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The Cluster Implant *Source*

Molecular Implant for Advanced USJs

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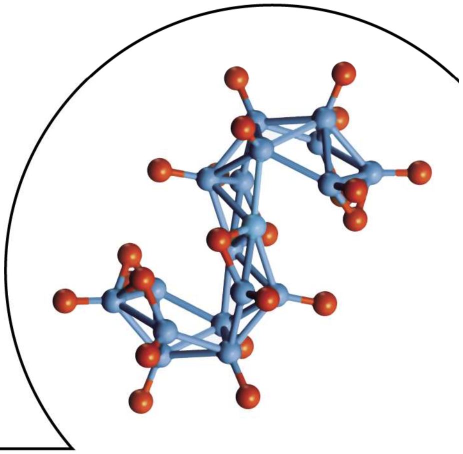
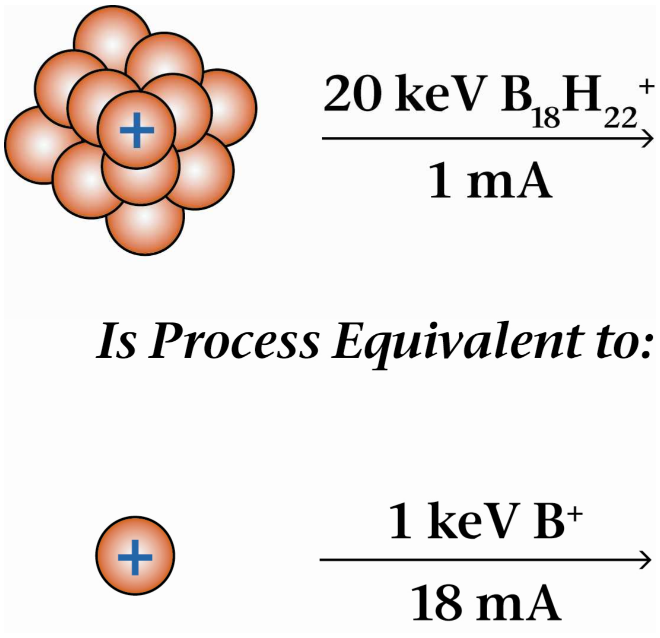
JTG SemiconWest, July 2010



Understanding ClusterBoron® Implants

- 18 Dopant Atoms per ClusterBoron® molecule
- Extract and Transport at 20X (higher energy)
- Increase effective dose rate by 18X
- Low Energy, High Dose Implant



$$\xrightarrow[\text{1 mA}]{\text{20 keV } B_{18}H_{22}^{+}}$$

Is Process Equivalent to:

$$\xrightarrow[\text{18 mA}]{\text{1 keV } B^{+}}$$

- Highest throughput
- Best implant quality
- Shallowest junctions
- Simplified process
- Extend process capability
- Improved device quality

Molecular Implant Features

- Self-amorphization
    - Amorphization is required, Ge PAI leaves defects
    - Recrystallization forces substitutionality
- No EOR defects
    - Complete recrystallization even with ms only
- High productivity at low energy
- Drift mode
    - No energy contamination
- Excellent beam control

Molecular Implant Options

- ClusterBoron®
    - B18, B36
- Decaborane, B10
- ClusterCarbon™
    - C16, C14, C7, C5
- N-type
    - P4, As4

USJ Requirements for PMOS SDE

45nm Node:

- $R_s \sim 1000\ \Omega/sq,\ X_j < 20nm$
- $R_s \cdot X_j < 20\ (k\Omega\text{-}nm)$

32nm Node:

- $R_s < 1000\ \Omega/sq,\ X_j < 15nm$
- $R_s \cdot X_j < 15\ (k\Omega\text{-}nm)$

28nm Node:

- $R_s < 1000\ \Omega/sq,\ X_j < 12nm$
- $R_s \cdot X_j < 12\ (k\Omega\text{-}nm)$

22nm Node:

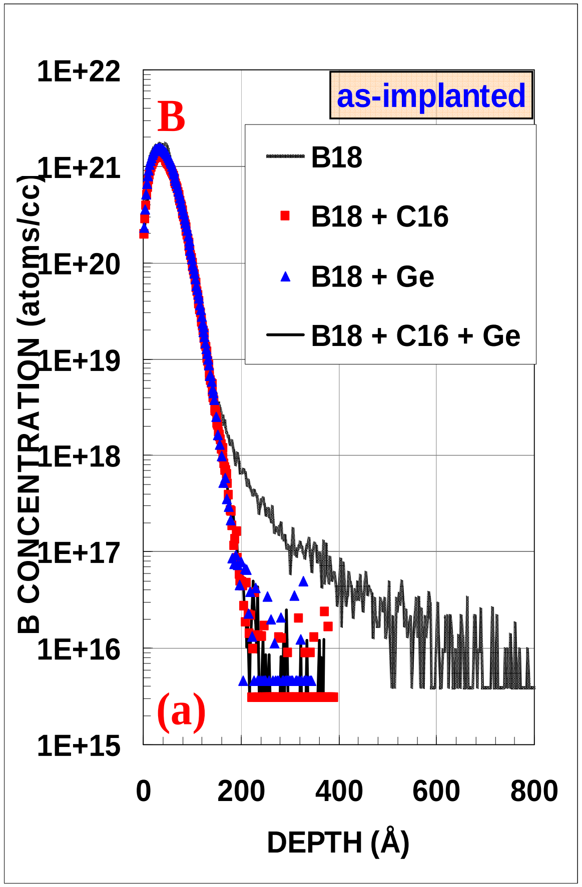
- $R_s < 1000\ \Omega/sq,\ X_j < 10nm$
- $R_s \cdot X_j < 10\ (k\Omega\text{-}nm)$

