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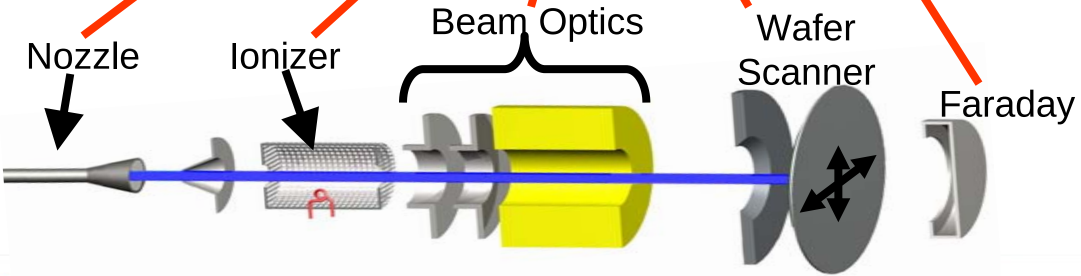
Infusion Doping for USJ Applications with Gas Cluster Ion Beam Processing

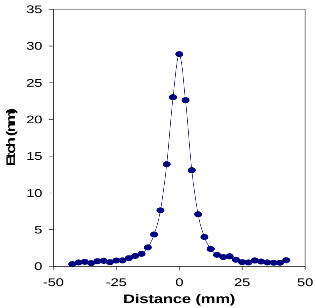
Nate Baxter
TEL-Epion
Semicon West 2008
AVS WCJUG

Outline

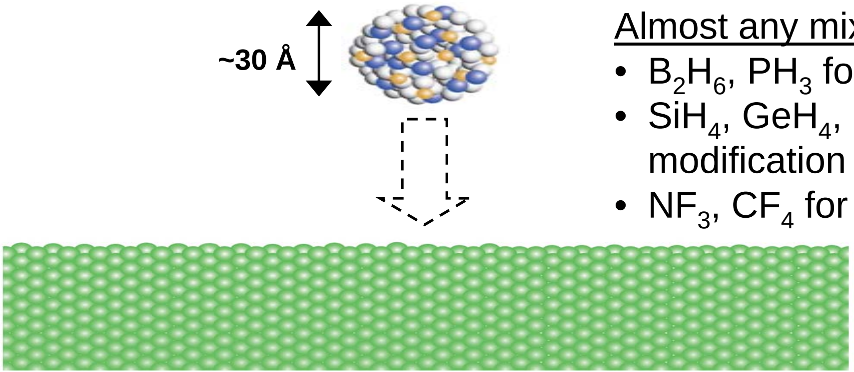
- Gas Cluster Ion Beam Introduction
- GCIB USJ Doping
- Defects
- Activation Enhancement
- Conclusion

Infusion: Gas Cluster Ion Beam Processing





Infusion: Gas Cluster Ion Beam Processing



Almost any mix of gaseous species

- B_2H_6, PH_3 for doping
- SiH_4, GeH_4, NH_3, CH_4, N_2, Ar, O_2 for surface modification or film deposition
- NF_3, CF_4 for etching

During transport, clusters have:

- High total energy (many kV)
  - Leads to extreme chemical and physical reactions at the substrate
- Low energy per molecule (<5eV)
  - No atom penetrates deeply into the substrate

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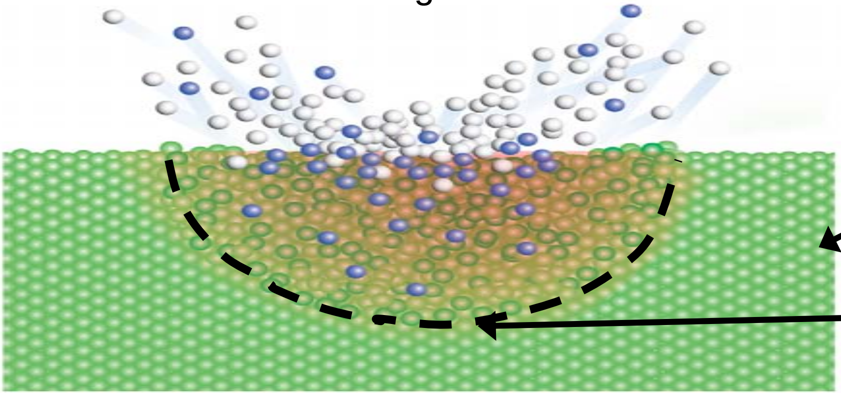
Gas Cluster / Surface Interaction

Upon Impact

- Cluster immediately dissociates
- Transient (<10psec) thermal and pressure spike defines infusion region



Bulk substrate remains at ***room temperature***

maximum depth ~2-20nm

The cluster/substrate interaction is unique

Infusion achieves process results not possible by conventional techniques

(Different from ion implantation and plasma process)

