Cluster Implants for Advanced Productivity

Dr. Leonard Rubin

Axcelis Technologies

Acknowledgements:

Patrick Splinter, Michael Graf

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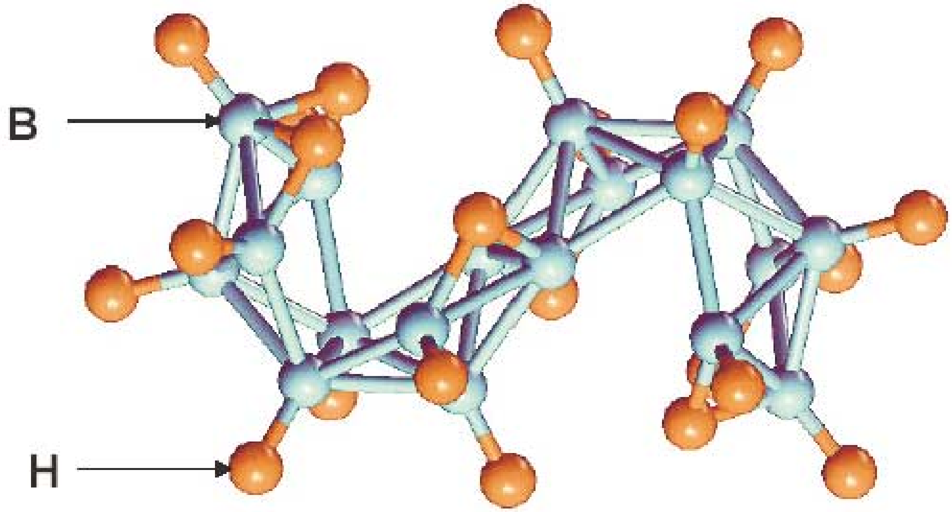
Cluster Implant Productivity Outline

- Productivity Advantages & Challenges of Borane Implantation
- Axcelis History of Borane Implantation
- Machine Design Considerations
- Process Applications, Effects and Results
- Summary



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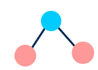
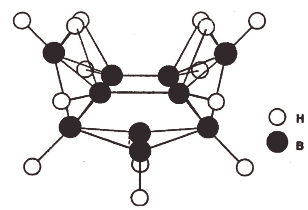
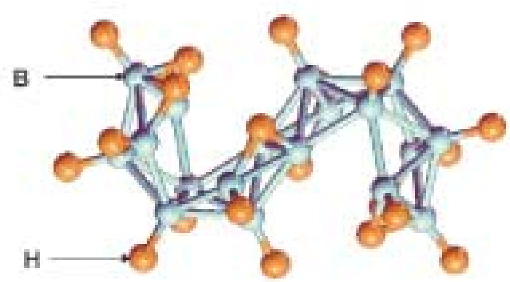
Boron & Borane Compounds

		Mass	Mass/11
Boron (B)		11	1
Boron Difluoride (BF_2)		49	~4.5
Decaborane ($B_{10}H_{14}$)		~120	~11
Octadecaborane ($B_{18}H_{22}$)		~210	~19

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“Big Borane” $B_{10}H_{14}$ & $B_{18}H_{22}$ Benefits and Motivation

- Can dramatically increase ultra-low energy implant throughput
- Implanter can run at much higher extraction energies
- “Drift” operation only thus no energy contamination caused by deceleration
- Same equivalent boron flux can be delivered with much lower electrical beam current
- Low angular divergence

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Boranes – Challenges

- Challenges
  - Machine design considerations
    - Achieving broad application space
    - Design of production capable hardware
  - Demonstration of process equivalence

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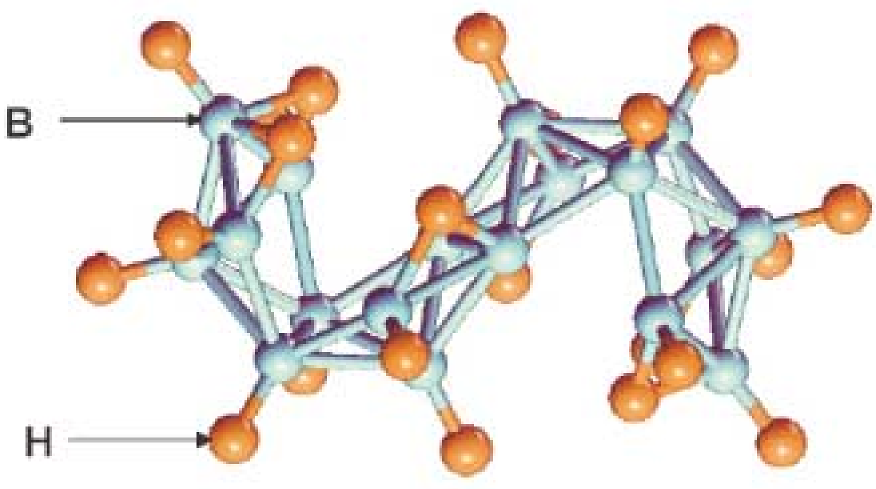

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Decaborane Development History at Axcelis

- Axcelis experimented with decaborane in 1995
  - R&D efforts suspended due to insufficient temperature control in the delivery system.
- Effort restarted in 1999