Junction Trends 2010

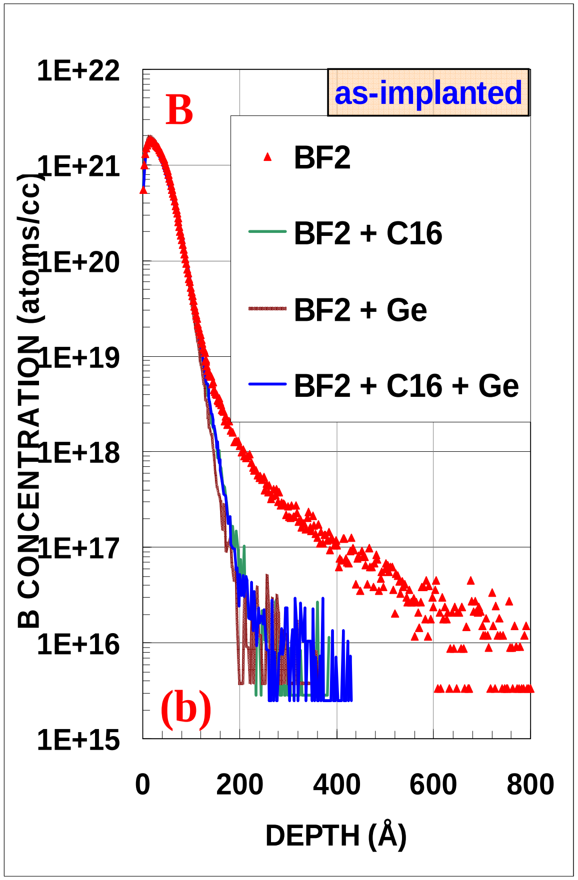
- Xj requirements push implant energy lower
- Rs requirements push anneal temp higher
  - Flash, laser necessary
- Process integration teams prefer keeping diffusion
  - Ms plus spike process common
  - “Several ms” anneals to tune diffusion
- Insufficient anneal to eliminate EOR defects
  - Damage engineering
- Diffusionless processes starting to appear

