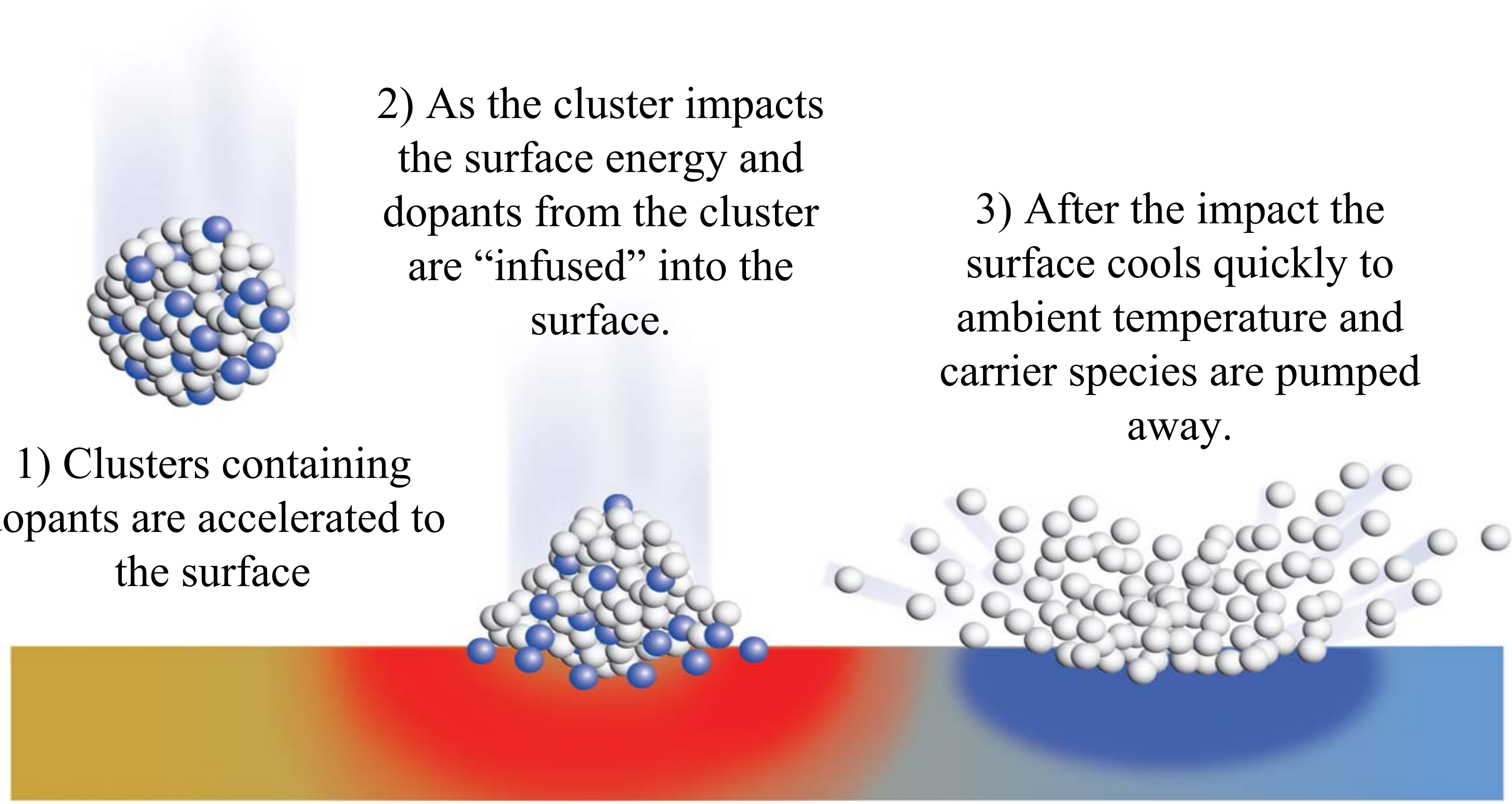
Adding chemistry to clusters

- Chemistry is mixed into the carrier gas prior to cluster formation



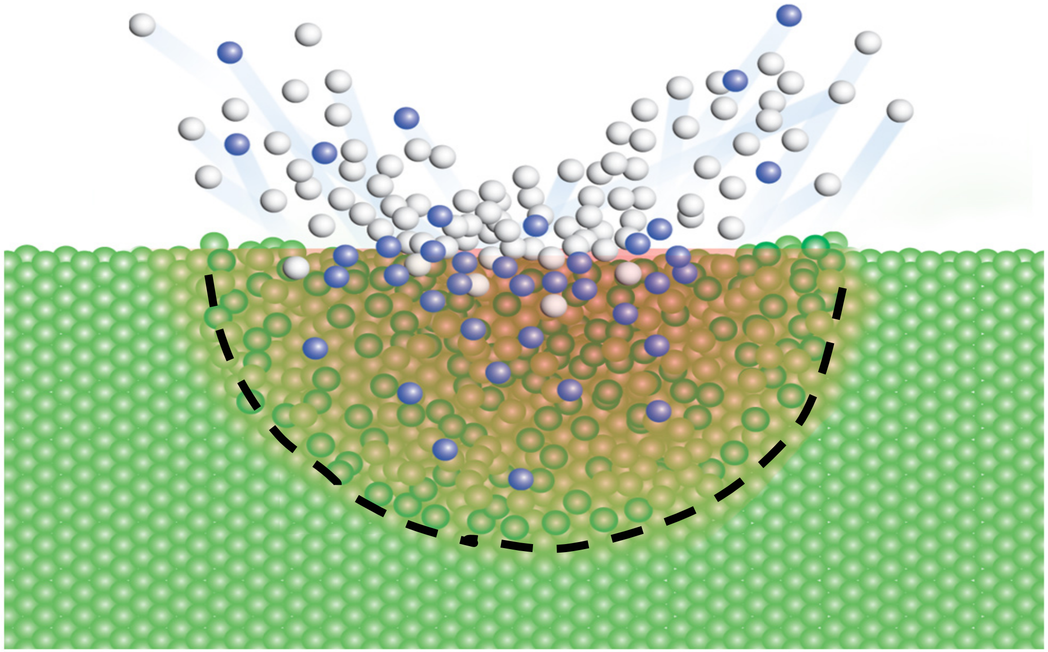
- Chemistry is carried in the cluster to the substrate

Infusion: Doping and Deposition



GCIB is fundamentally distinct from monomer or molecular ($B_{10}H_{14}$, $B_{18}H_{22}$) ion beam processing:

- >5000 atoms / cluster = < 10 eV / atom
- Volume of infusion region depends upon E of cluster
- **Infusion depth depends upon $E^{1/3}$ and is <u>species independent</u>**
- Multiple gas species can be combined in the cluster and be co-infused
- Multiple overlapping impacts create uniform amorphous layer
- Abrupt amorphous interface with no channeling and no EOR defects



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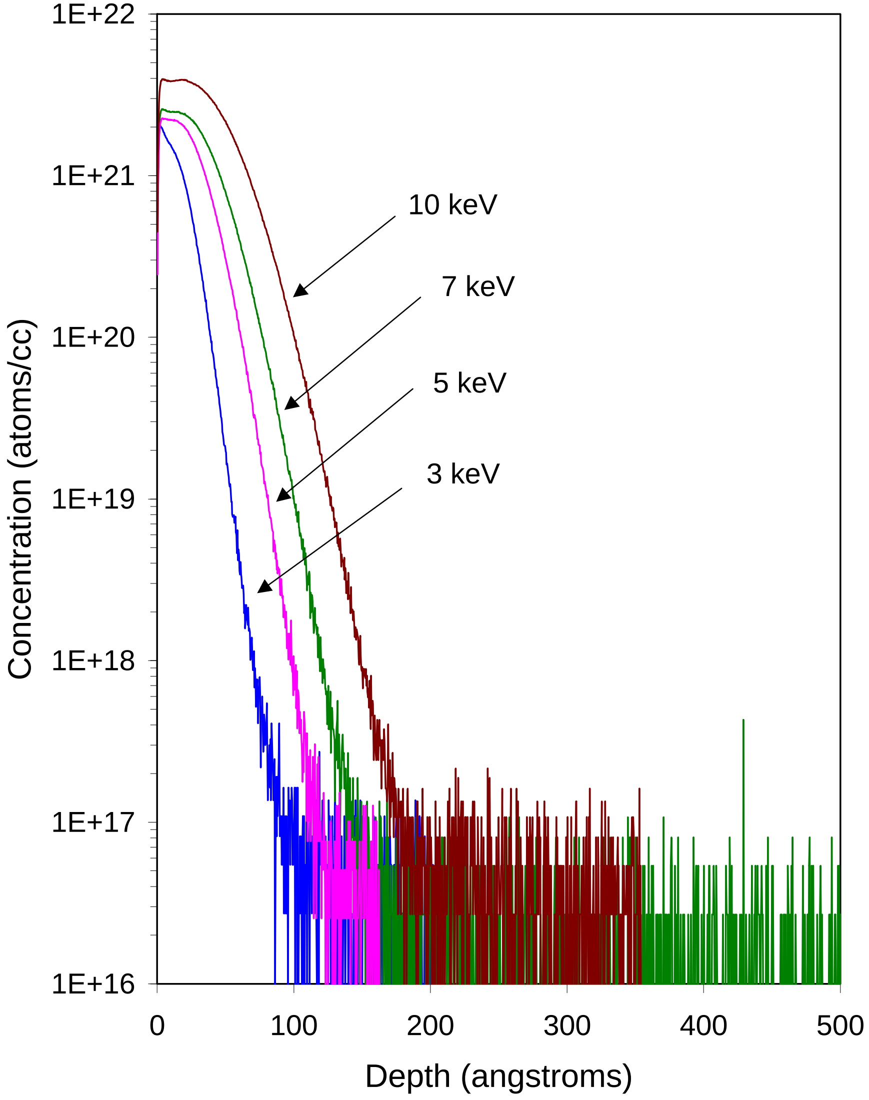
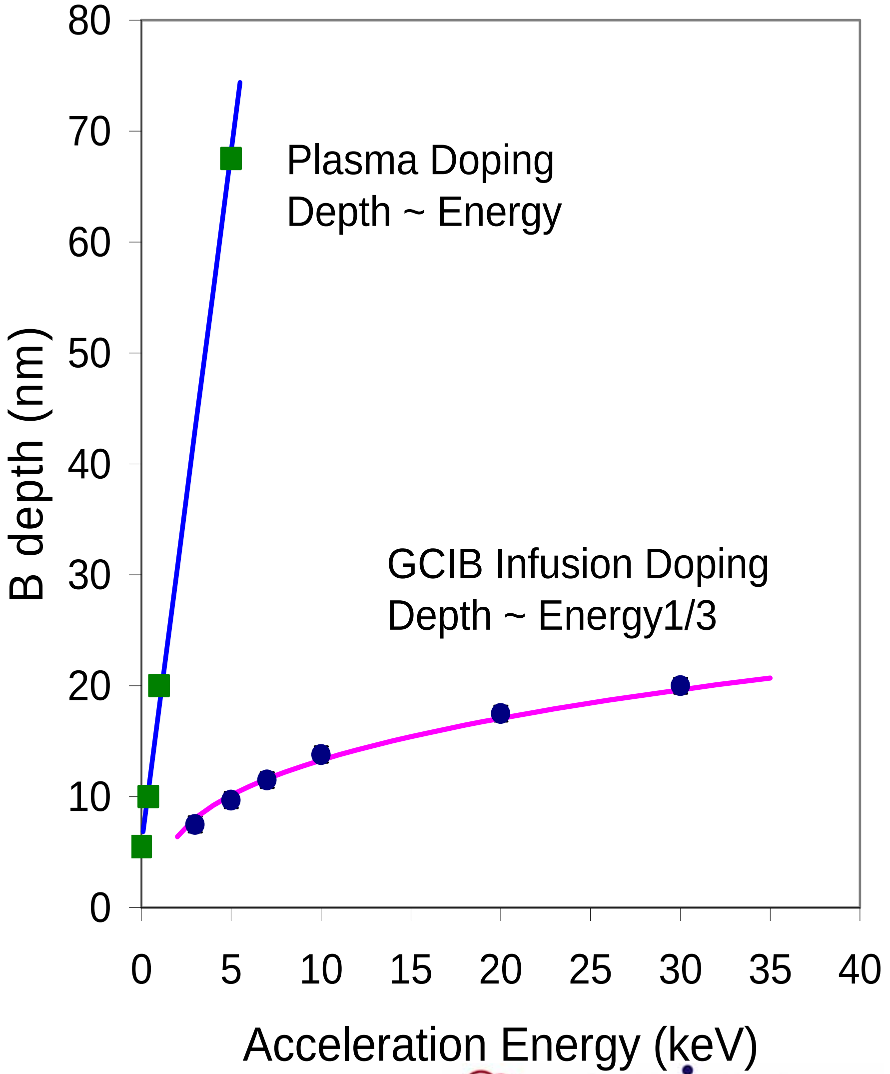
Xj vs Energy