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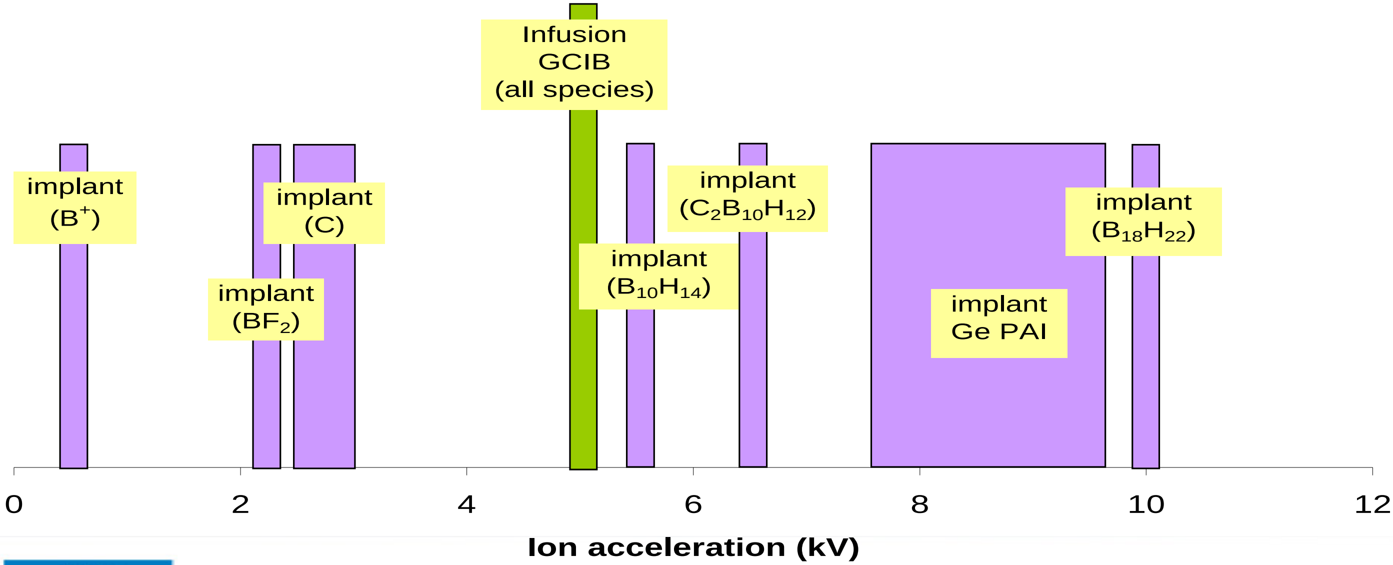
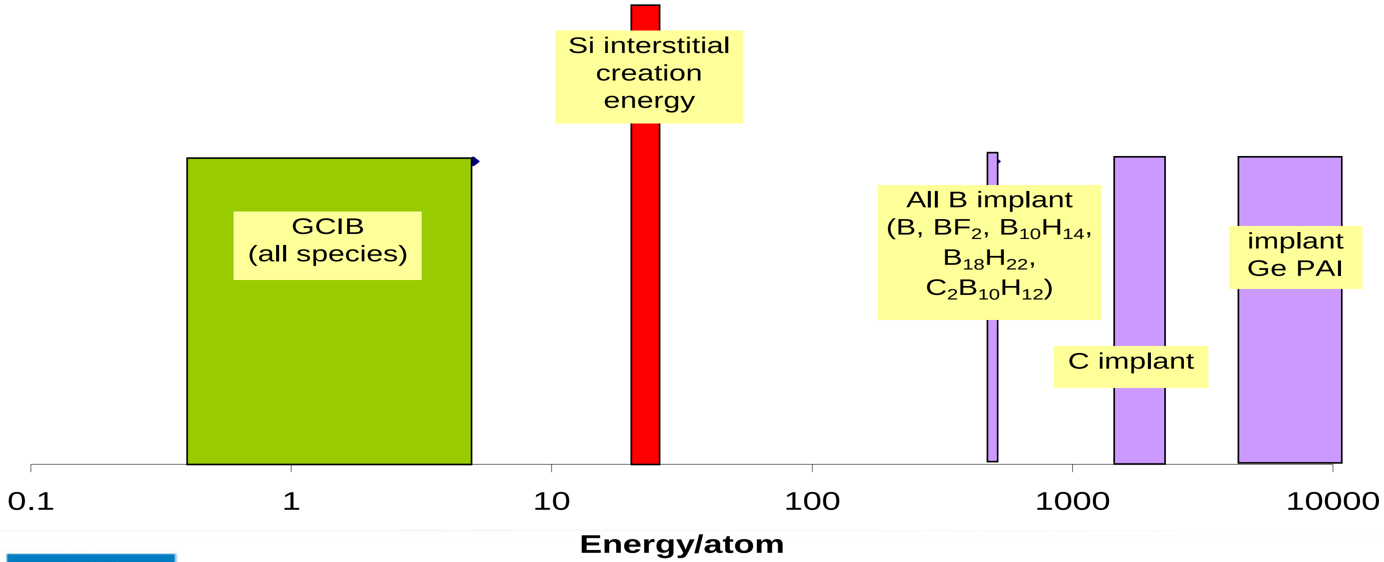
USJ doping energies for Xj ~10nm

(Ge PAI + B 500eV)



USJ per atom doping energies for Xj ~10nm

(Ge PAI + B 500eV)