$B_{18}H_{22}$ and BF_2 with Co-implants

$B_{18}H_{22}$ with co-implant



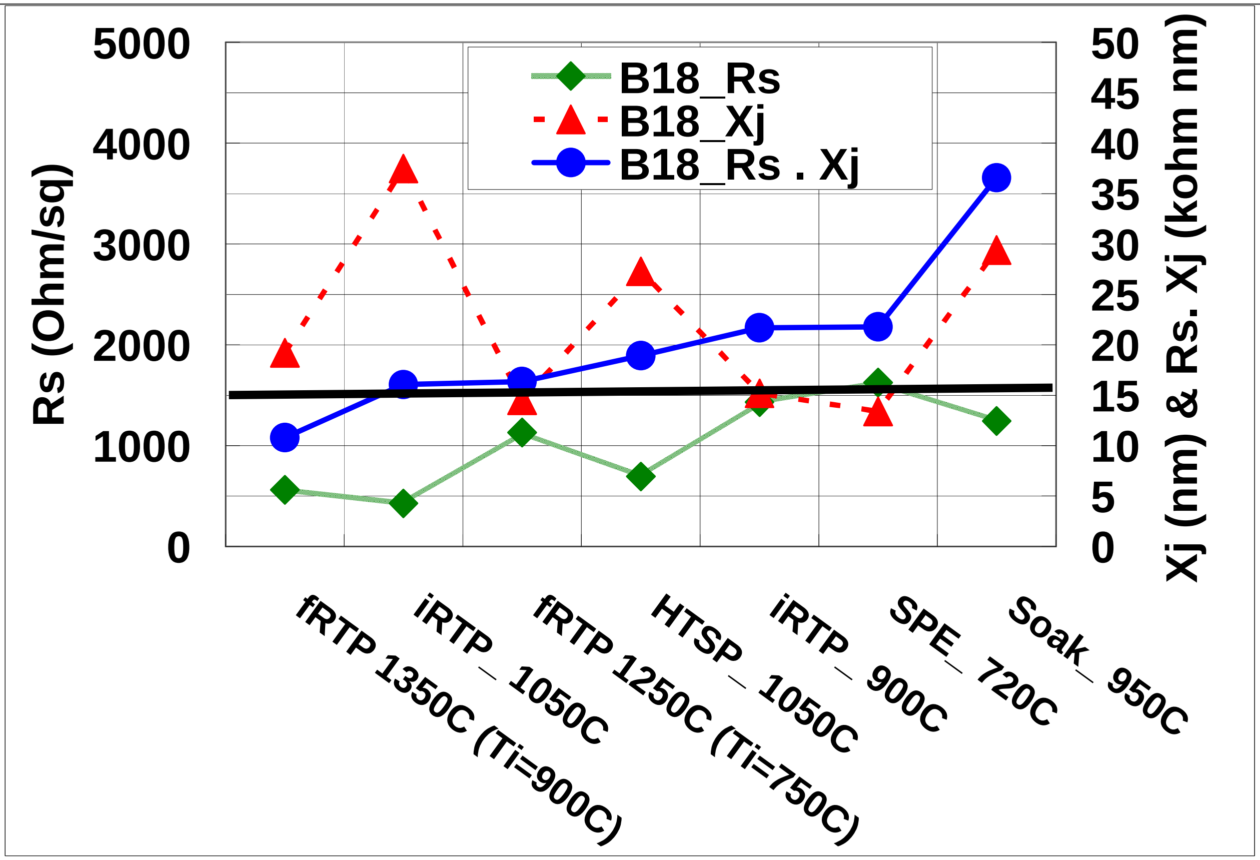
BF_2 with co-implant



$B_{18}H_{22}$ & BF_2 implant - 500eV (equiv), 1e15

$R_s \cdot X_j$: 32 nm Node

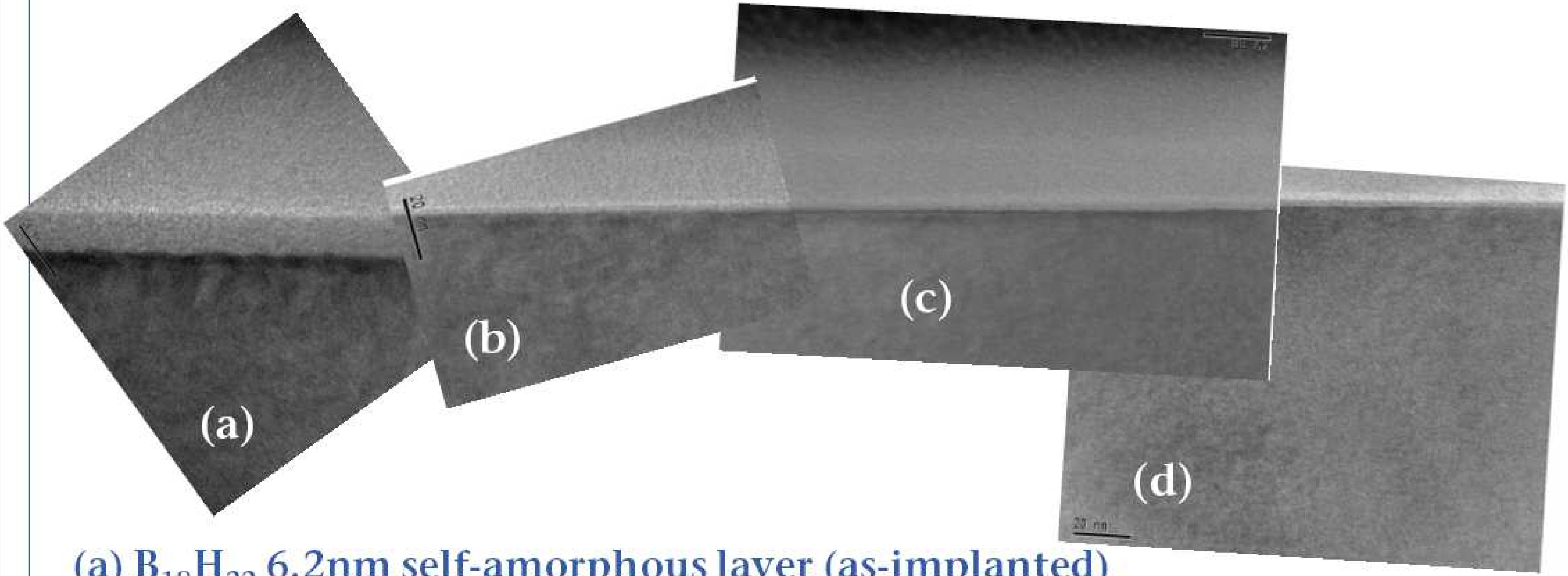
Anneal Conditions for $B_{18}H_{22}$



$R_s \cdot X_j$ shows that the flash anneal satisfies the 32nm requirement.