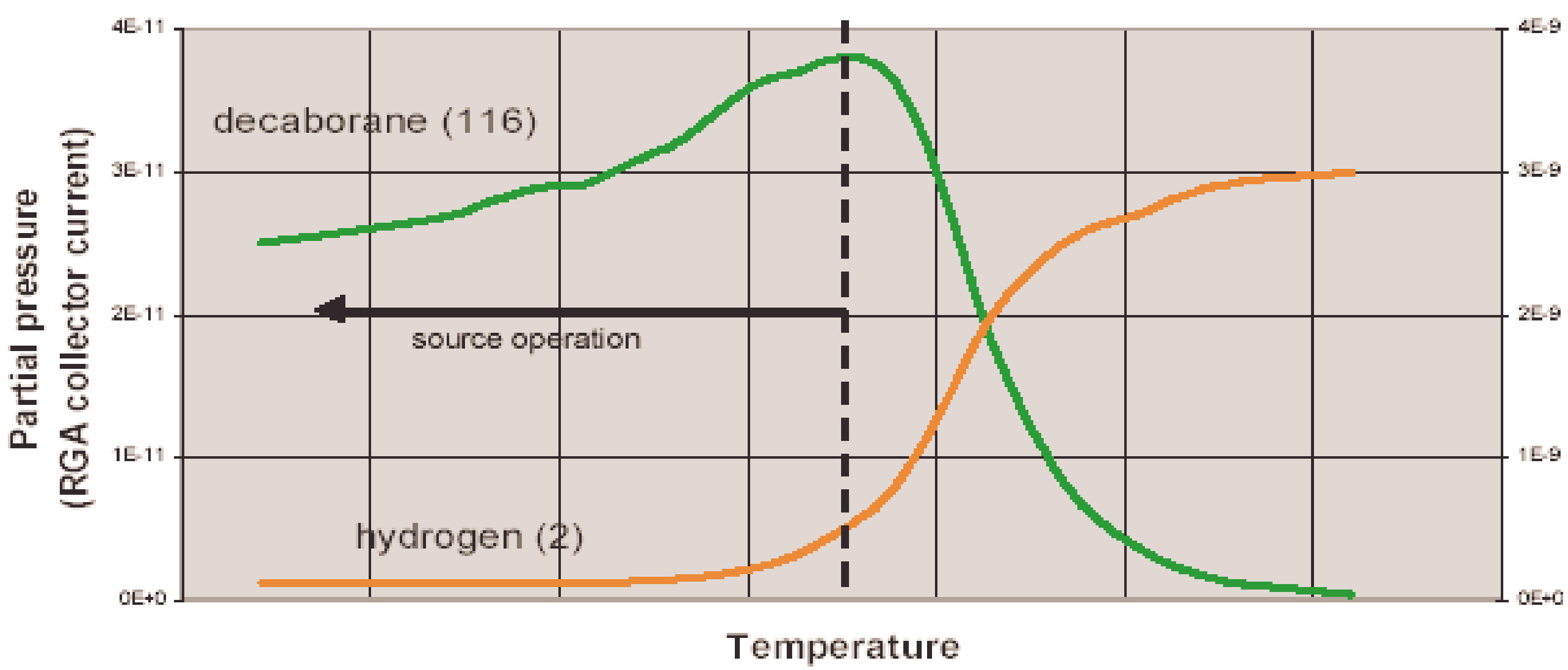
- Using Decaborane, equivalent beam current on GSD200/E^2 platform
  - 6.5mA @ 2keV
  - 3.5mA @ 0.5keV

- Source lasted only 10-20 hours before maintenance required
- Production version not completed due to short source life and machine dedication issue

Decaborane Development History at Axcelis Source Technology – Temperature Control 1999

- **Decaborane production is dependent on arc chamber temperature**
- **Operating temperature is less than decomposition temperature**

Pressure vs. arc chamber temperature



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Decaborane Development History at Axcelis
Source Technology – Temperature Control 1999

- External temperature control
  - Circulating coolant loop around vaporizer and delivery tube maintains temperature equilibrium
- Internal temperature control
  - Circulating coolant loop through source body limits upper temperature range

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Decaborane Development History at Axcelis 1999-2000 Summary

- **Determined temperature range of decaborane decomposition**
- **Designed and built a temperature-controlled decaborane ion source**
- **Observed the dimer of decaborane ($B_{20}H_{28}$)**
- **Oral presentation at IIT 2000**

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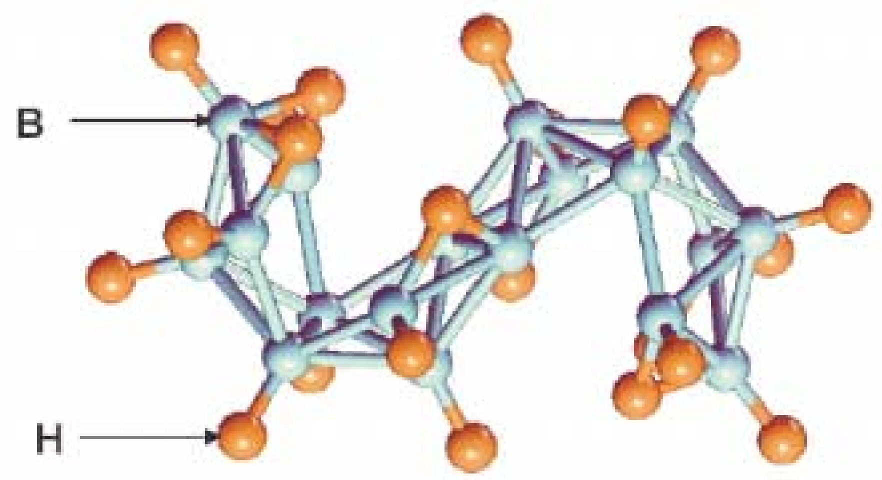