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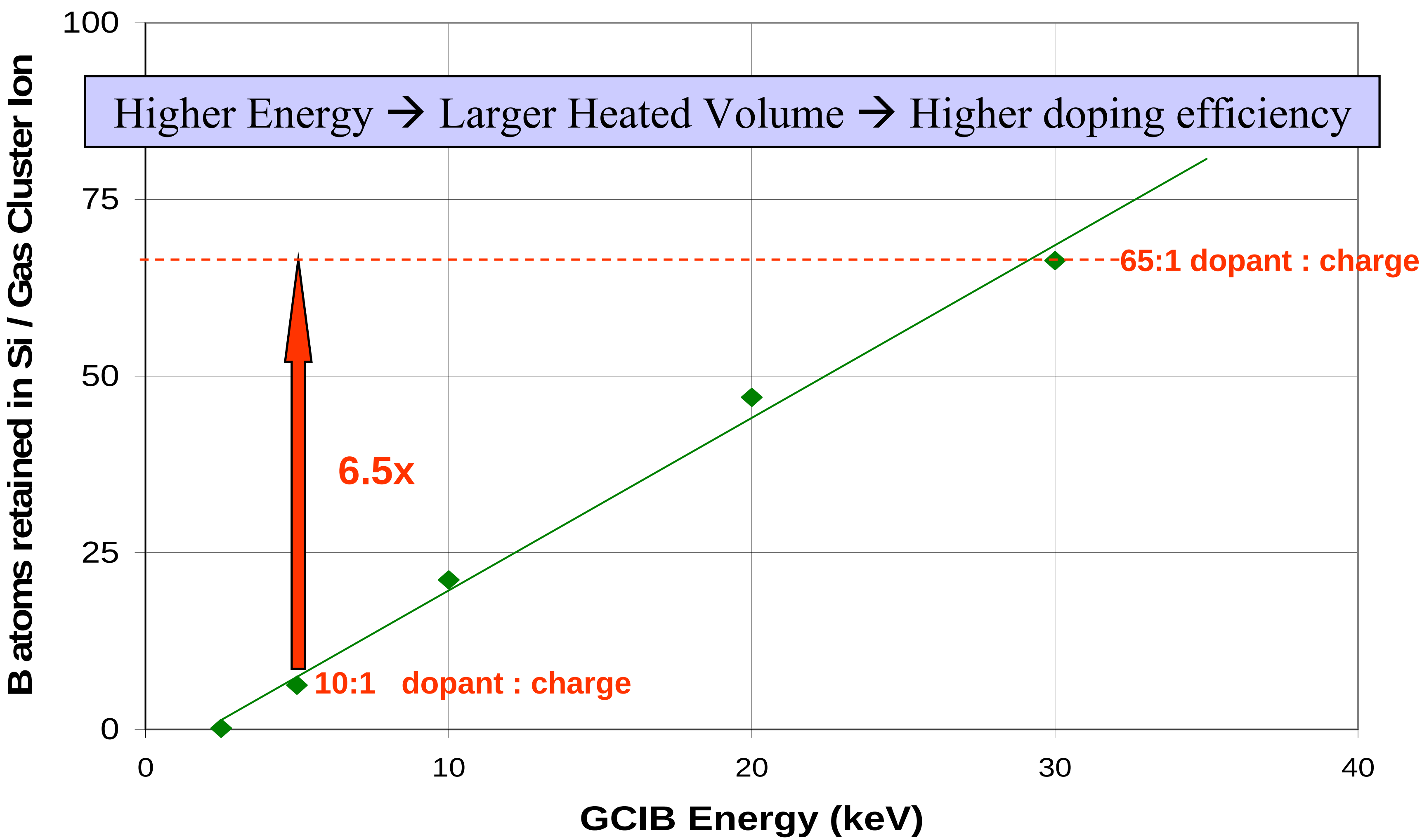
Infusion Doping:
Efficiency vs. Energy



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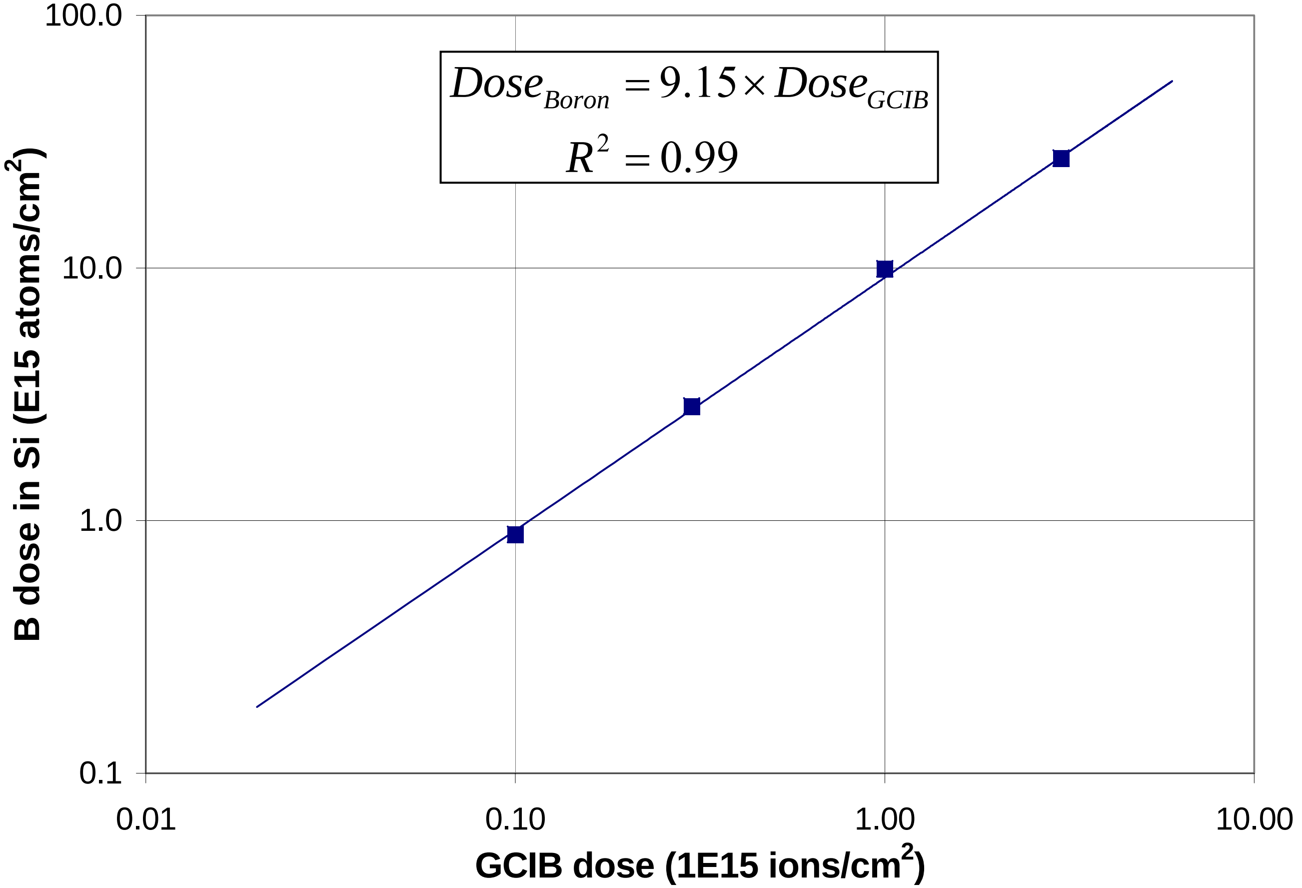
Infusion Doping: Scalability



Infusion doping scalability : B doping vs. Infusion dose for a given Ar+B_2H_6 mix and Infusion energy

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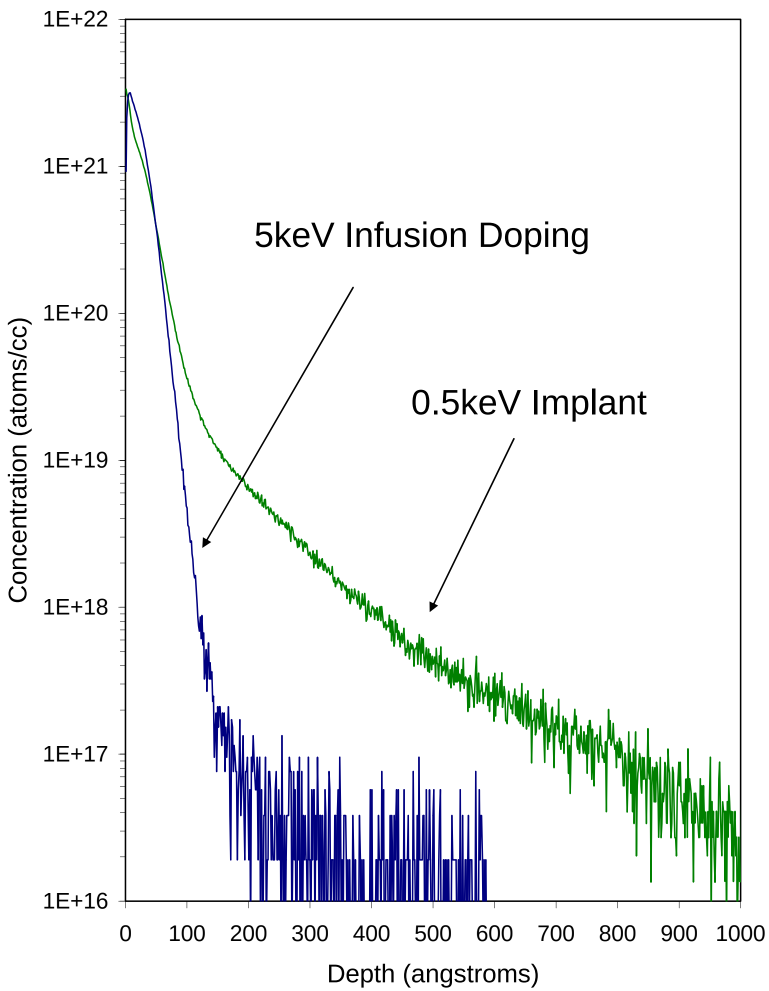
Ultra shallow junction (USJ) formation



Advantages offered by GCIB infusion doping:

- no channeling
- no energy contamination effect
- no pre-amorphization step required
- scales to high dopant levels
- extremely abrupt profiles
- no end-of-range damage
- versatility and extendibility

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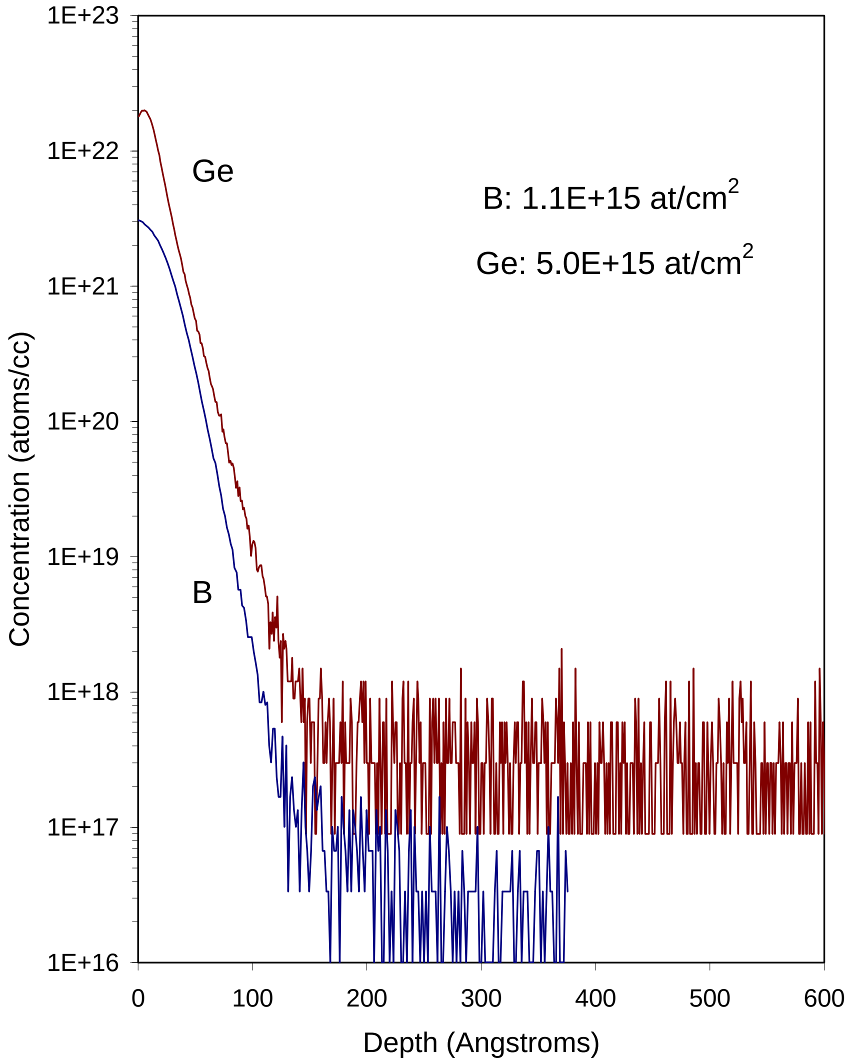
“Cocktail” Doping



B_2H_6+GeH_4 co-infusion

- By mixing source gasses multiple species can be co-infused.
- All species infuse to same depth which is dependent only on the beam energy and not atomic mass.