$B_{18}H_{22}$ X-TEM with various anneals

(JOB & NEC, IWJT2006 & SST2006)



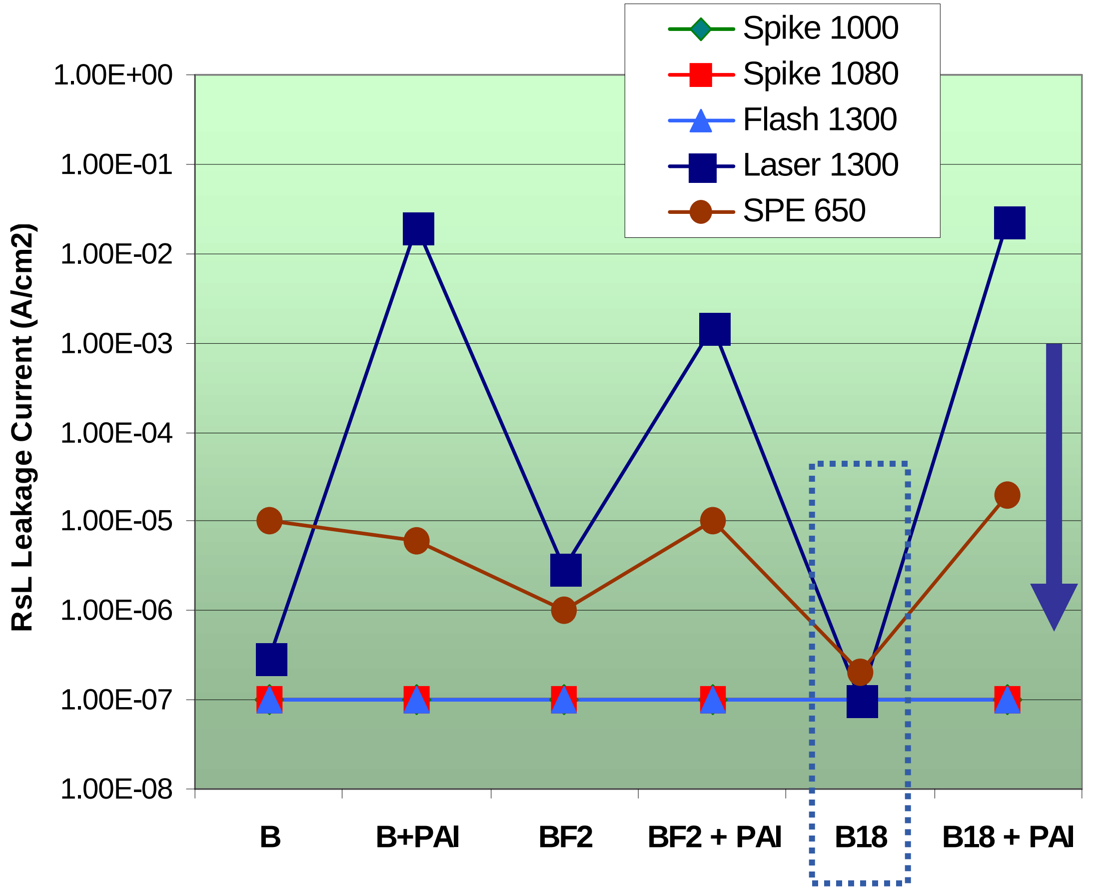
(a) $B_{18}H_{22}$ 6.2nm self-amorphous layer (as-implanted)