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Analyzer Magnet Design

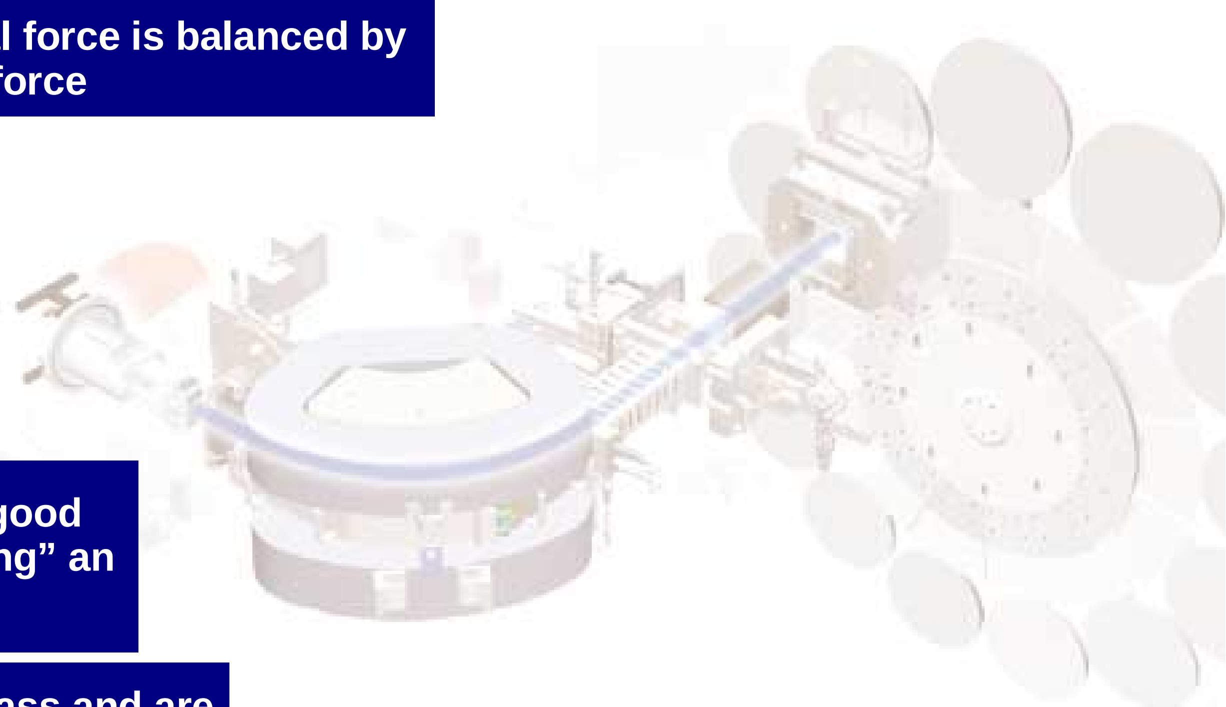
$$\frac{mv^2}{R} = qvB$$

↓

$$\frac{mE}{q} \propto (BR)^2$$

Basic magnet design:

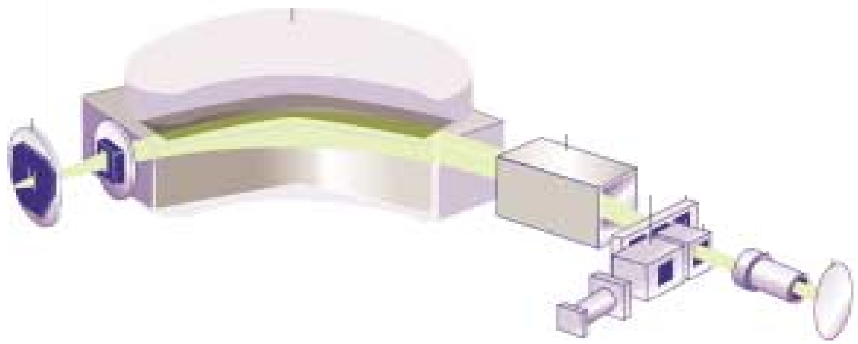
Centripetal force is balanced by magnetic force



Mass-energy product is a good way to describe how “strong” an analyzer magnet is

Borane ions have higher mass and are transported at higher energy – this is challenging for standard analyzer magnet systems

Transport of B18
Existing Tool Configurations – Optics Details



Tool	Extraction Energy (kV)	Acceleration Energy (kV)	Analyzer Magnet (bend angle, radius)
Ultra	**80**	**None**	**90º,30cm**
GSD200/E2-90	90	None	70º,54cm
GSD200/E2-180	90	90	70º,54cm

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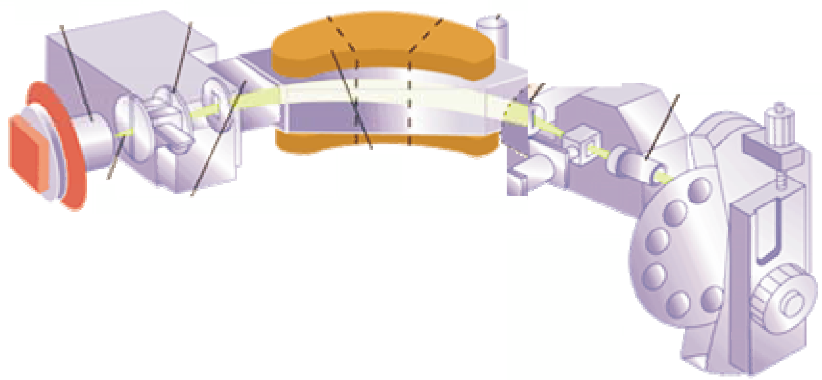

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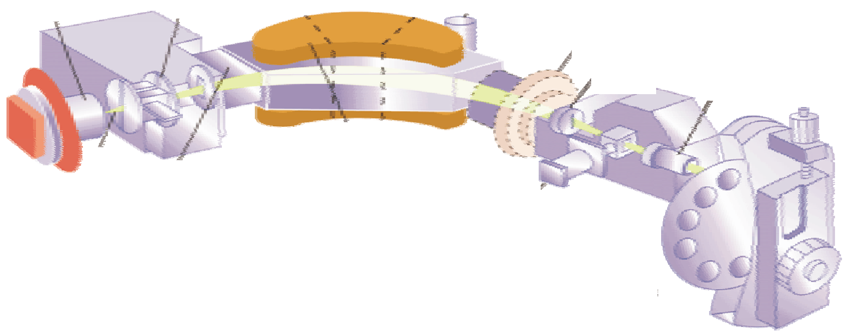