USJ per atom doping energies for Xj ~10nm

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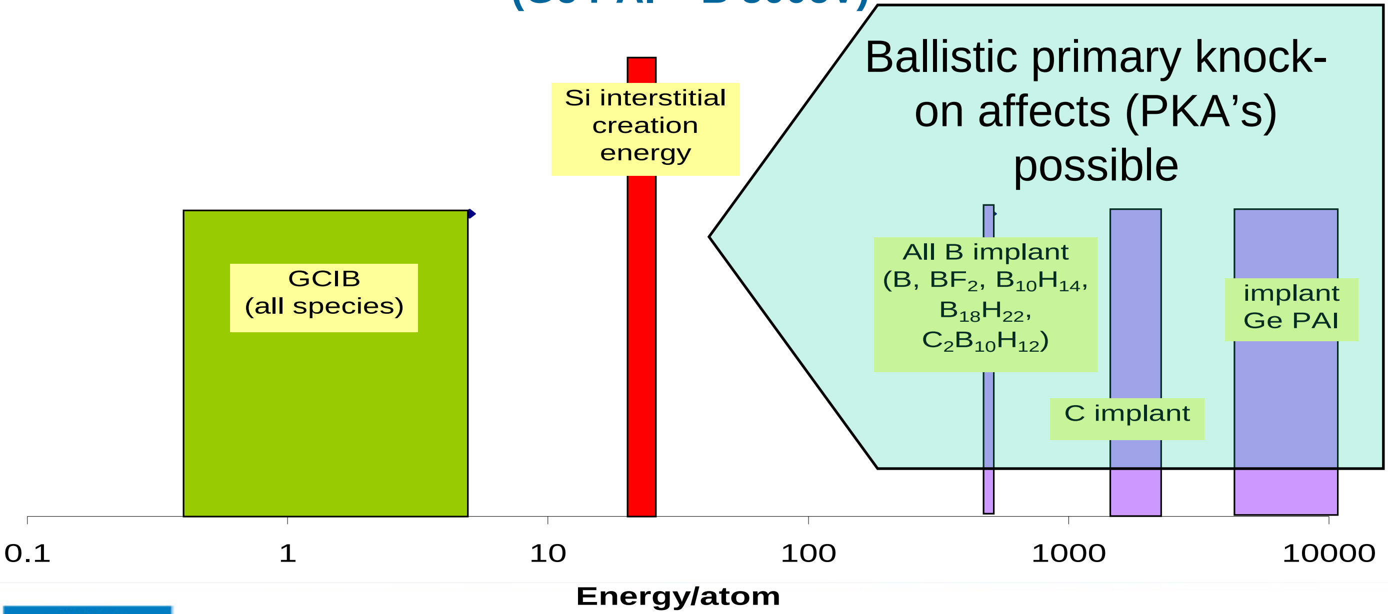
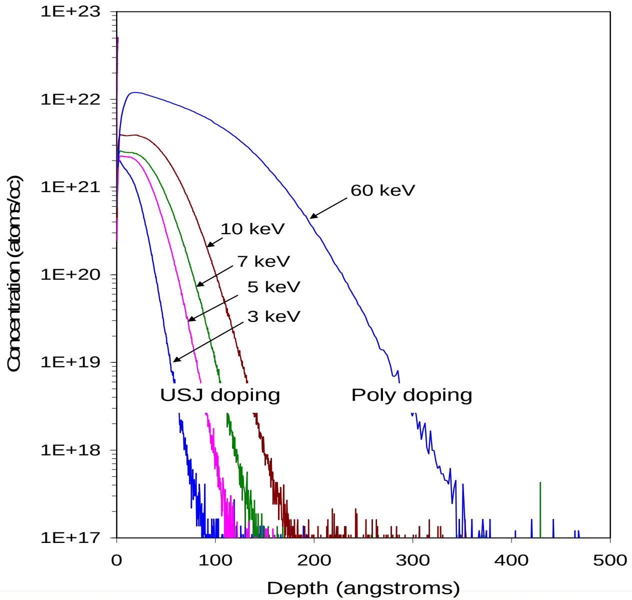
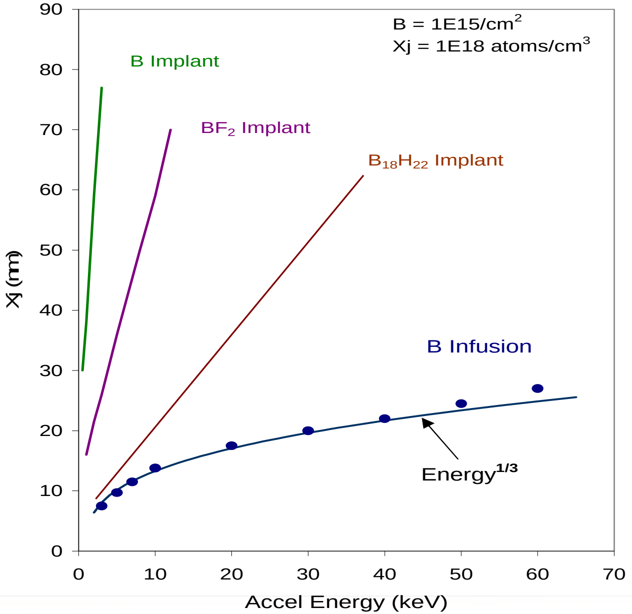


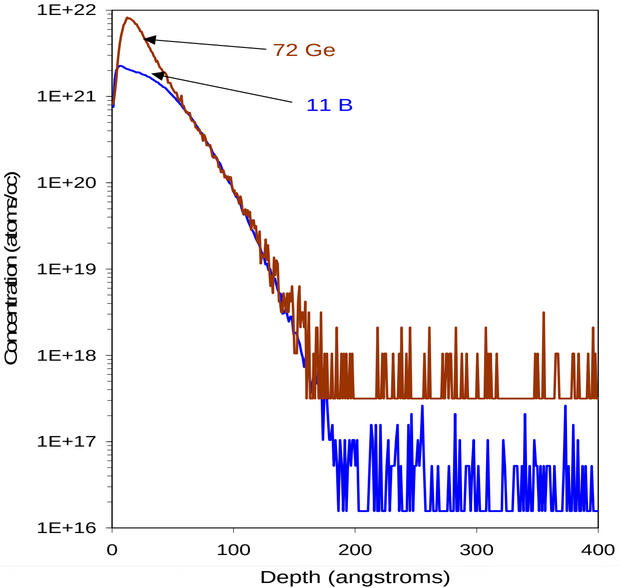
Infusion doping for USJ



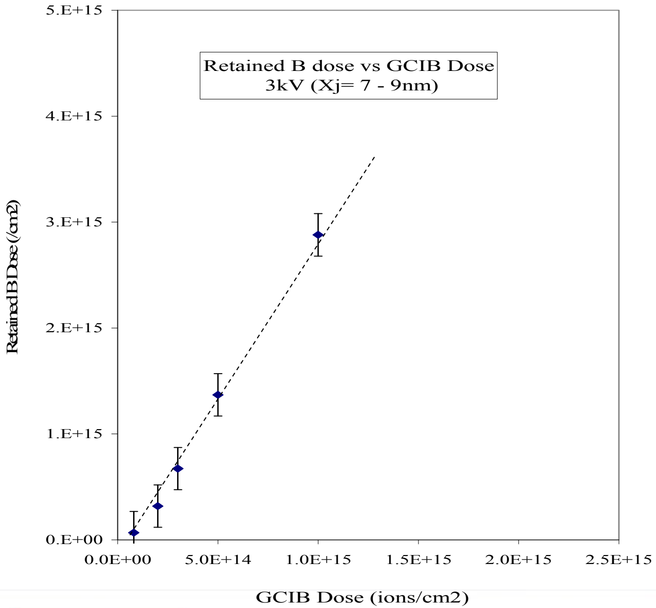
- Abrupt box-like profiles
  - Improved SCE
- Low energy (<5eV) per atom
  - No channeling
  - No beam angle effects or straggle.
  - Improved Vt spread.
- Low power (<1W)
  - No wafer level thermal effects
- Fully self amorphizing by localized thermal (non-ballistic) events
  - No evidence of EOR damage
  - Improved leakage performance