(b) SPE with no EOR damage

(c) Laser with no EOR damage

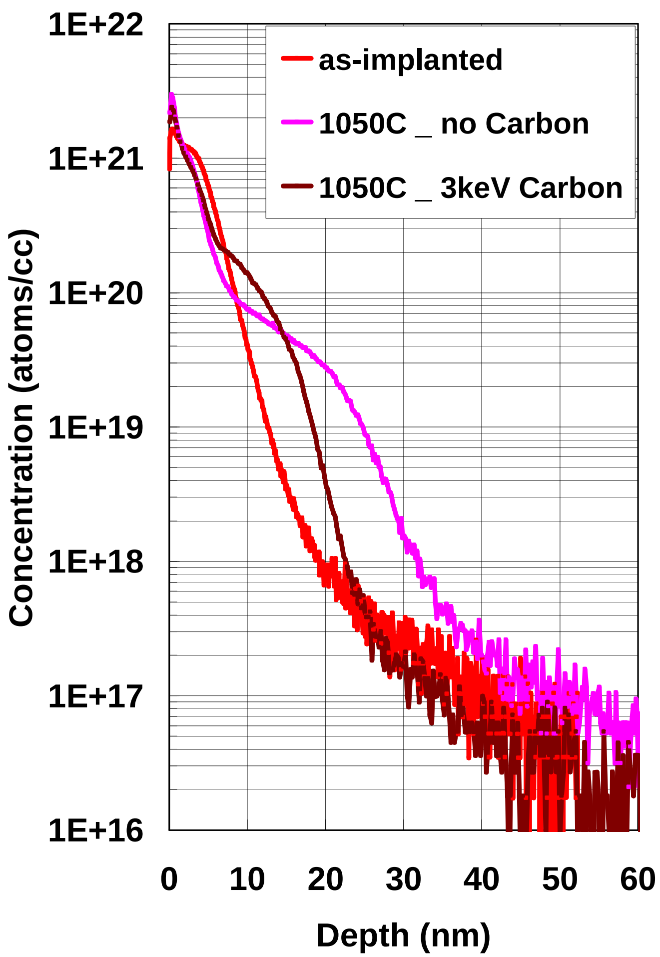
(d) Flash with no EOR damage

Junction Leakage Current



- Non-PAI B_{18} has > 2 orders of magnitude lower junction leakage current using diffusion-less laser and SPE anneals
- This is consistent with low damage junction in PL results

ClusterCarbon™ Co-Implant



Carbon co-implant provides the following:

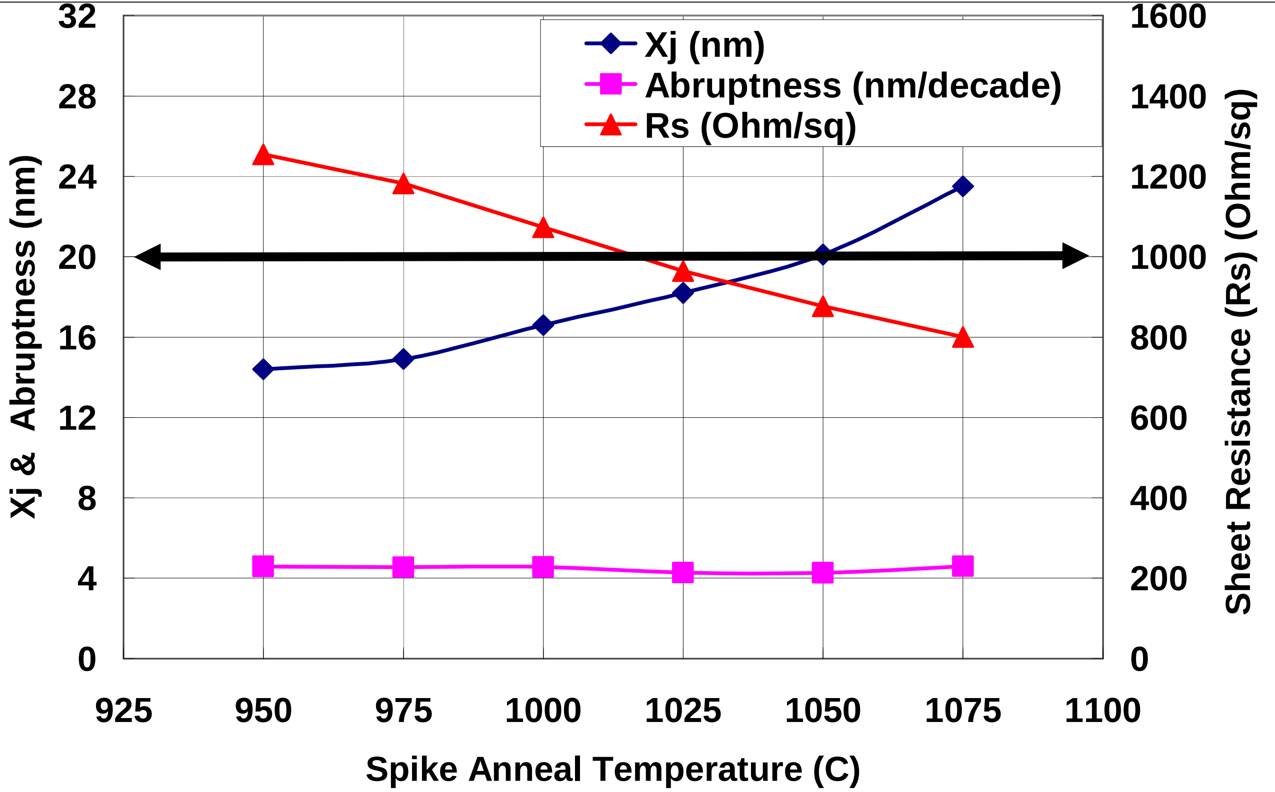
- Shallower Junctions
- Higher Solid Solubility
- Improved Junction Abruptness

(Cluster Boron 500eV, 1e15

– Spike anneal 1050^{o}C with and without Carbon)