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Maximum Equivalent Boron Energies – B18

Tool	Maximum Mass x Energy (keV-AMU)	Maximum Extraction Energy - B18 (keV)	Maximum B - Equivalent Extraction (keV)	Maximum B Equivalent Acceleration (keV)	Maximum Total B - Equivalent Energy (keV)
Ultra	6000	28.5	1.5	0.0	1.5
GSD200/E^2-90	9840	46.9	2.5	0.0	2.5
GSD200/E^2-180	9840	46.9	2.5	4.7	7.2

Fixed by Magnet Design

(Radius and Magnetic Field)

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= (Mass*Energy)/210

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= (Max B18 Extraction)*(11/210)

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= (Max Accel)*(11/210)

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= (Max Ext) + (Max Accel)

Low Energy Beam Propagation – the effects of space charge

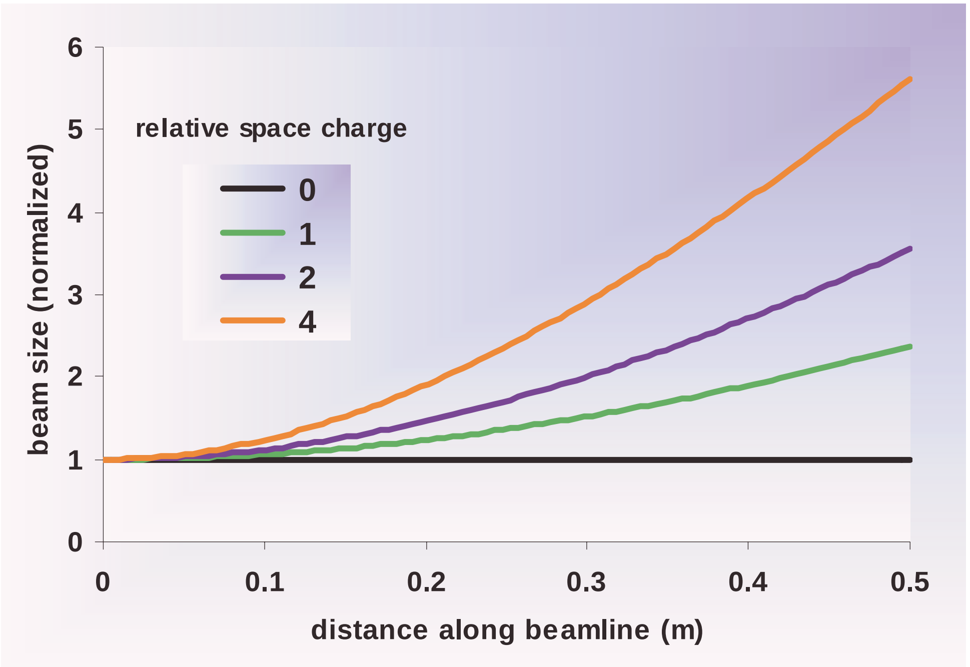
Perveance (K) is an important beam transport parameter that determines space charge forces

$$K \propto \frac{I\sqrt{m}}{E^{3/2}} \propto \frac{I}{mv^3}$$

Methods for controlling space charge for low energy transport – Magnetic confinement, beamline plasma's, PEF's, etc.

Example of beam expansion due to space charge:

2 keV B^+ 10 mA



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Space charge is significantly improved for Boranes

B18 delivers 18:1 dopant for given ion charge

	B^+ (11)	BF_2^+ (49)	$B_{10}H_x^+$ (~ 120)	$B_{18}H_x^+$ (~ 210)
Dopant flux for equivalent ion current	1	1	10	18
Ion energy for equivalent dopant velocity	1	4.45	~ 11	~ 19
Relative space charge for equivalent dopant flux	1	0.22	~ 0.009	~ 0.0029

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Space charge is significantly improved for Borane's

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Ion energy 19 times higher

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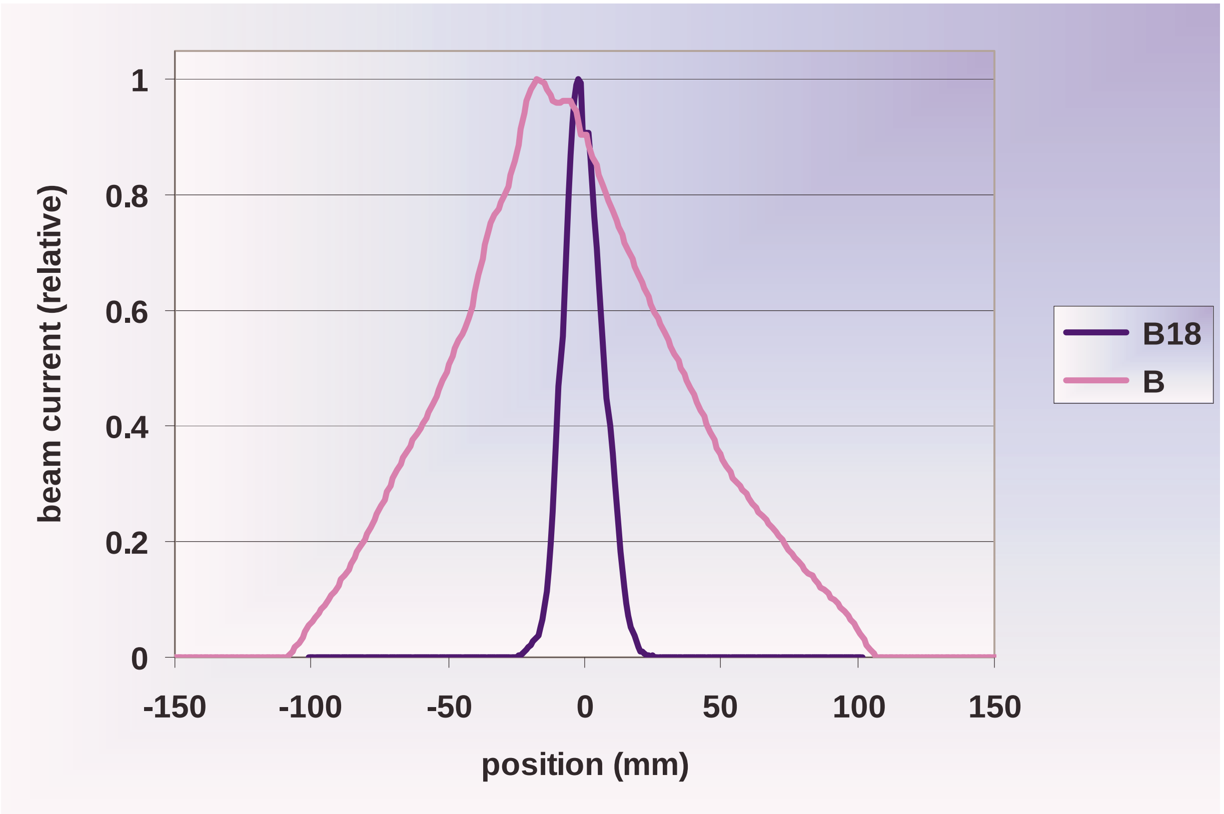
Space charge reduced by a factor of more than 300