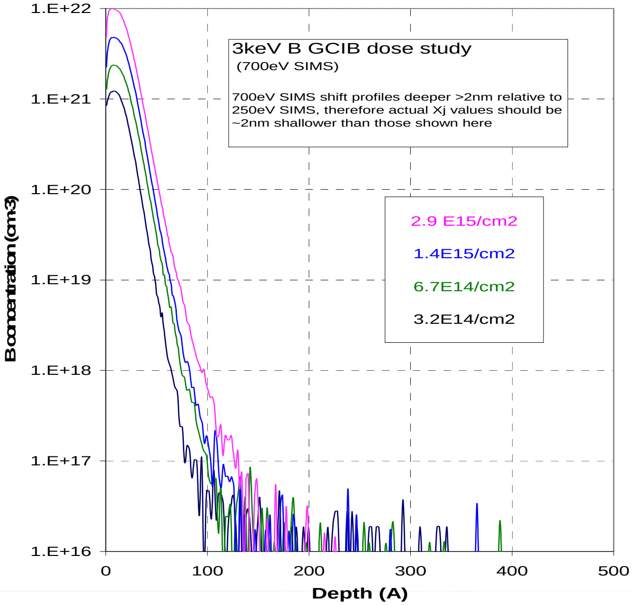
GCIB doping depth scales with $E^{1/3}$ and is mass independent





Self-sputtering test for ultra shallow GCIB: Linear Relationship GCIB Dose vs Retained Dose

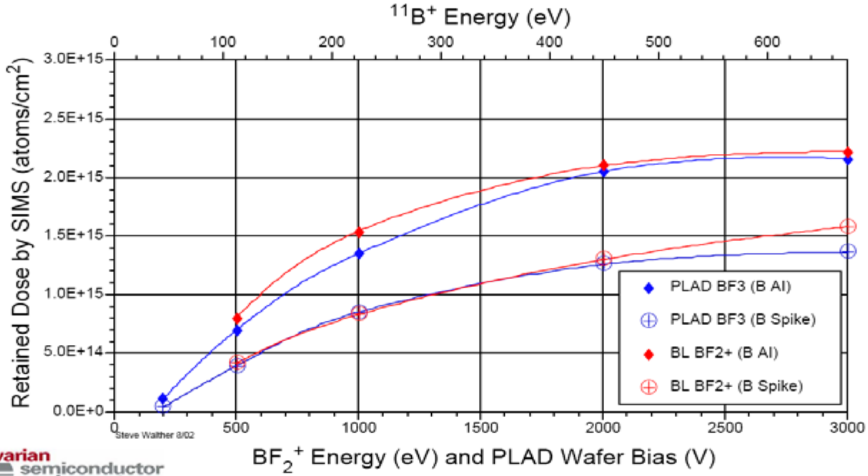




Ion implant Self-Sputtering limitations

As-implanted (3E15) and Spike Annealed

Equivalent dose control and retention over energy range



varian semiconductor equipment SRW 6/05

From IIT 2002 °C, 200 °C/s, Spike Anneal, AST 3000

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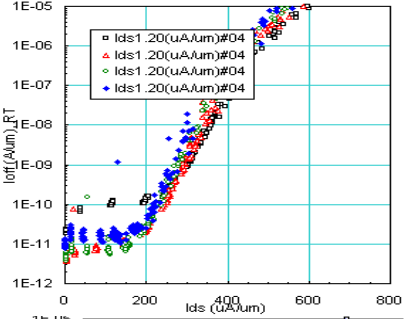
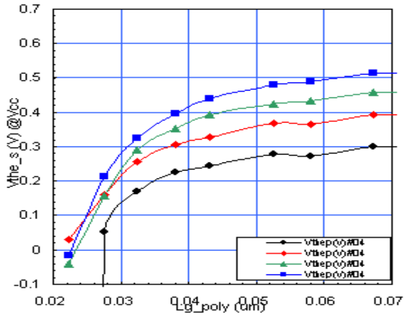
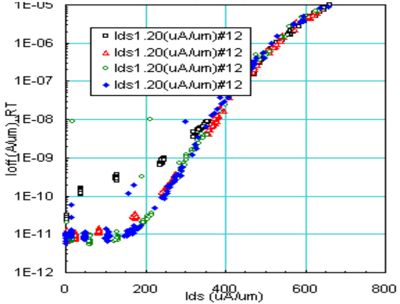
USJ Boron Doping: Device Lots

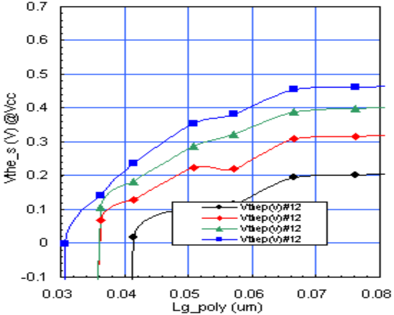


Infusion: 5kV 1%B2H6/Ar





Implant: 0.2keV 1.0E+15 B



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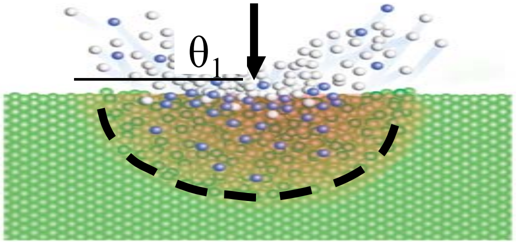
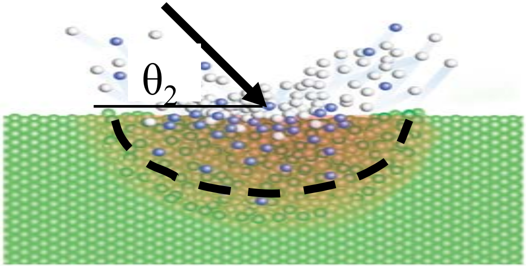
Non-ballistic process means no angular variation effects (improved lateral abruptness) for improved V_t spread.