45nm results

$B_{18}H_{22}$ 500eV & $C_{16}H_{10}$ 3keV @ 1E15 atoms/cm^2

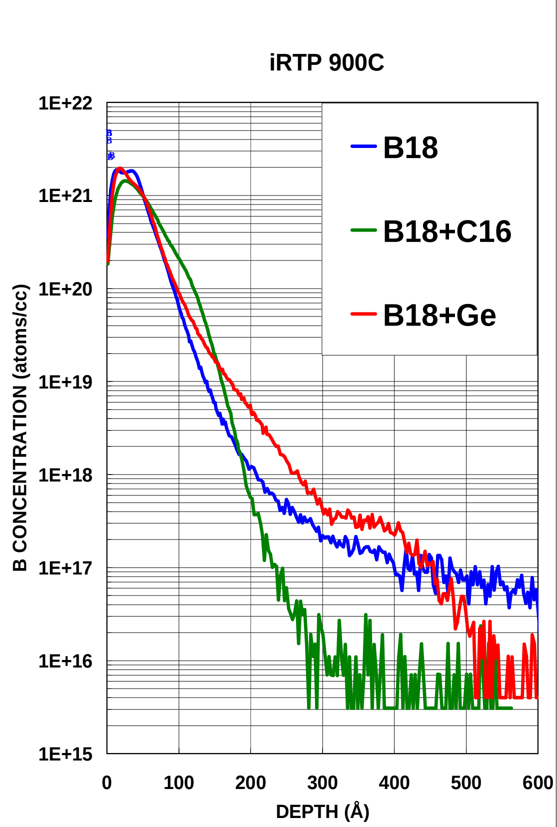


X_j < 20nm below 1050°C

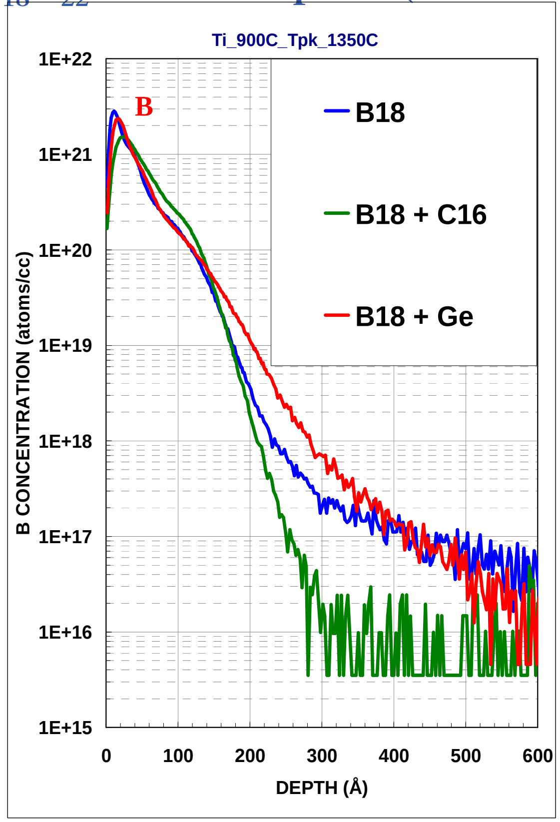
$R_s < 1000\ \Omega$/sq for spike anneal temp ≥ 1000°C

iRTP 900°C, fRTP T_i 750°C - T_{pk} 1350°C

$B_{18}H_{22}$ co-implant (iRTP 900°C)



$B_{18}H_{22}$ with co-implant (fRTP 1350°C)



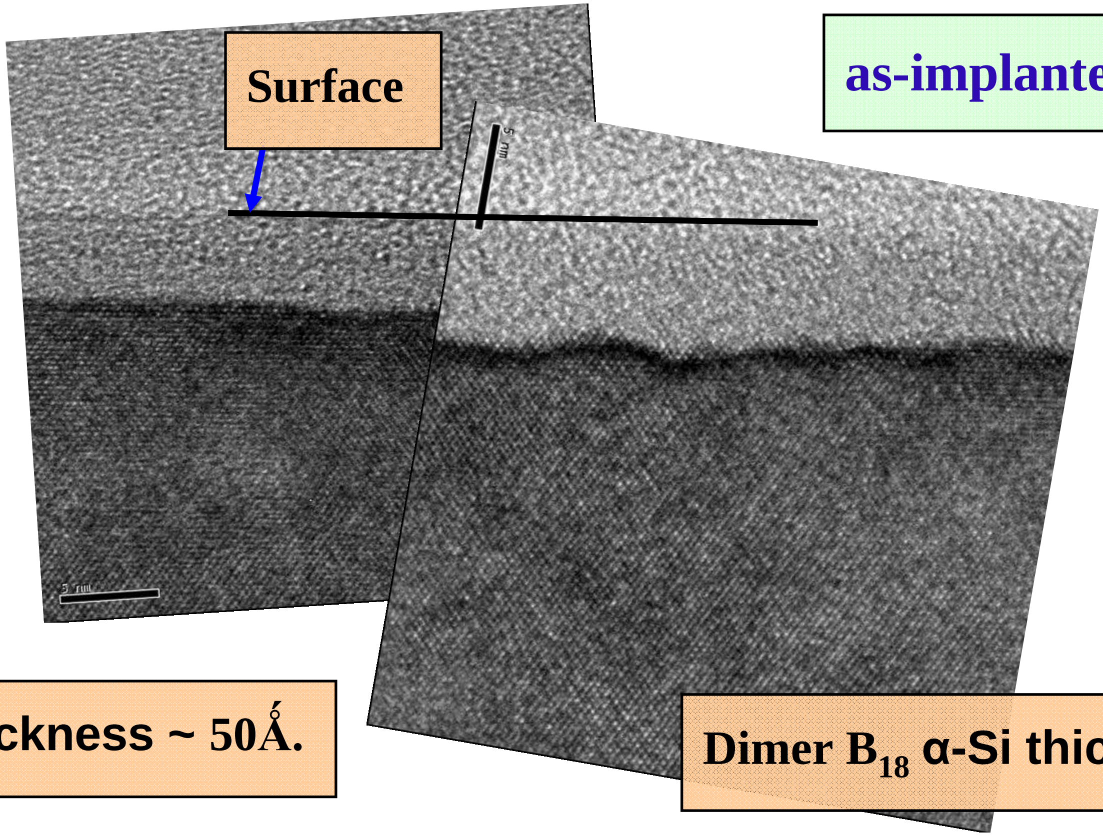
High boron concentration at Ge EOR defect region. Reduced concentration with $C_{16}H_{10}$ at iRTP 900°C. The concentration is removed at the higher flash temperature Tpk = 1350°C.