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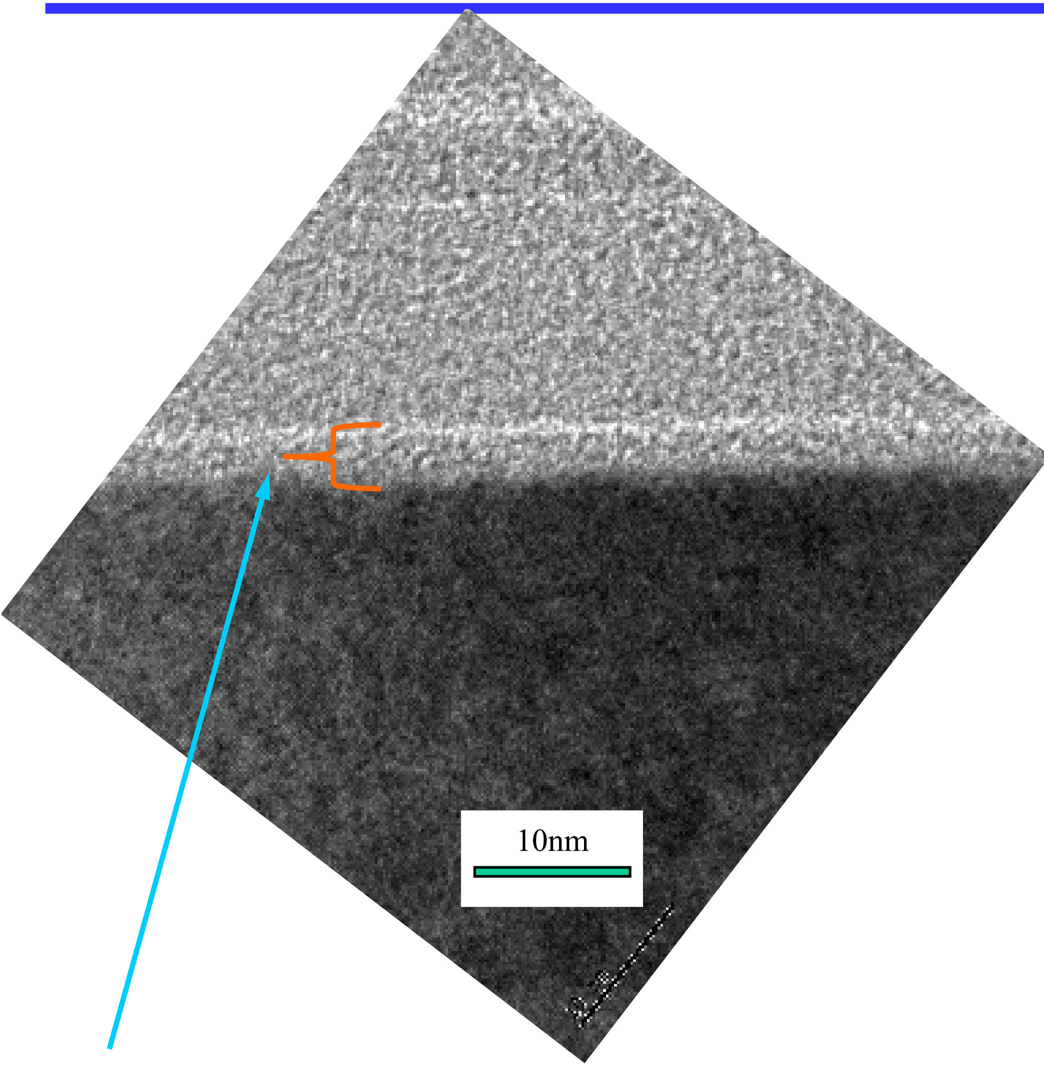
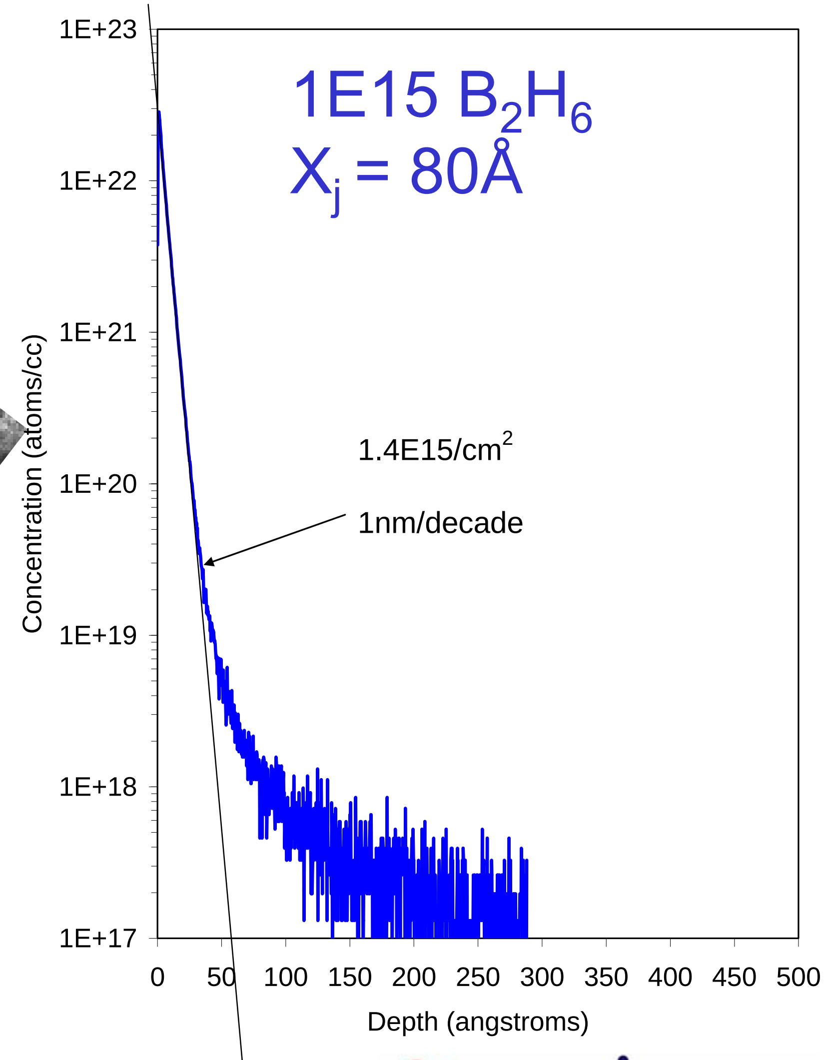
Infusion Processing Results

GCIB Infusion doping : Ultra-shallow + self amorphizing



5nm amorphous region



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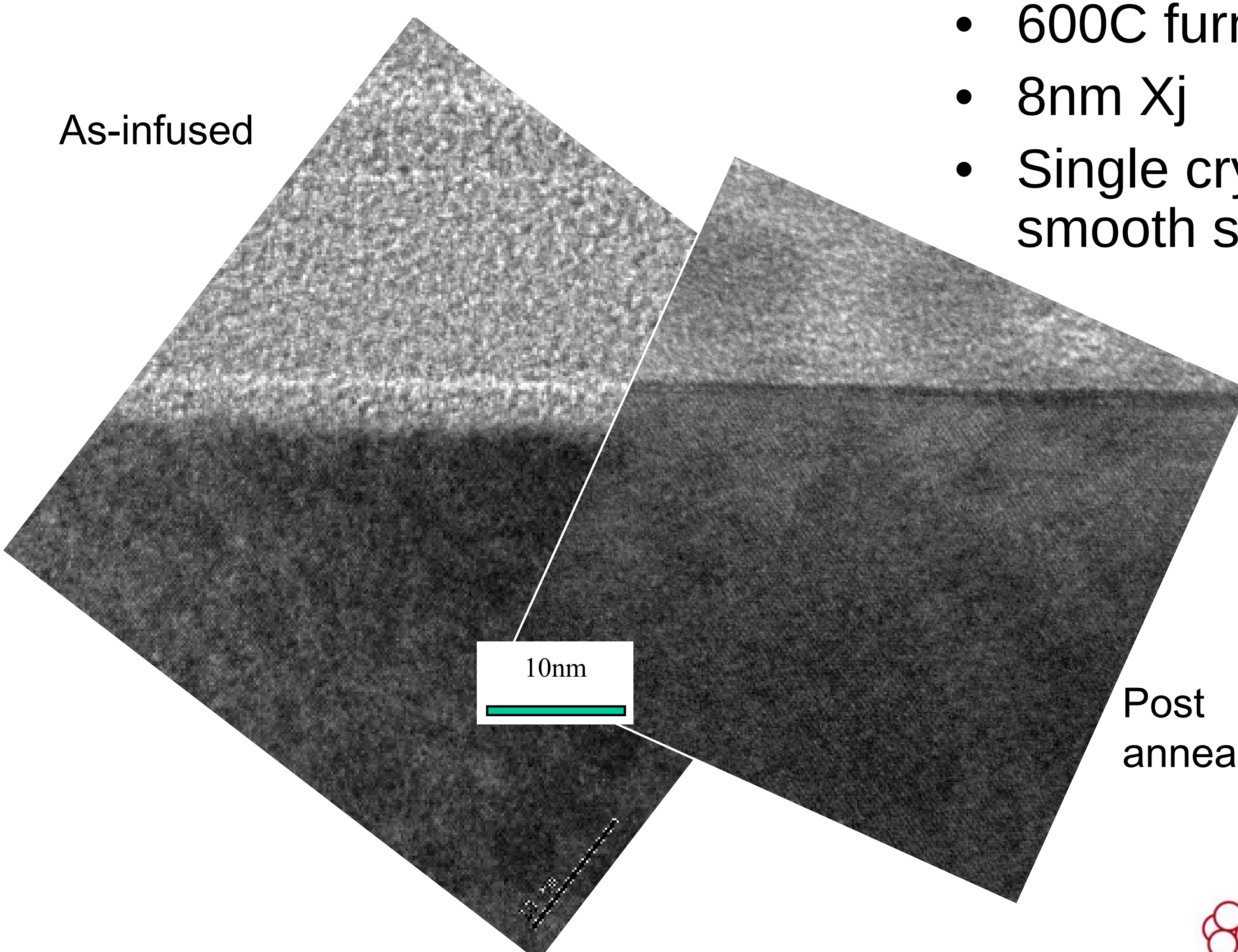
SPE anneal of self-amorphized B infused layer