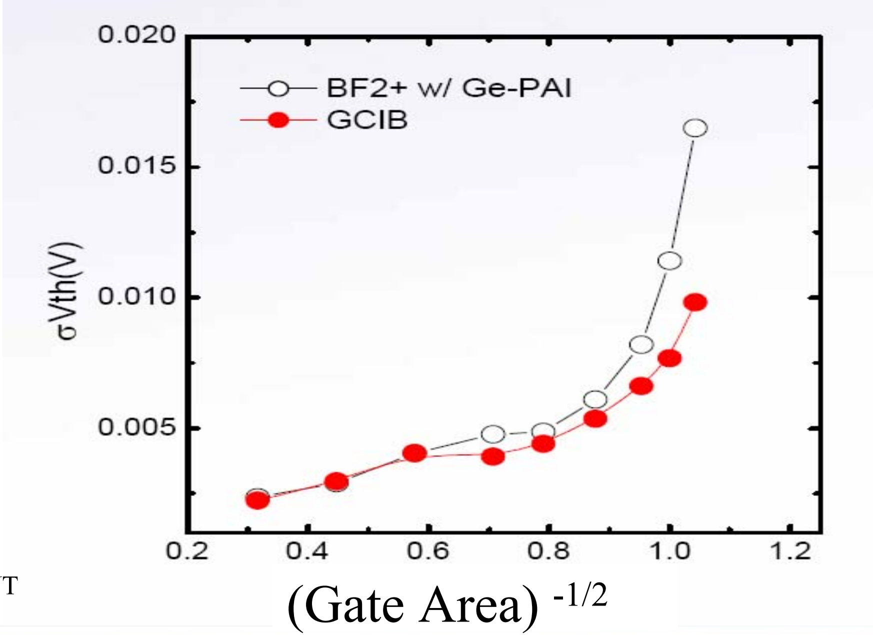


Individual B energy ~1eV, therefore depth is determined exclusively by the collective cluster energy transferred to the Si surface. No straggle possible.

The lack of energetic ballistic B means there will be no angular component to the B infusion.

Any variations in beam angle will have no changes in overlap control or skew.

Vt spread



Ho Lee, Samsung, 2006 IWJT

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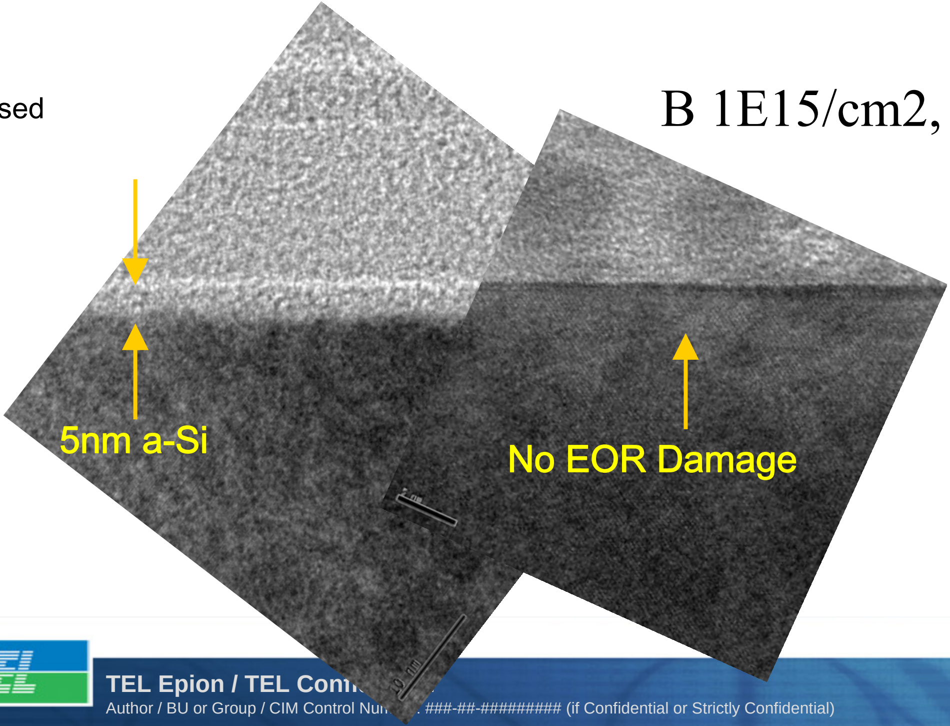
EOR test