Reduced space charge with borane molecules results in beam size improvement – experimental evidence

Lower space charge can result in a much narrower beam profile at the wafer

Results in increased beam utilization efficiency on multi-wafer and scanned platforms



Axcelis 8250

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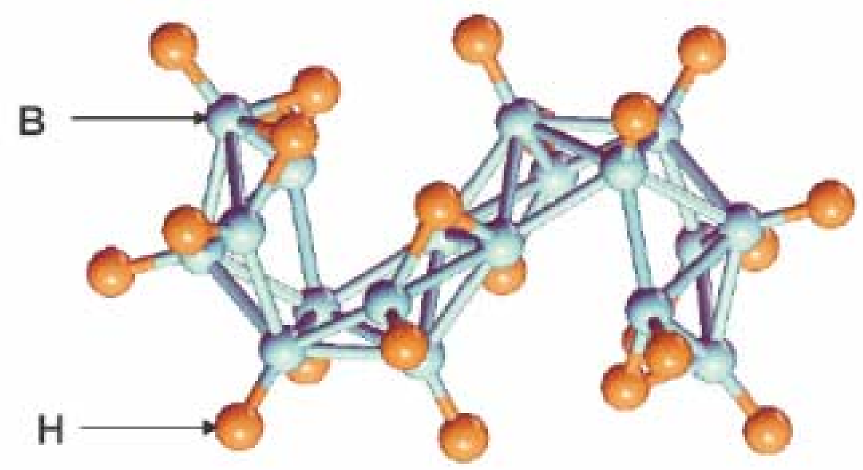

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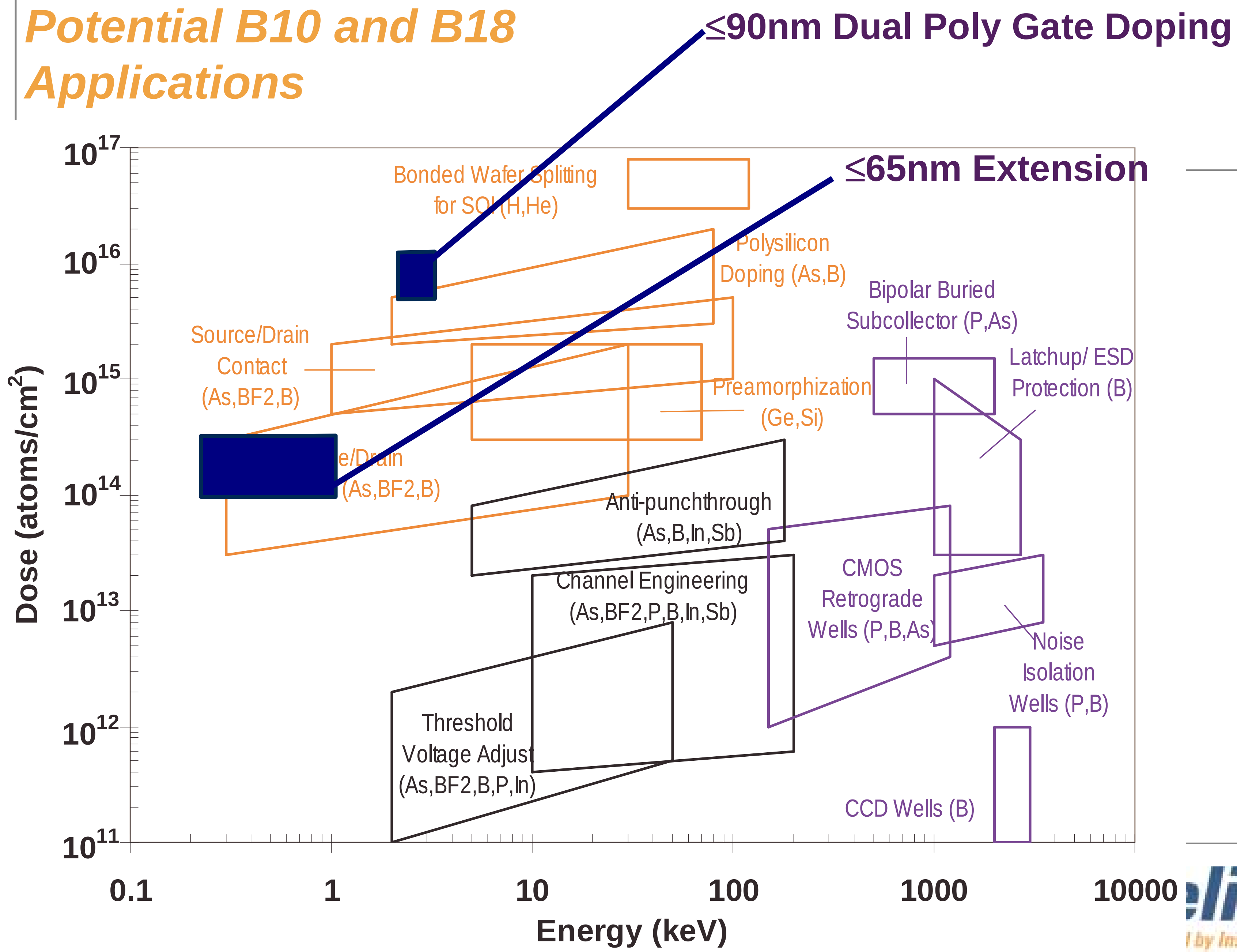
Potential B10 and B18 Applications