- 600C furnace anneal
- 8nm Xj
- Single crystal with smooth surface

As-infused



Post anneal

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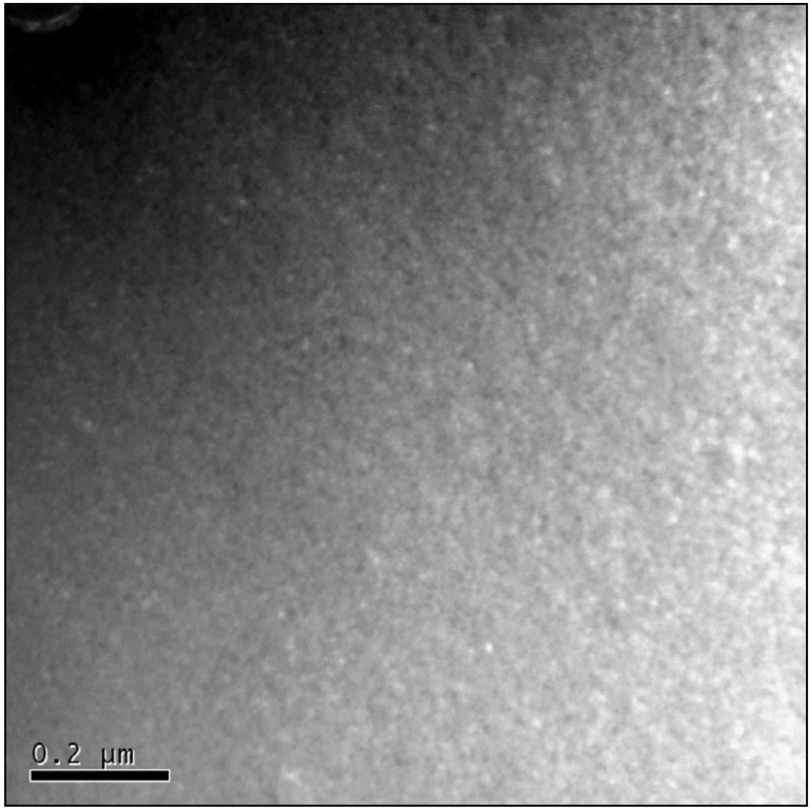
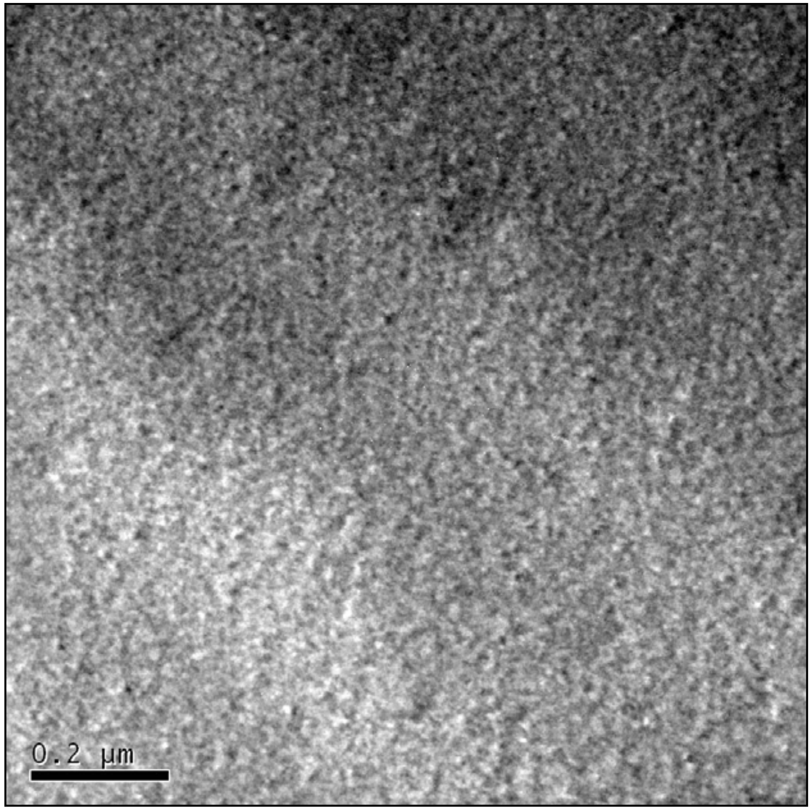
PV-TEM: New Shallow Process after anneal



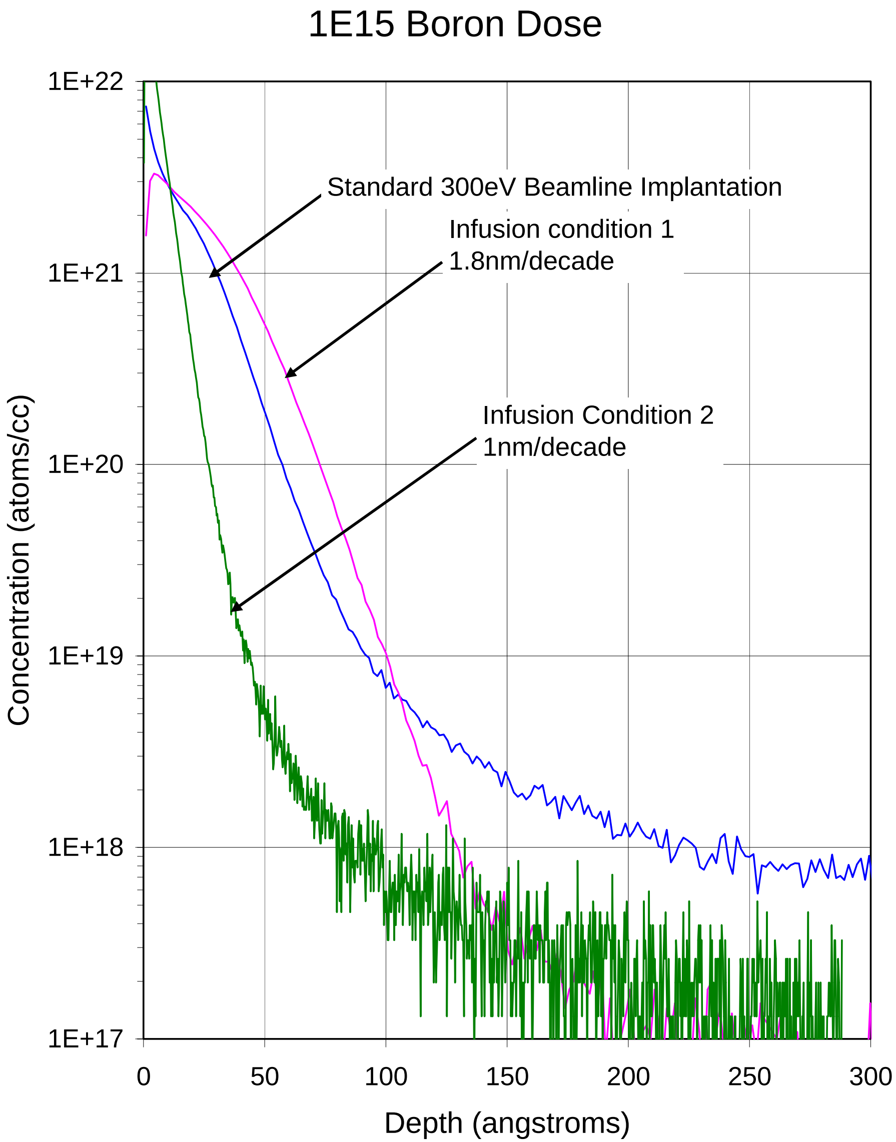
After 900C, 30 Sec



After 1000C+350C Flash

PV TEM: Silicon is in excellent condition after anneal

Infusion Conditions and Beam Line Implant



- Ultra shallow and Ultra abrupt doping profile opens up opportunities for annealing.
- Because the boron starts so shallow we can allow for more diffusion of the profile.
- Process Time for both Infusion Processes: ~2.5minutes/wafer (200mm)

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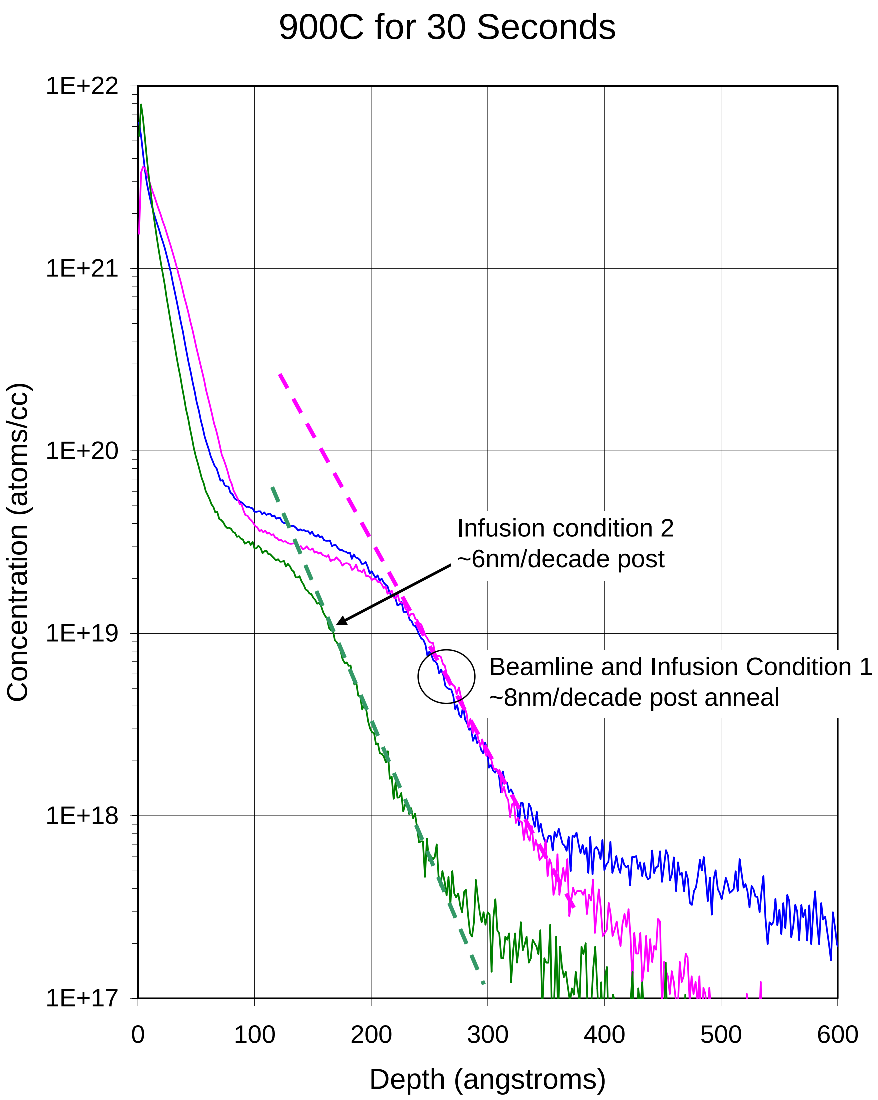
Infusion Conditions: Spike Anneal



- Shallow Doping condition *remains more* shallow than other conditions.
- More abrupt doping profile post anneal: 6nm/decade post anneal.
- Infusion Cond. 1 Rs = 990 Ohms/Sq
- Infusion Cond. 2 Rs = 1370 Ohms/Sq
- Beamline Rs = 940 Ohms/Sq

Spike anneal performed by Sematech

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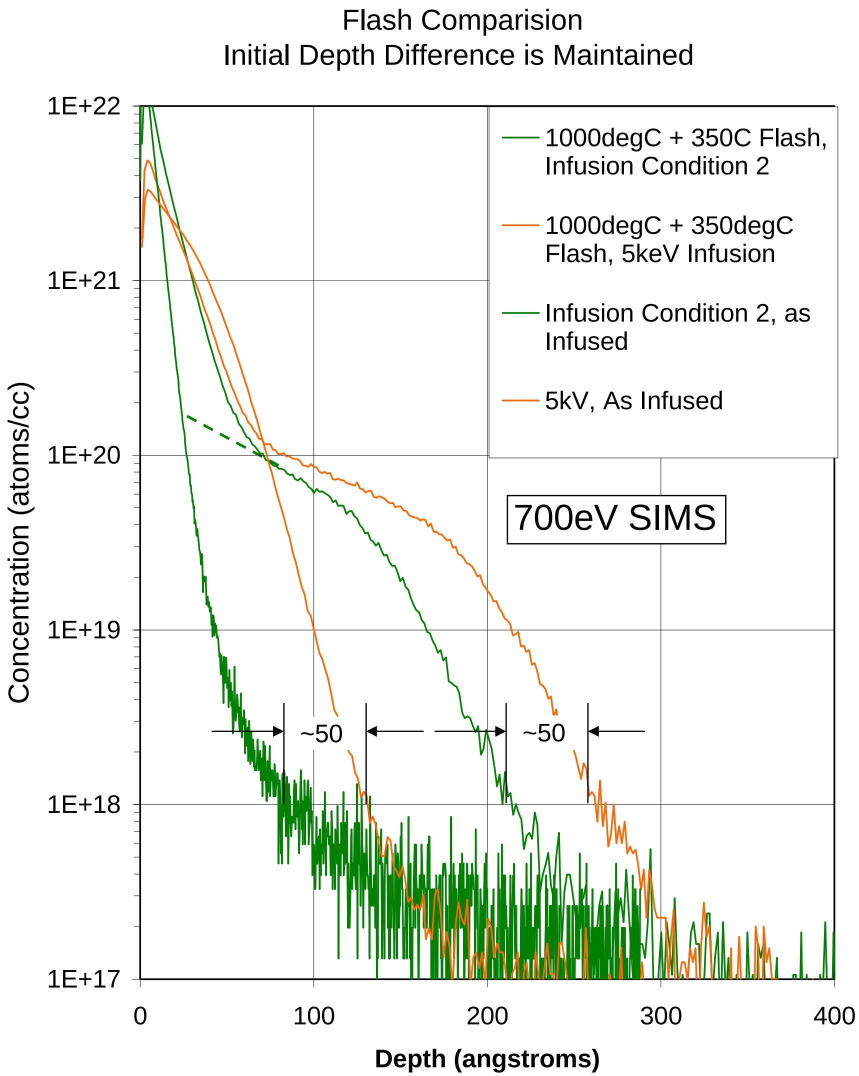
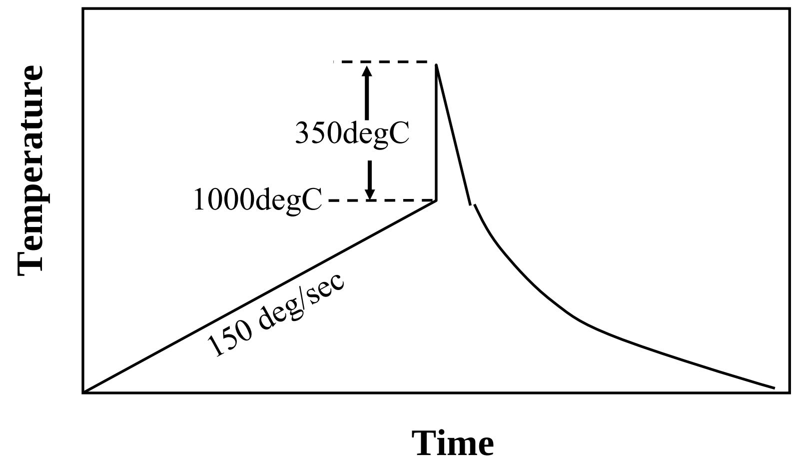
Anneal Conditions: Flash Anneal