As-infused

B 1E15/cm2, 10nm Xj



Post anneal

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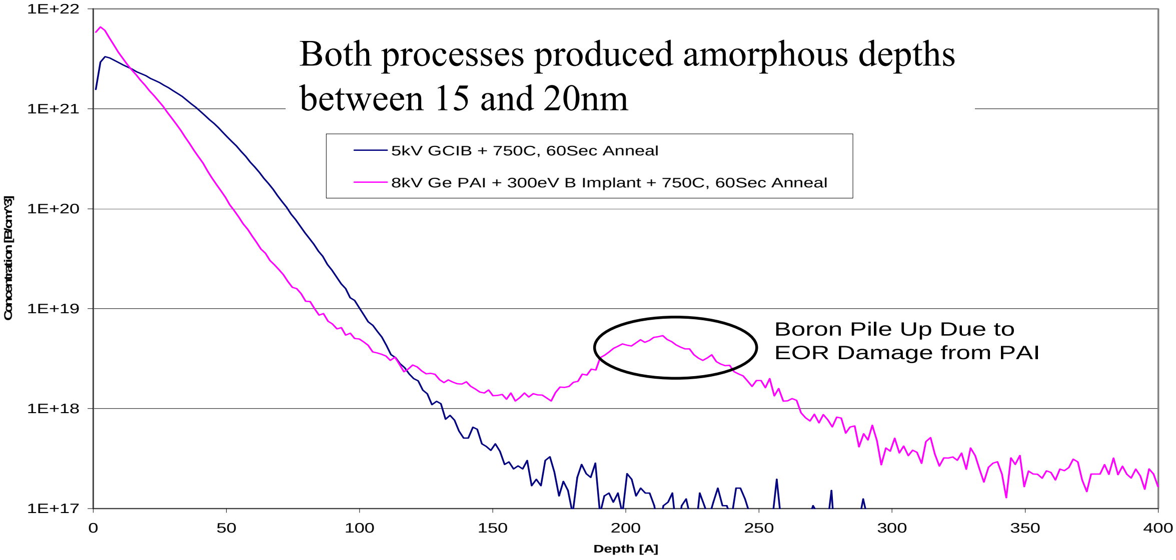
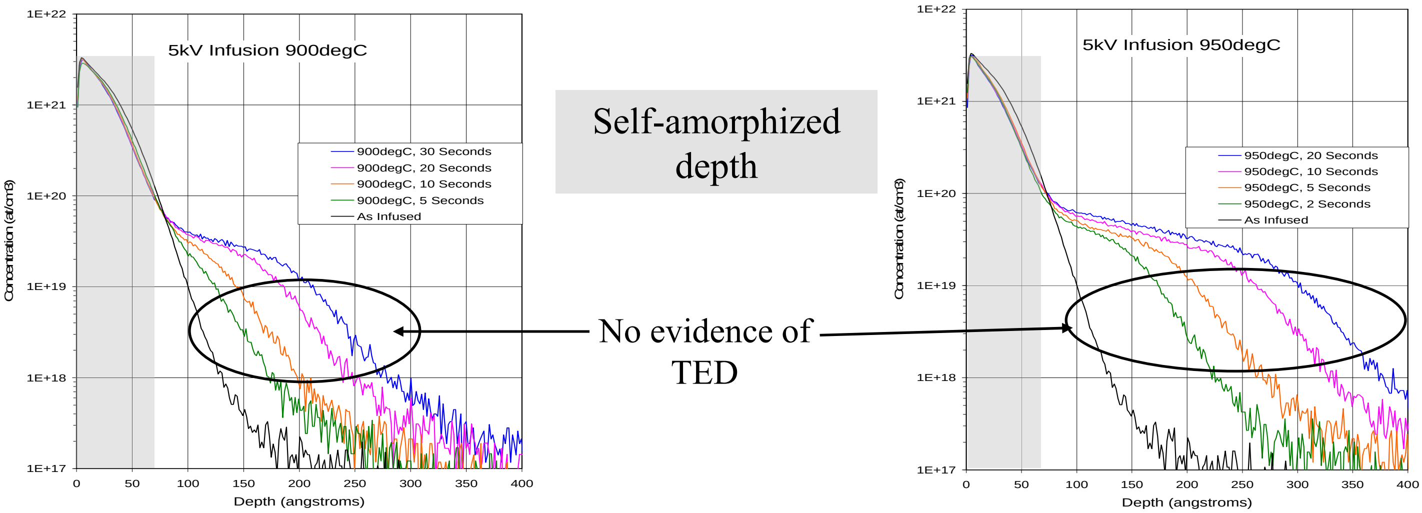
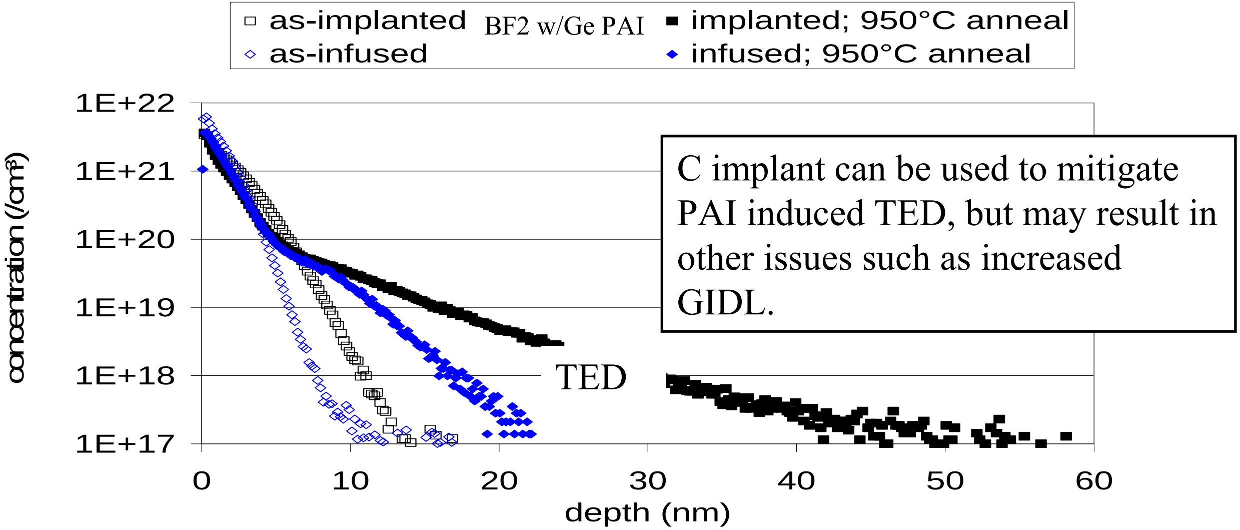
EOR pile up test



EOR / TED test


5kV Infusion 900degC
Concentration (at/cm3)
Depth (angstroms)
1E+22
1E+21
1E+20
1E+19
1E+18
1E+17
0
50
100
150
200
250
300
350
400
900degC, 30 Seconds
900degC, 20 Seconds
900degC, 10 Seconds
900degC, 5 Seconds
As Infused
Self-amorphized depth
No evidence of TED
5kV Infusion 950degC
950degC, 20 Seconds
950degC, 10 Seconds
950degC, 5 Seconds
950degC, 2 Seconds
As Infused

EOR / TED test



No EOR interstitials generated by GCIB → No TED → No C required → **Improved GIDL**