ClusterBoron Dimer Technology

- ClusterIon source with ClusterBoron (B18H22) feed material produces ClusterBoron-Dimer (B36Hx) ion beam
- Dimer production by ion source is less than the B18 primary beam, but transport conditions produce dose rate advantage for the dimer at low energy (<400eV)
- B36 Process Evaluation
  - Amorphization
  - Depth Profile
  - Activation

Self-amorphization - B_{18} vs B_{36}

300eV@1e15



as-implanted

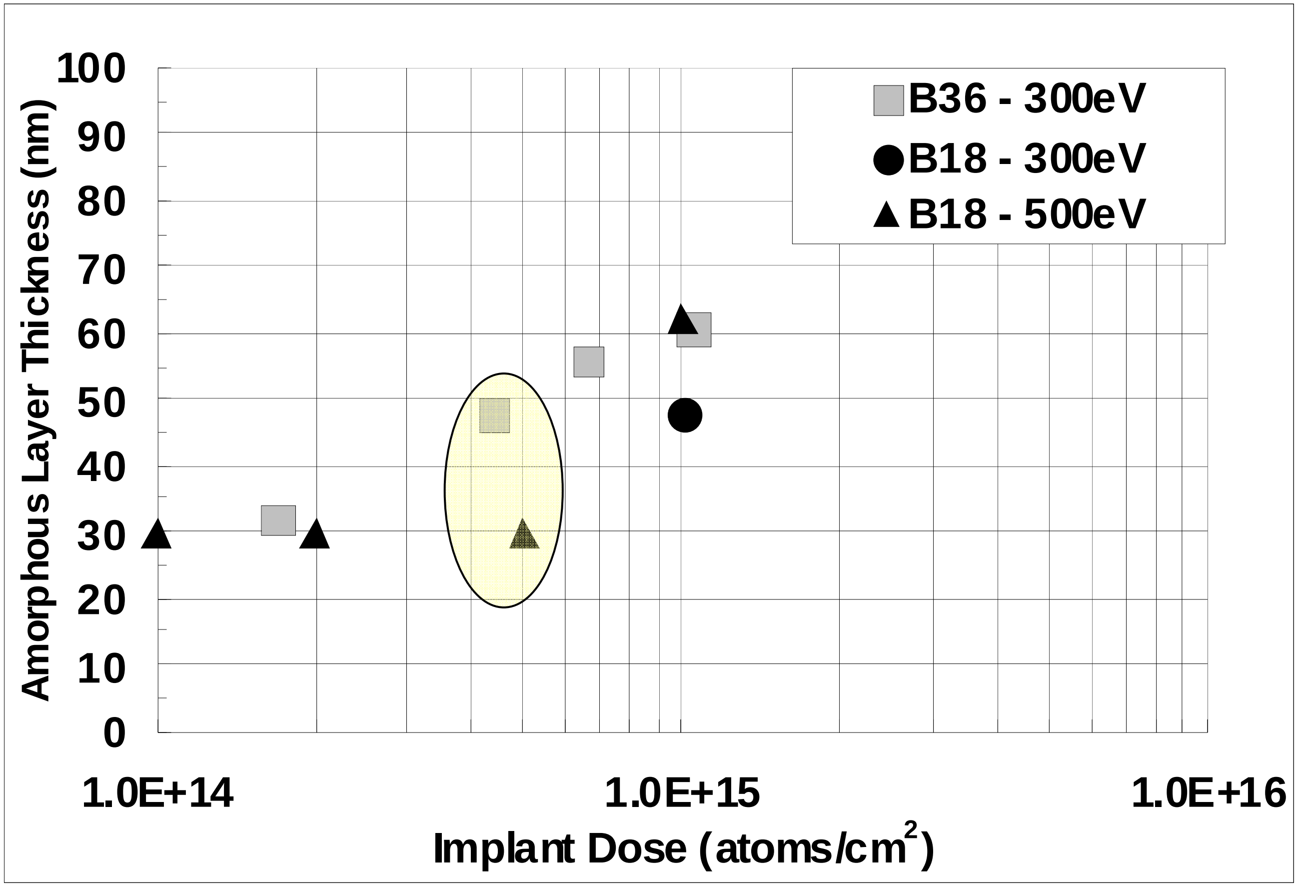
B_{18} α-Si thickness ~ 50Å.