•Infusion Cond. 1 Rs = 570 Ohms/Sq

•Infusion Cond. 2 Rs = 840 Ohms/Sq

•Initial Depth advantage of shallow condition is maintained

Flash anneal performed courtesy of Mattson/Vortek

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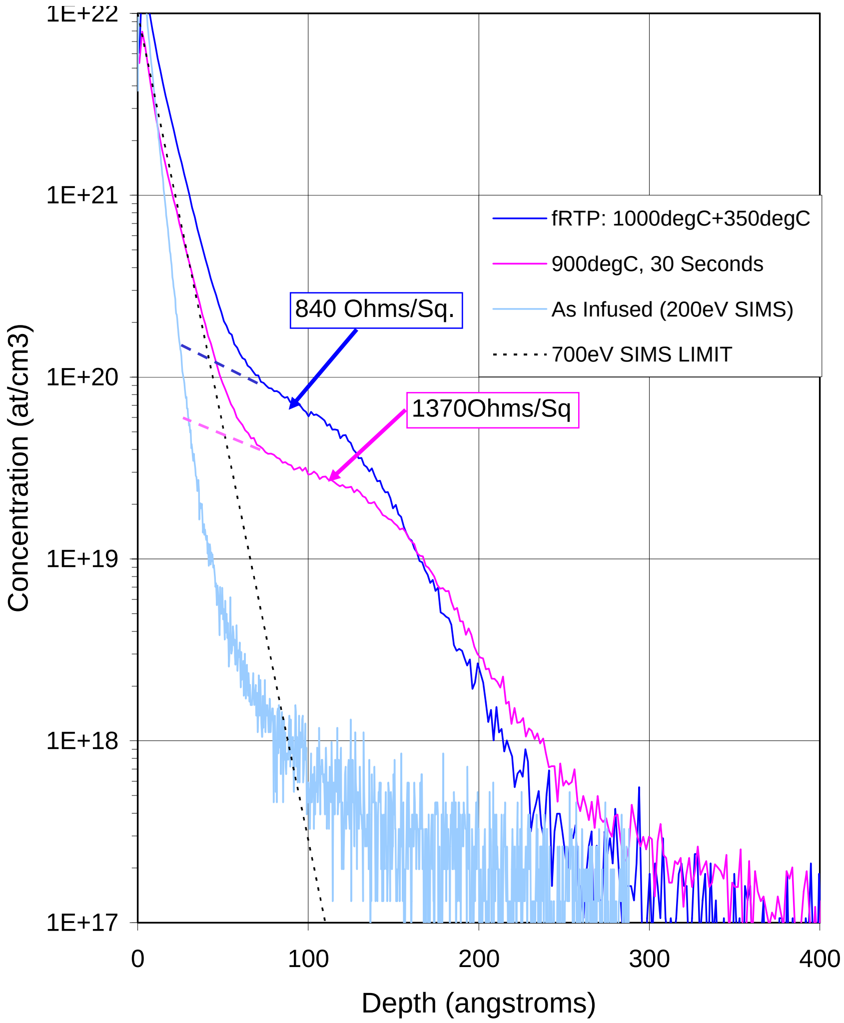
Anneal Conditions: Spike vs. Flash



- Different annealing conditions can give the same Xj
- Activation level drives Rs.
- More shallow as doped Xj allows for more higher temperature with higher activation and more diffusion.

Flash anneal performed by Mattson/Vortek

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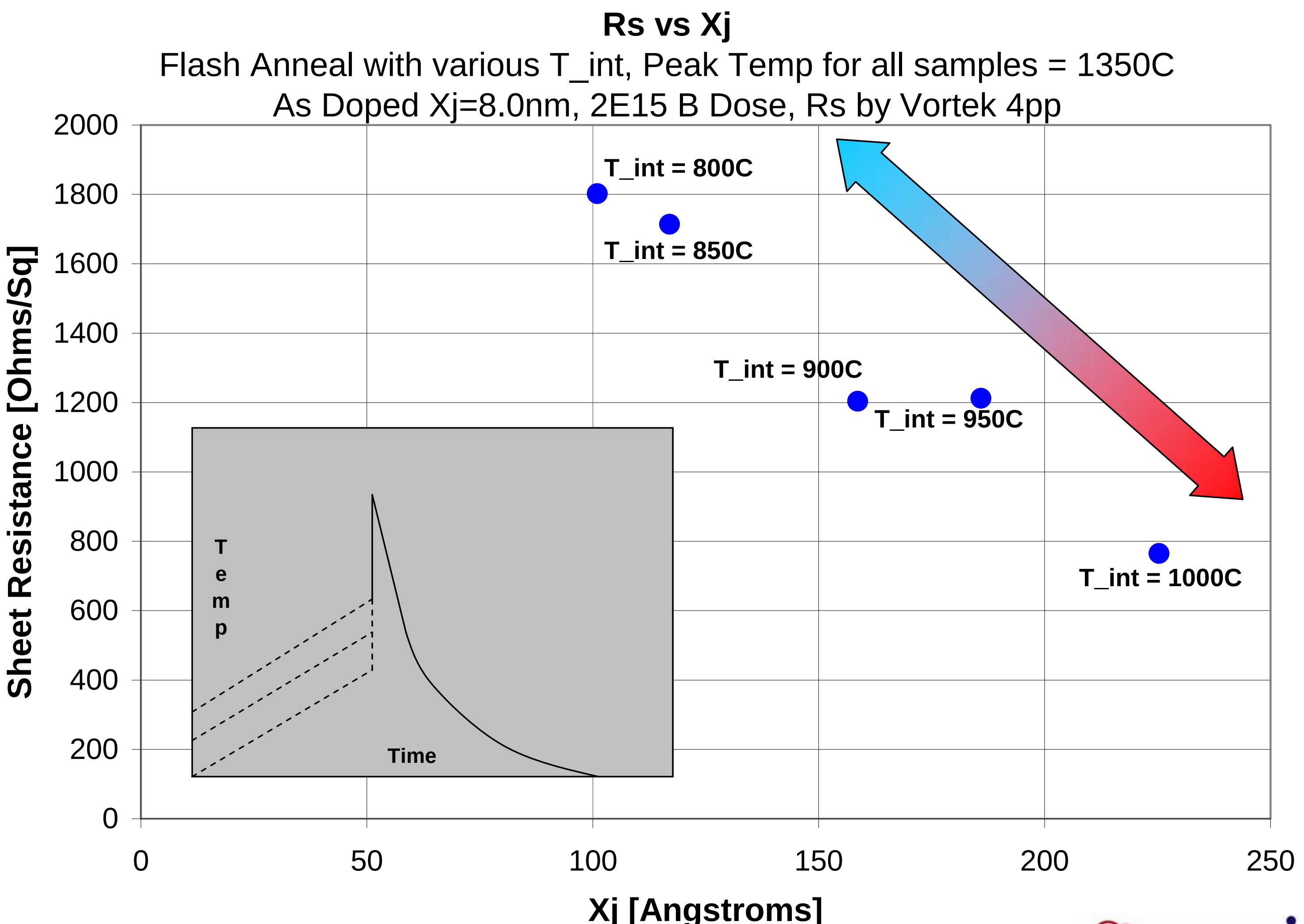
Xj for Various Flash Conditions



(1E18)

Flash anneal performed courtesy of Mattson/Vortek

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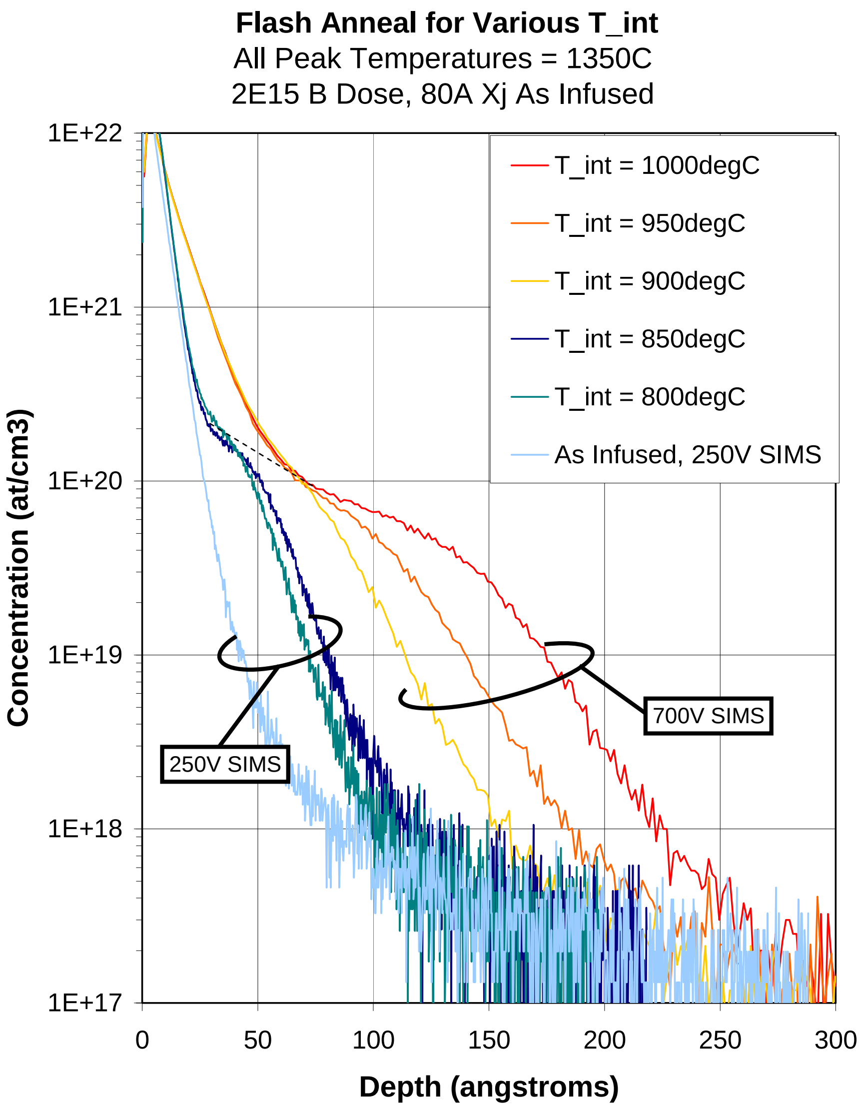
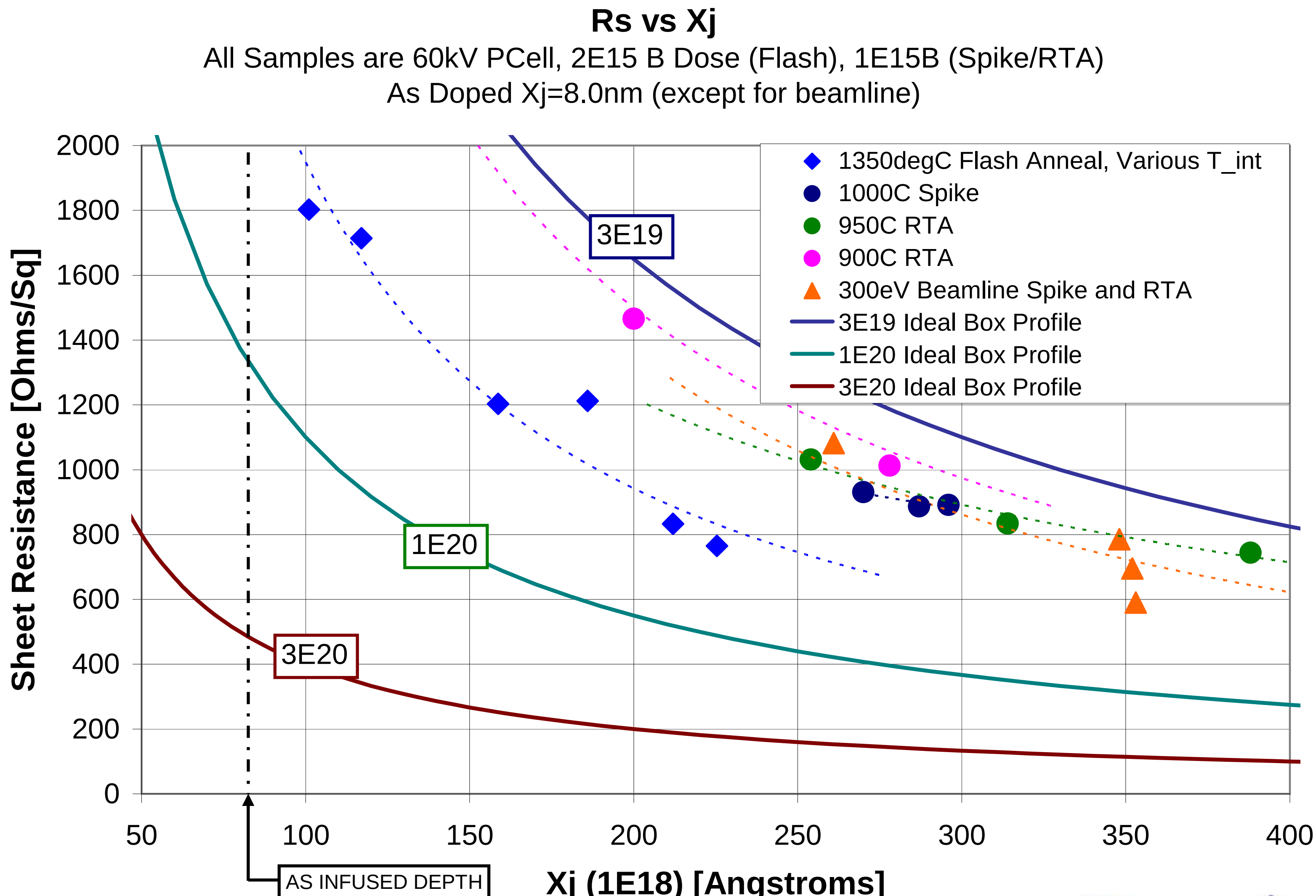
SIMS for Various T_{int} , 1350degC T_{Peak}