Ultra Low Energy Extension Device Investigations

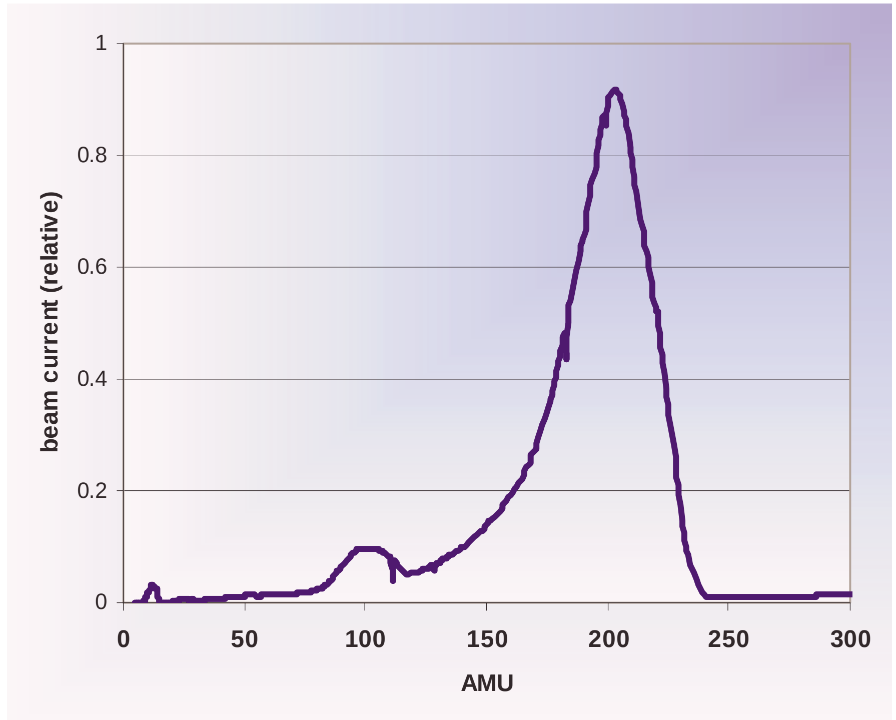
- **Published**
  - **2004 Renesas/SemEquip @ IIT (B_{18}^+; showed B^+ equivalence)**
  - **2002 Agere/Axcelis (B_{10}^+; showed B^+ equivalence)**
  - **1997 Fujitsu (B_{10}^+; showed B^+ equivalence)**

- **All indications that big borane will work for extension implants**

$B_{18}H_{22}$ Spectrum

- Typical mass spectrum
  - With mass resolution ~ 15
- Peak B_{18} current in the range of AMU 200 – 210
  - Contains contributions ranging from $^{10}B_{18}H_6$ to $^{11}B_{18}H_{22}$
  - Contribution from any B_{17} or other B_x combinations is typically very small