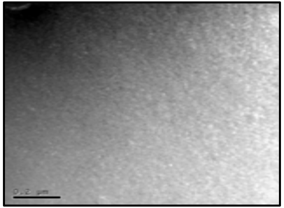
Plan view TEMs

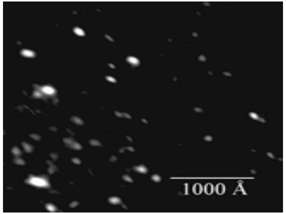
Infusion

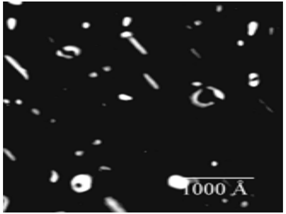
Implant

Flash temperature:
1200°C 1350°C

900C, 30 Sec



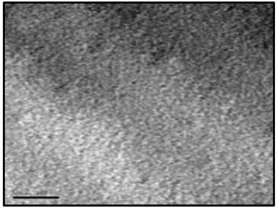


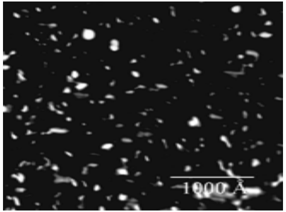


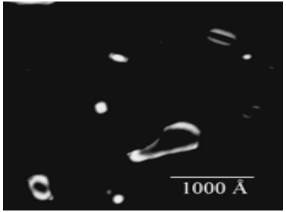
Intermediate temperature:

800°C

1350C Flash
1000C intermediate







900°C

Amitabh Jain, Mat. Res. Soc. Symp. Proc. vol. 810, C5.6.1, 2004.

Leakage comparison

Doping condition	Anneal	Rs Measurement (Ω/sq)		Leakage I (uA/cm^2)	Xj @ 1E18 (Å)
		4 PP	RsL		
GCIB	Laser	2076	2103	**0.1**	125
GCIB	450 °C 1 hour + Laser	1513	1547	0.437	125
20kV Ge PAI + 2kV C + GCIB	Laser	1365	1299	**1.475**	135

1. The addition of PAI + C implants + laser anneal increases leakage as compared to GCIB + laser anneal alone.
2. Adding a VLTA pre-laser anneal to GCIB doping significantly improves activation.
3. Adding a VLTA pre-laser anneal to GCIB doping exhibits increased leakage..

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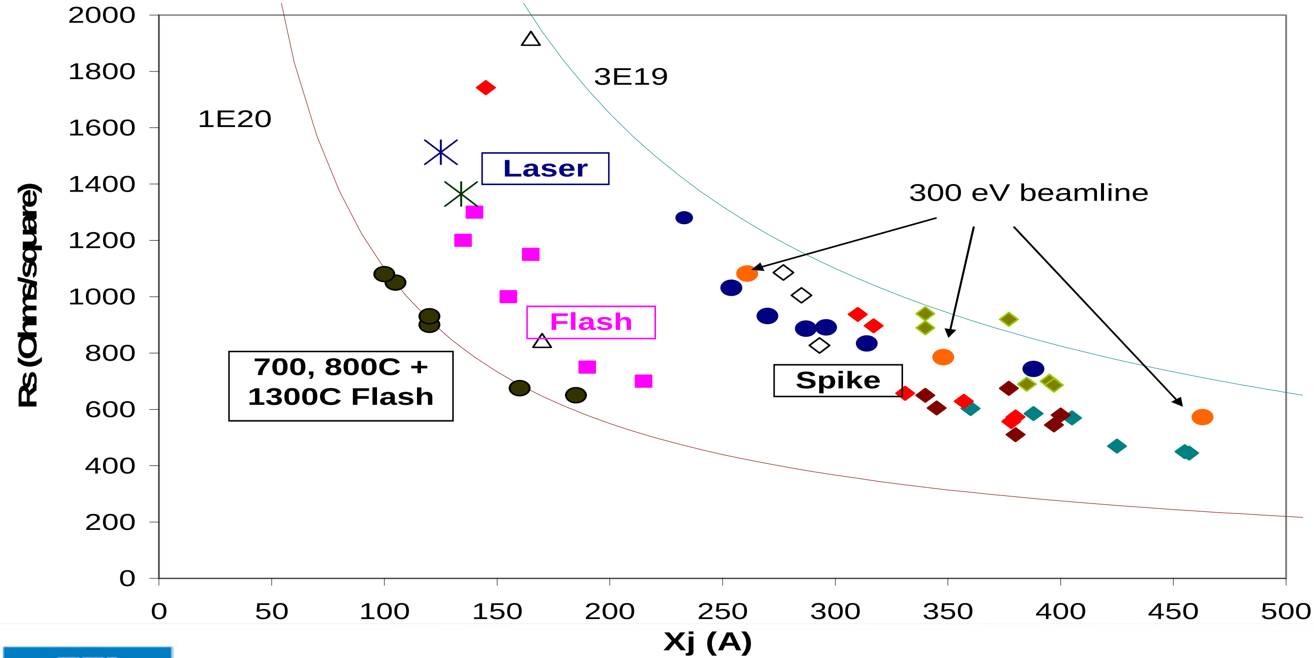
GCIB B activation studies