250V SIMS reveals true profile and Xj for shallow samples.

Summary of anneals



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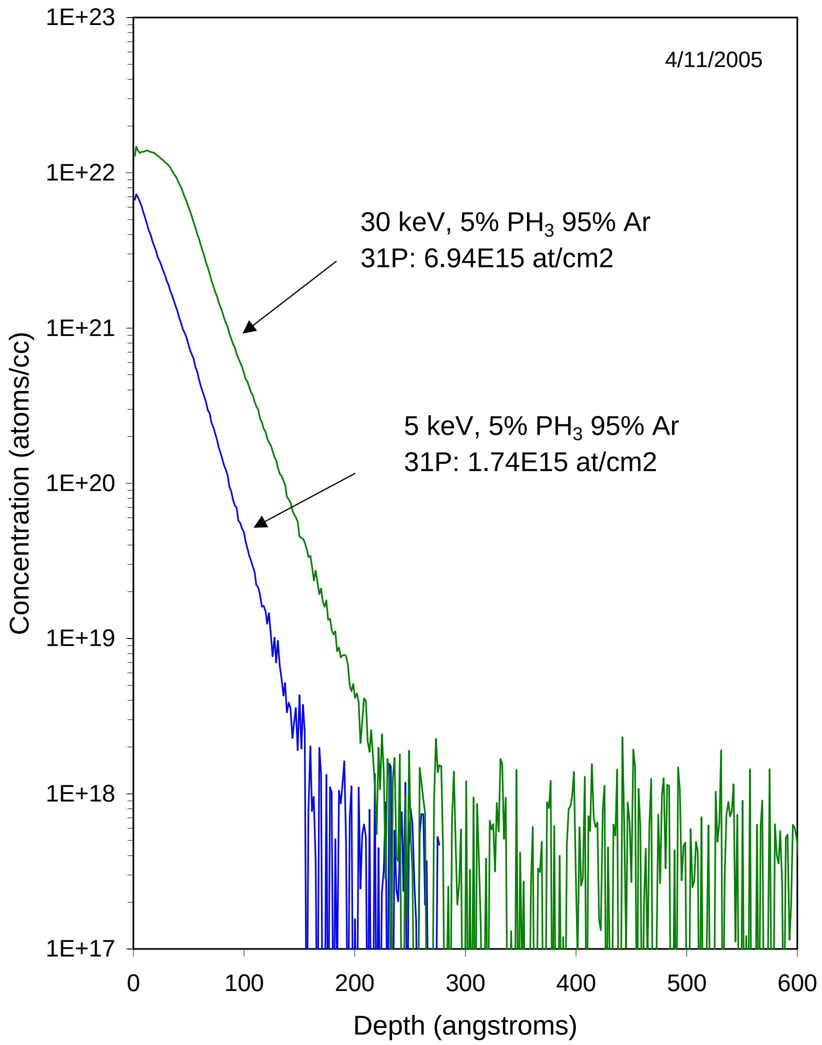
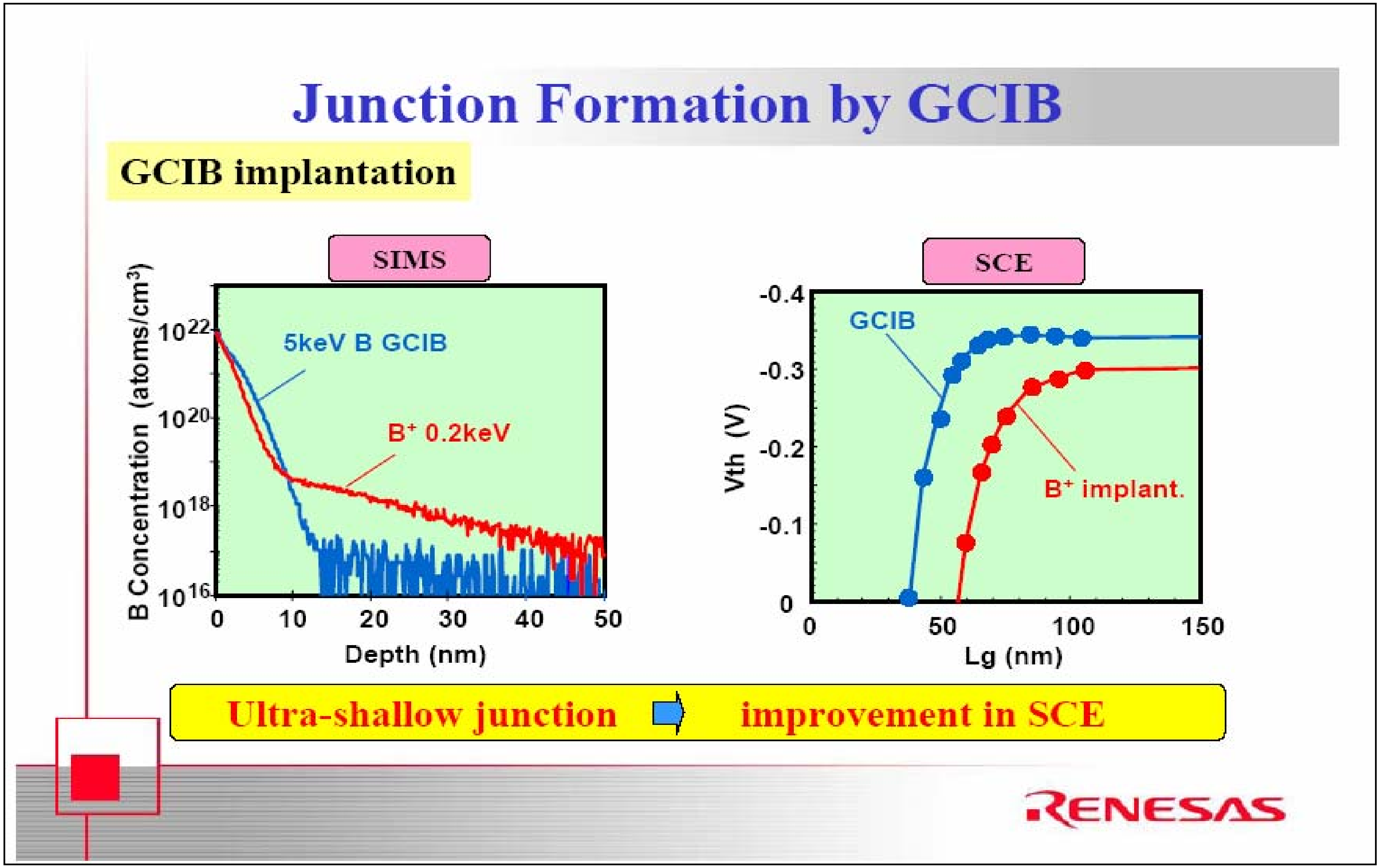
N Type Doping



- N-type doping with PH3 has been demonstrated.
- As doping is also possible, but not demonstrated yet

Device Data



Kuroi and Kawasaki, Renesas Technology Corporation, USJ 2005

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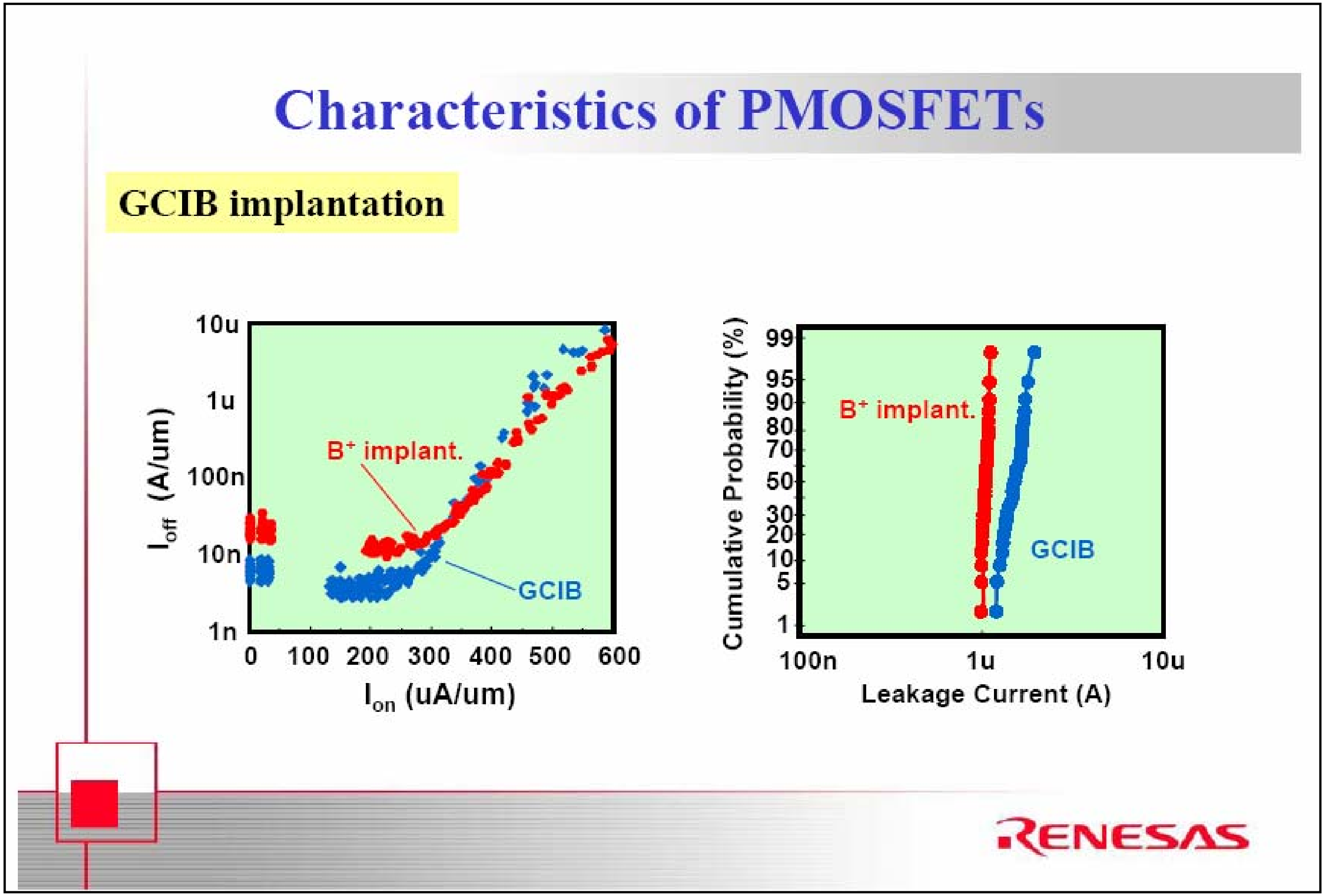
Device Data