2 keV B equivalent spectrum



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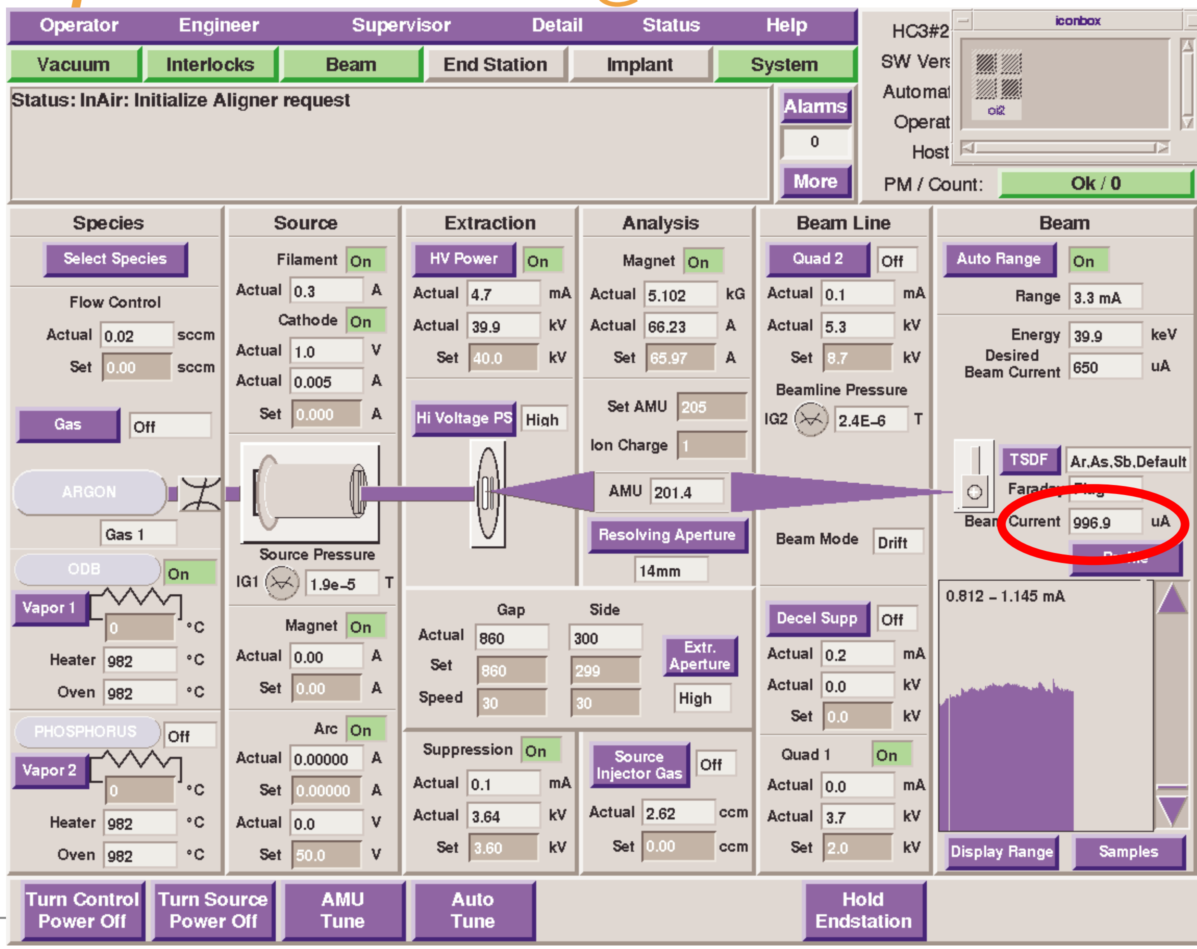
SemEquip ClusterIon™ Source
18 mA equivalent current @ 2 keV on Axcelis Ultra



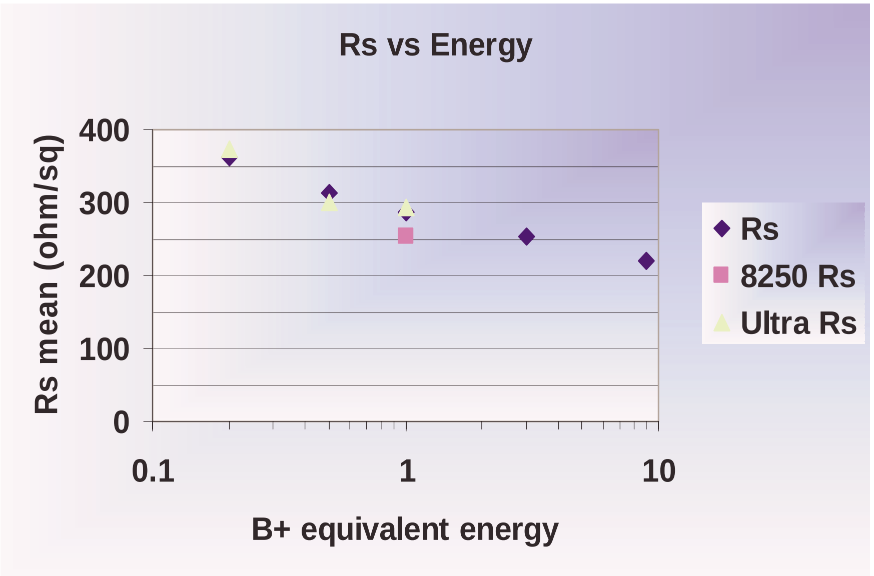
996.9 µA

Courtesy Dr. Ned Eisner Nov-2004

ClusterIon™ Source Evaluation on Axcelis 8250 – Uniformity & Dose

- **B18 bare wafer uniformity roughly equivalent to B^+ results**
  - **No SEF was used**
  - **All beams corrected to better than 0.5% non-uniformity**
- **Dose matching to Ultra confirmed**

Energy (equiv keV)	Ibeam (equiv uA)	Rs uniformity (1 sigma)
9	1178	0.54
3	1190	0.71
1	1176	0.99
0.5	1041	1.07
0.2	536	1.98