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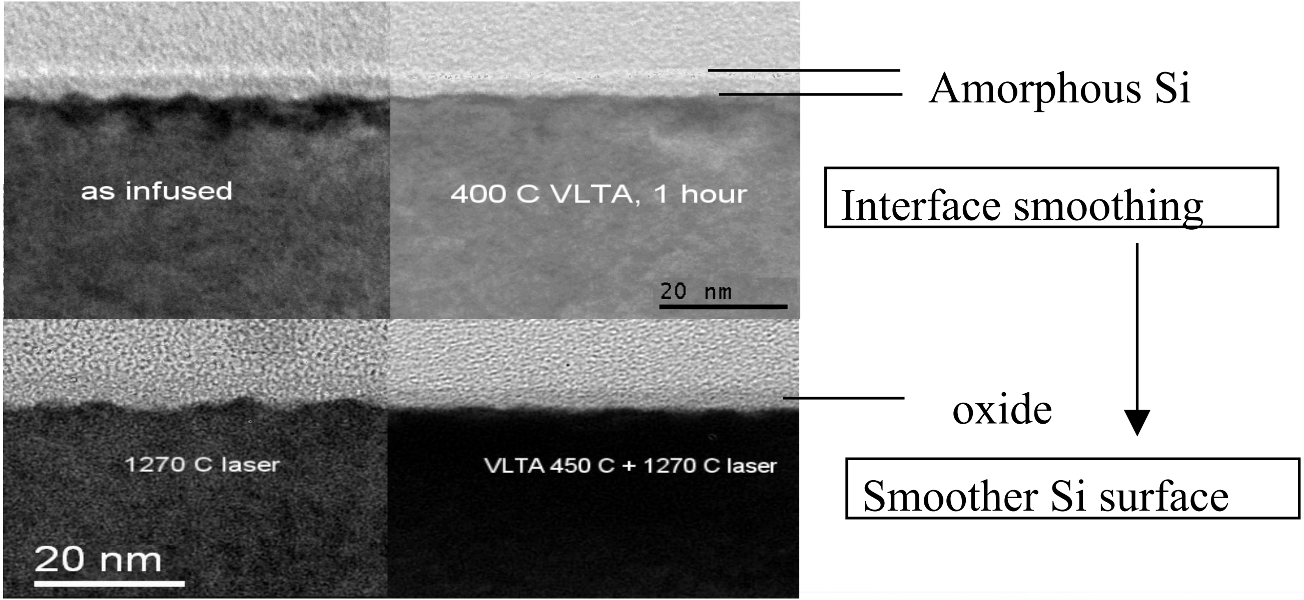
Interface smoothing by VLTA



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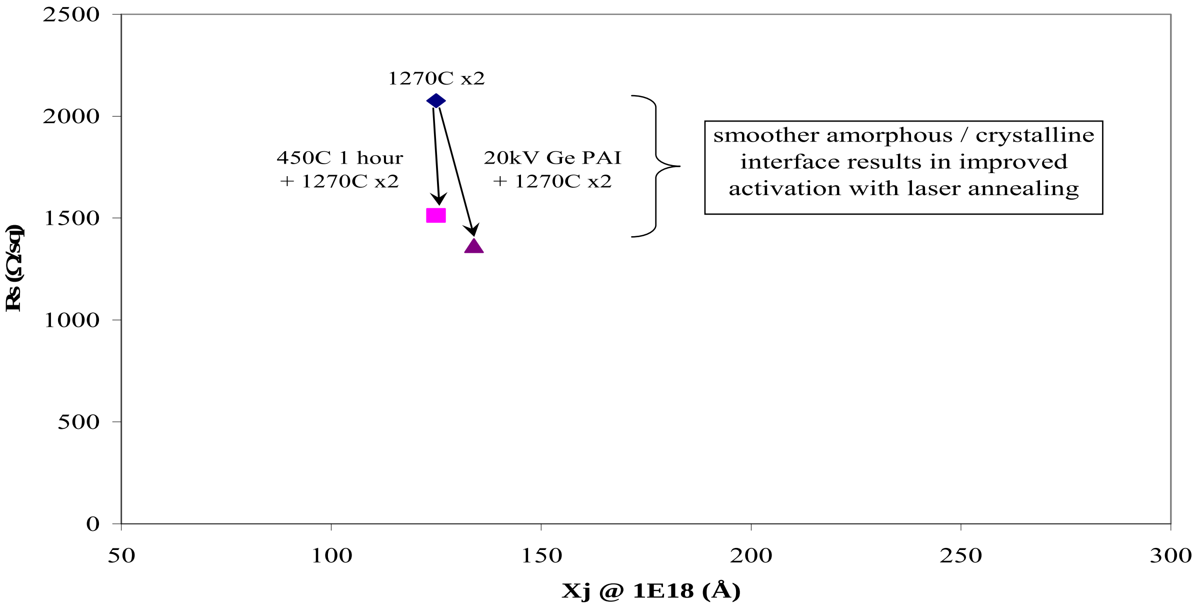
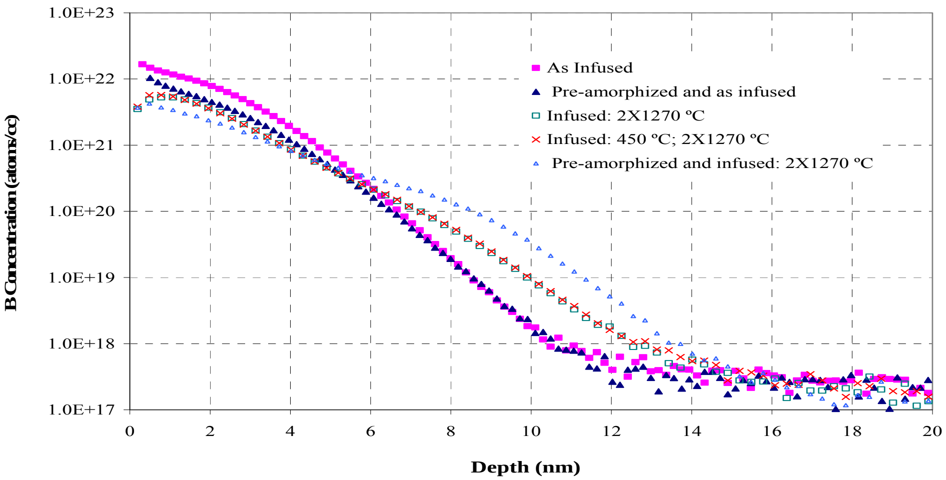
Interface smoothing improves activation



Interface smoothing tests : SIMS



1. GCIB infusion into crystalline or pre-amorphized Si show same doping profile.
2. VLTA pre-anneal does not affect the diffused profile.
3. Ge PAI + C implants enhance B diffusion.

Conclusions

- **GCIB doping is a shallow self-amorphizing low energy per atom process.**
  - Abrupt profiles produced without Ge PAI (C implant)
- **GCIB doping is not implantation (ballistic)**
  - Channeling or straggle not possible.
    - *Improved Vt sigma*
  - No Si interstitial defect pile-up at EOR observed
    - *No TED observed*
    - *Lower leakage is observed when compared to Ge PAI+C implanted sample.*
- **GCIB USJ formation requires hybrid anneals for optimal activation**
  - Initial data suggests VLTA improves activation but will require further optimization to reduce leakage.

Acknowlegements

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