Kuroi and Kawasaki, Renesas Technology Corporation, USJ 2005

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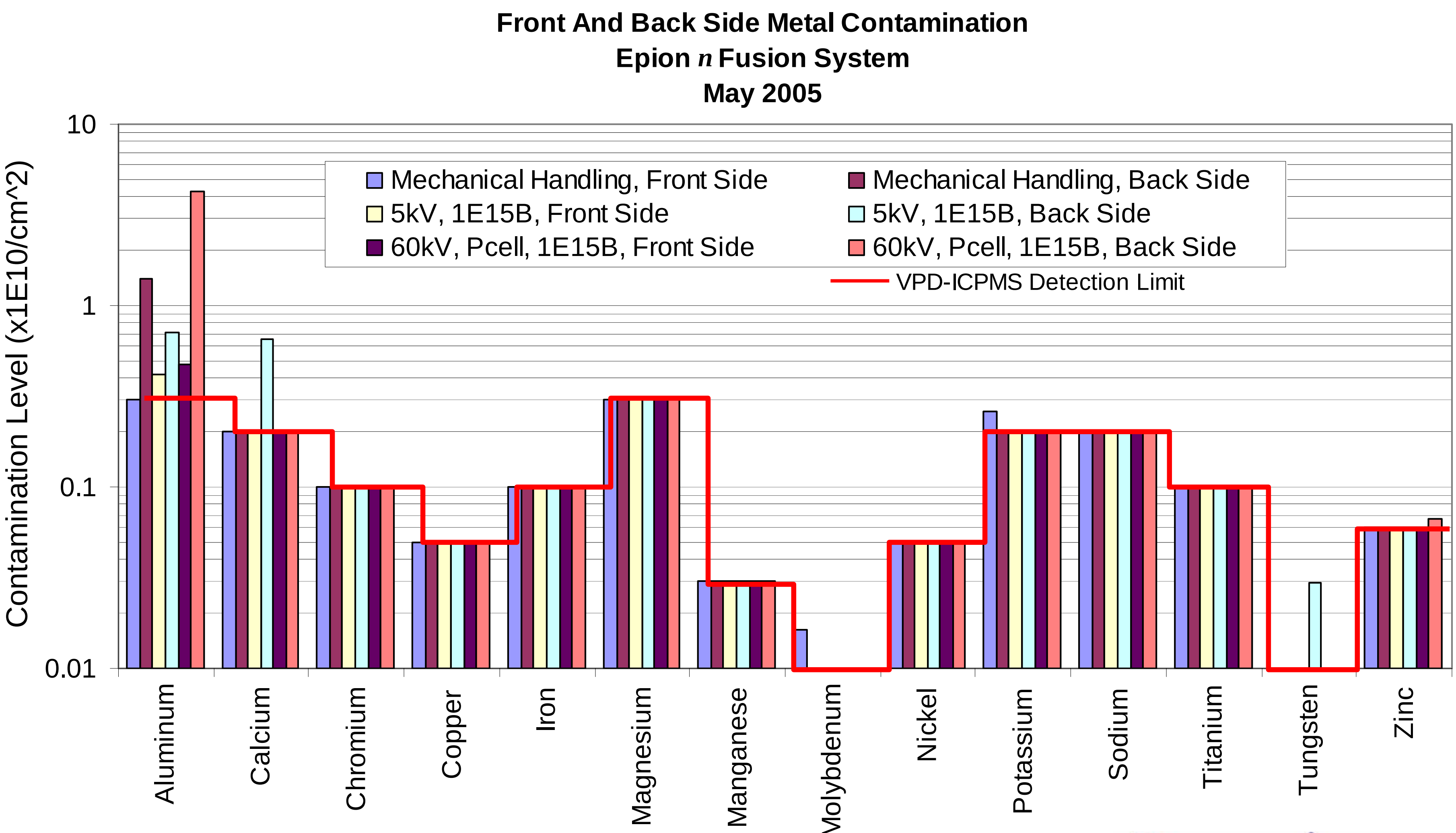
Metal Contamination



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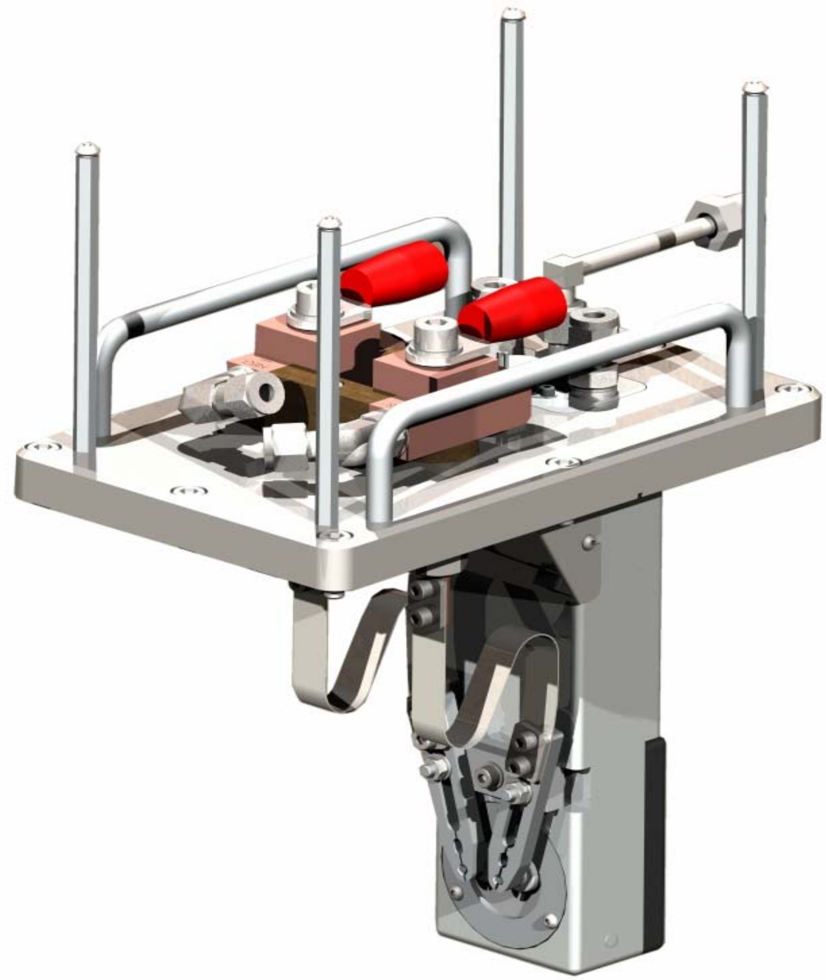
Wafer Charging

PEF:
"Plasma Electron Flood"

•Provides low energy electrons to the beam.

•Makes the average net charge in the beam near zero.



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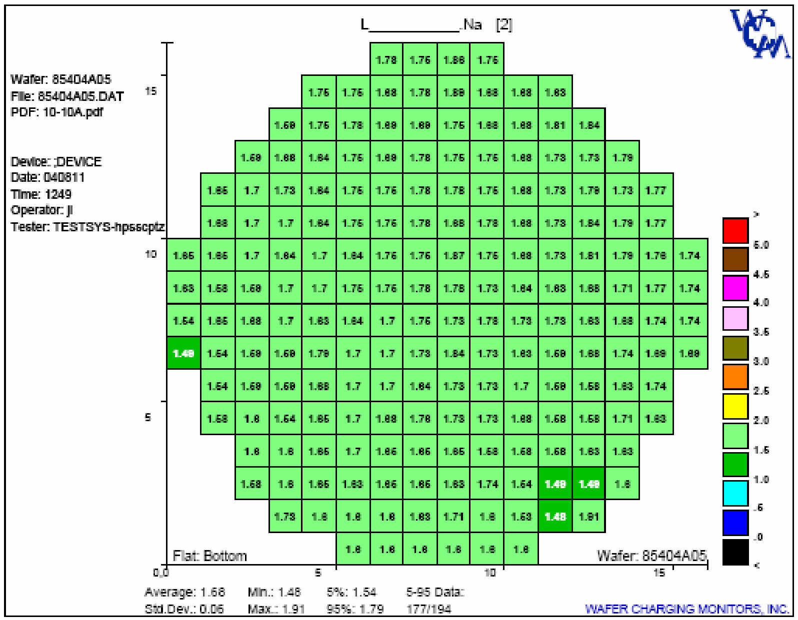
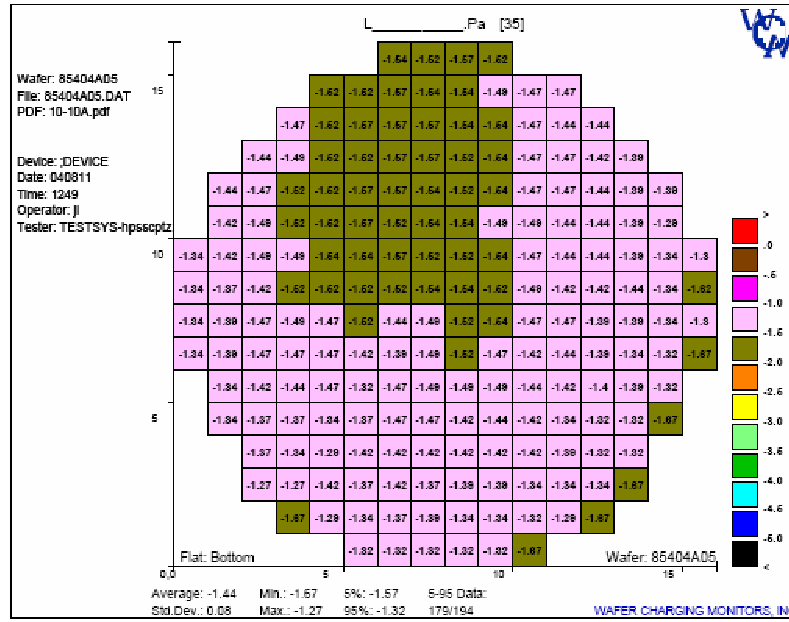
Wafer Charging

Positive Charging
Maximum = 1.78V

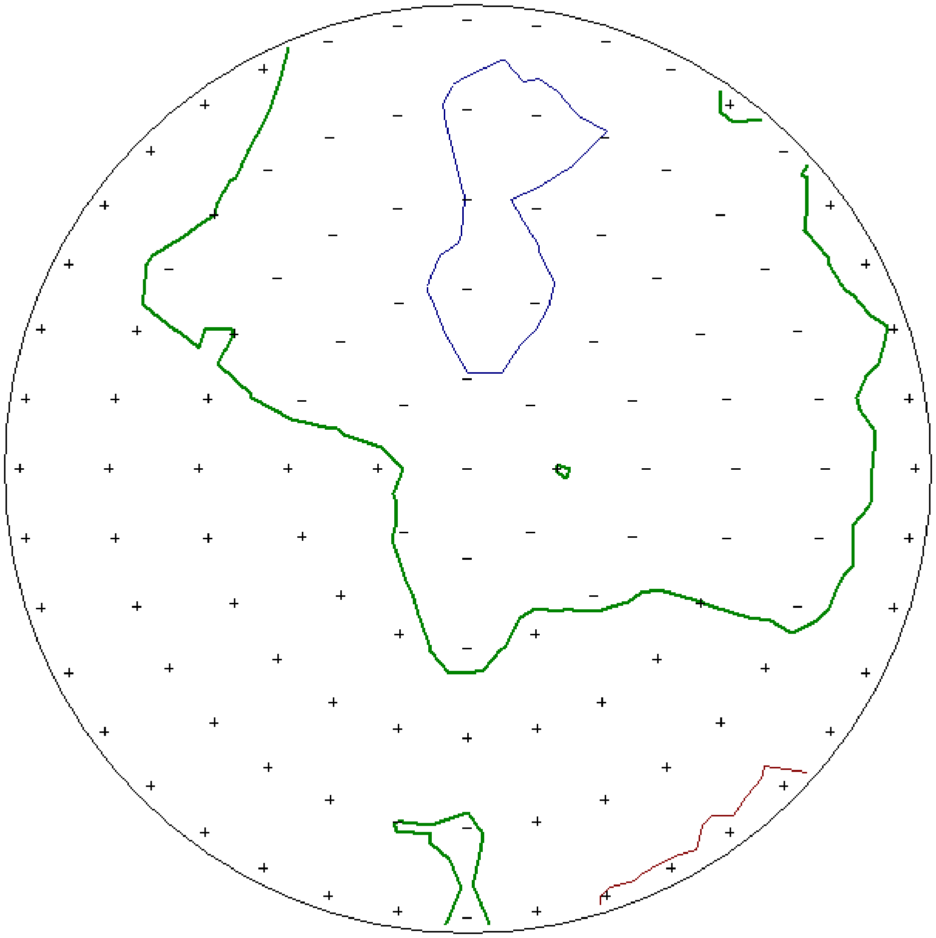


Negative Charging
Minimum = -1.67V



Most values are at the minimum limit for measuring via CHARM wafer.
Boron Dose = 1e15