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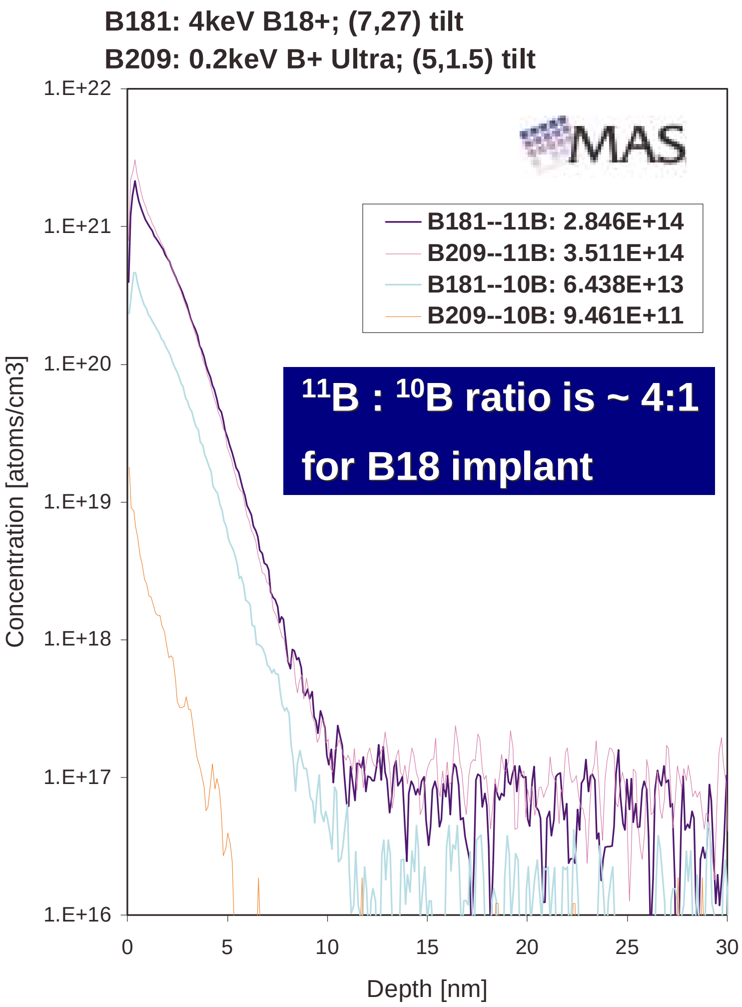
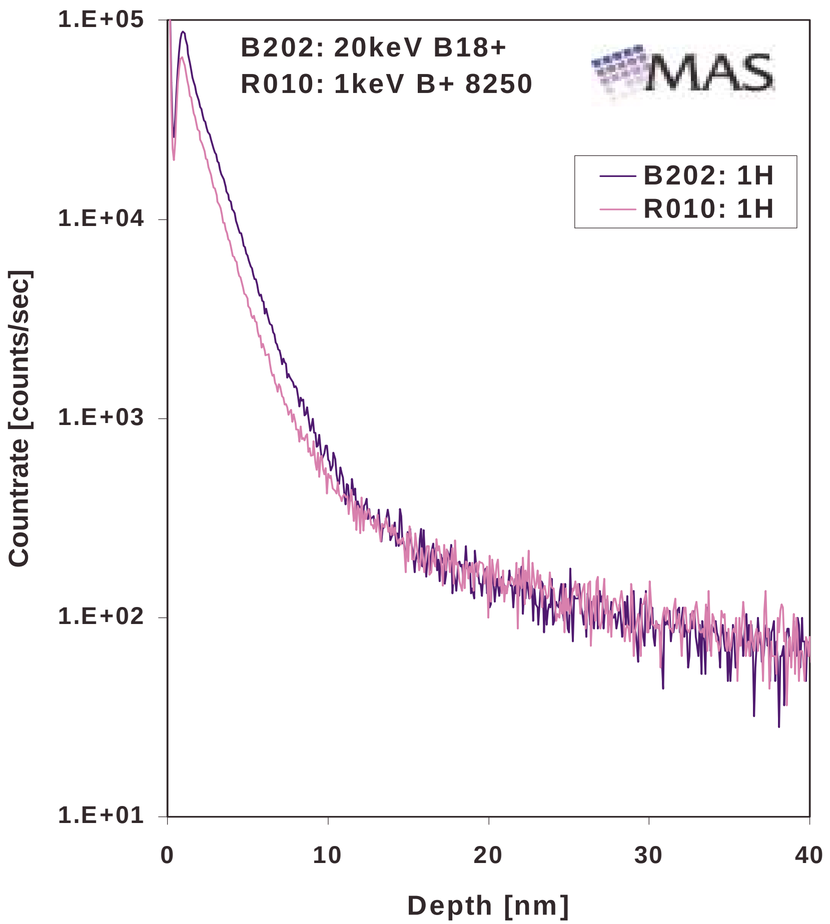
0.2 keV Equivalent Boron SIMS – Comparison with Ultra

- **Overall SIMS profile is well-matched to B^+ implant**
- **Large difference in ^{10}B concentrations is expected**
  - **Ultra uses enriched BF_3**
  - **B_{18} is isotopically natural (contains ^{10}B and ^{11}B)**



Hydrogen SIMS

- H SIMS profile with B_{18} shows small difference from standard B^+ implant
  - Assumption: implanted hydrogen relatively small compared to hydrogen at the wafer



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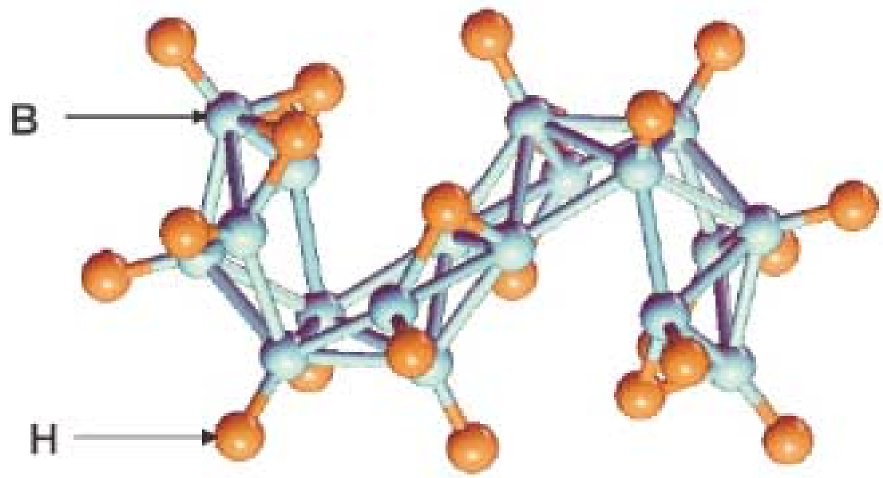

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Summary

- Significant productivity improvements are possible with Borane implantations
  - Extension Implants
  - Dual Poly Gate

- Existing machines support generation and transport
  - But have limits in the maximum energy due to the analyzer magnet capability
  - Dedicated machines?

- Process integration is promising
  - Little measureable difference between borane implants and boron implants.