Uniformity:



- Ge deposition: 80nm thick.
- <0.5% 1σ non-uniformity
- Why germanium?
  - Easy to map with spectroscopic ellipsometer

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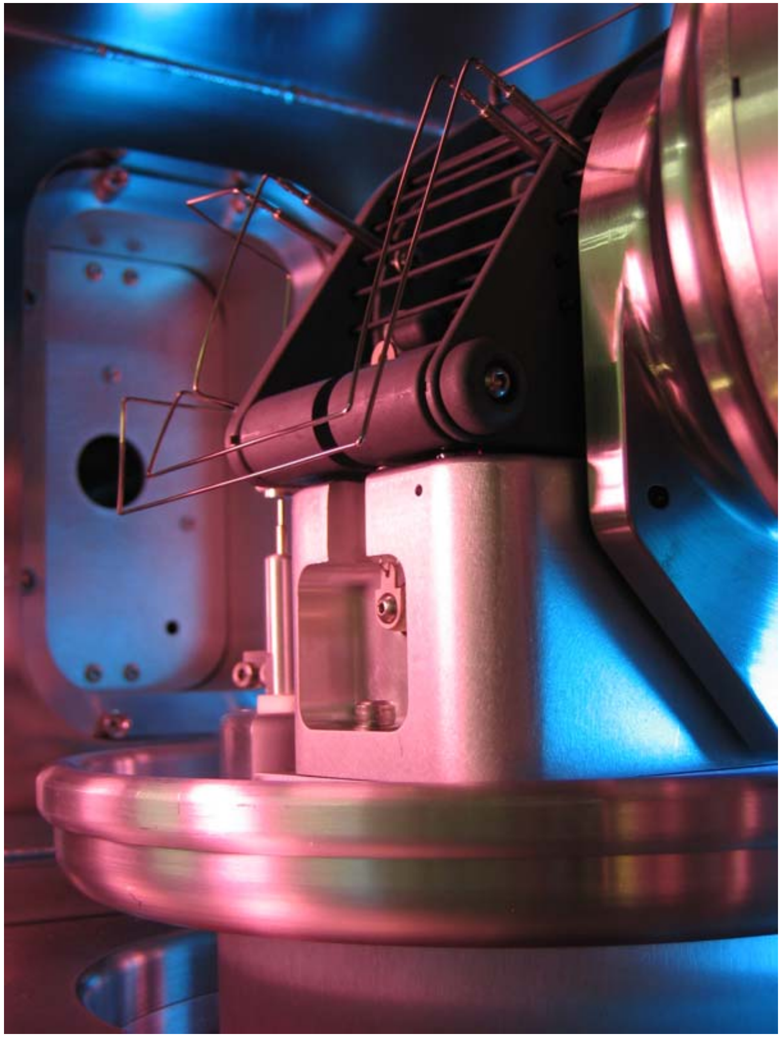
Advanced GCIB Source

- Long life Ion Source
- Higher beam currents
- Easy servicing
- Up to 60keV



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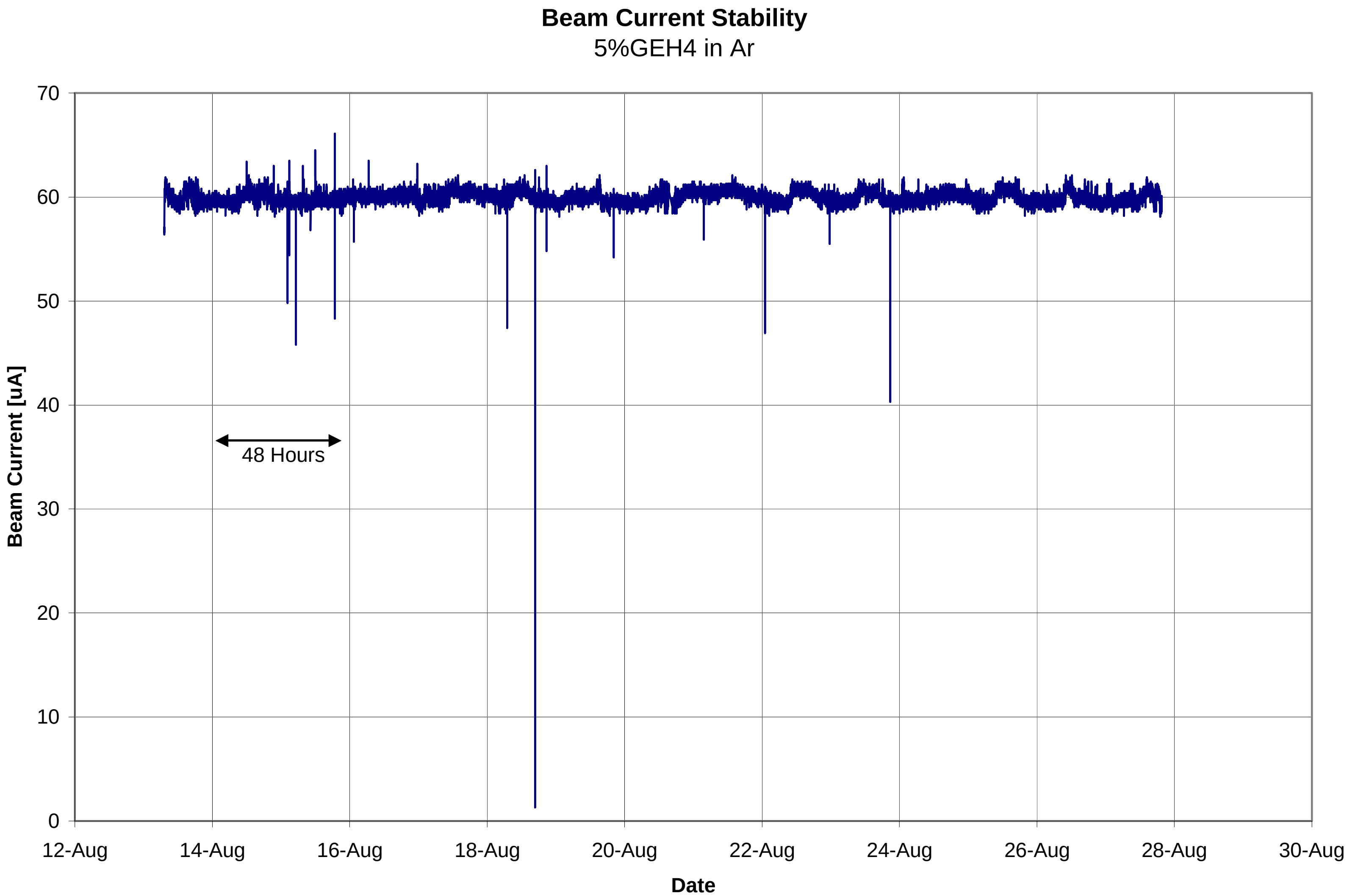
Source Life: >350Hrs running GeH4



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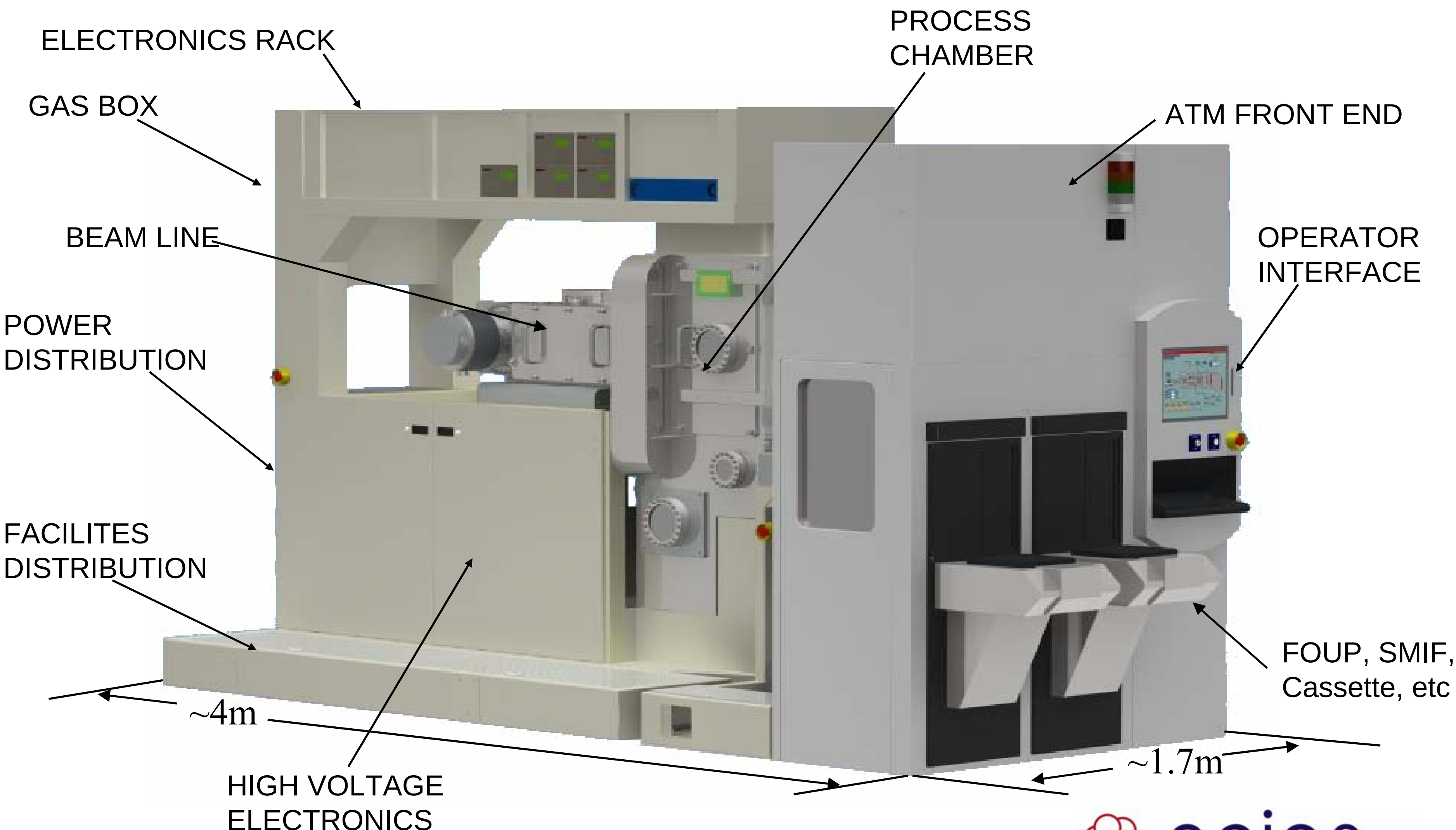
nFusion™ System overview: layout



Foot Print = 4m x 1.7m

Summary

- Infusion represents a new doping technology with several key benefits:
  - Very shallow processing at good throughputs
  - Very abrupt doping profiles
  - Self Amorphizing
  - True Co-Doping abilities
  - Ability to dope to high concentrations
  - Room Temperature processing
  - Photoresist compatible
  - Single wafer endstation
  - No Channeling
  - No Energy Contamination
  - No EOR Defects
- Infusion processing offers extendibility to other areas:
  - Localized strain by Germanium infusion
  - Germanium channel devices
  - Applications for Low-k integration