Dimer B_{18} α-Si thickness ~ 63Å.

- Thicker amorphous layer leaves less Si interstitials for residual EOR defect formation and also less TED. All leads to higher dopant activation.

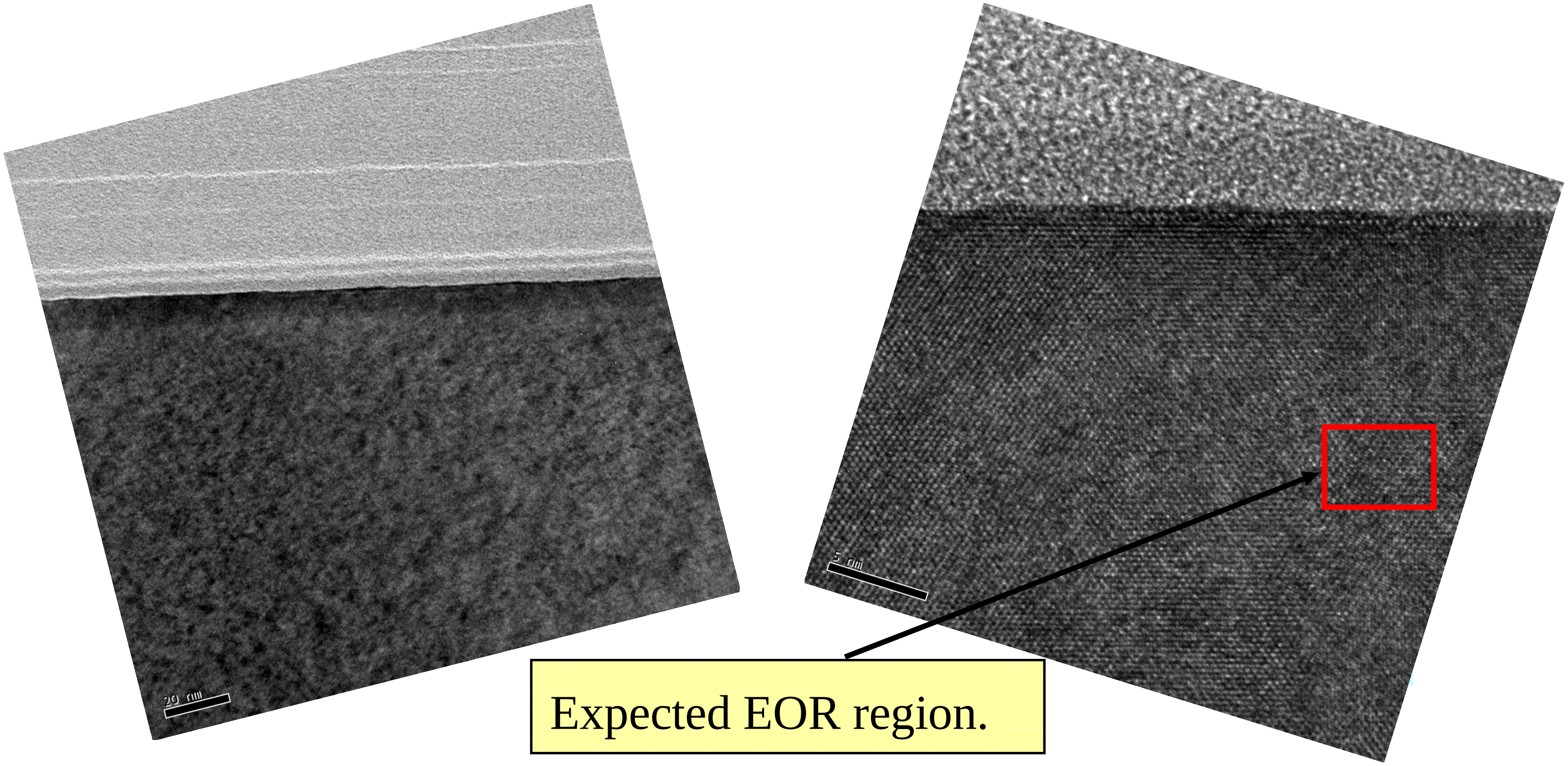
XTEM

$B_{18}H_{22}$ and $B_{36}H_x$ – 300eV@1e15



Amorphization threshold is lower with B_{36} compared to B_{18} even for $E_{B36} < E_{B18}$

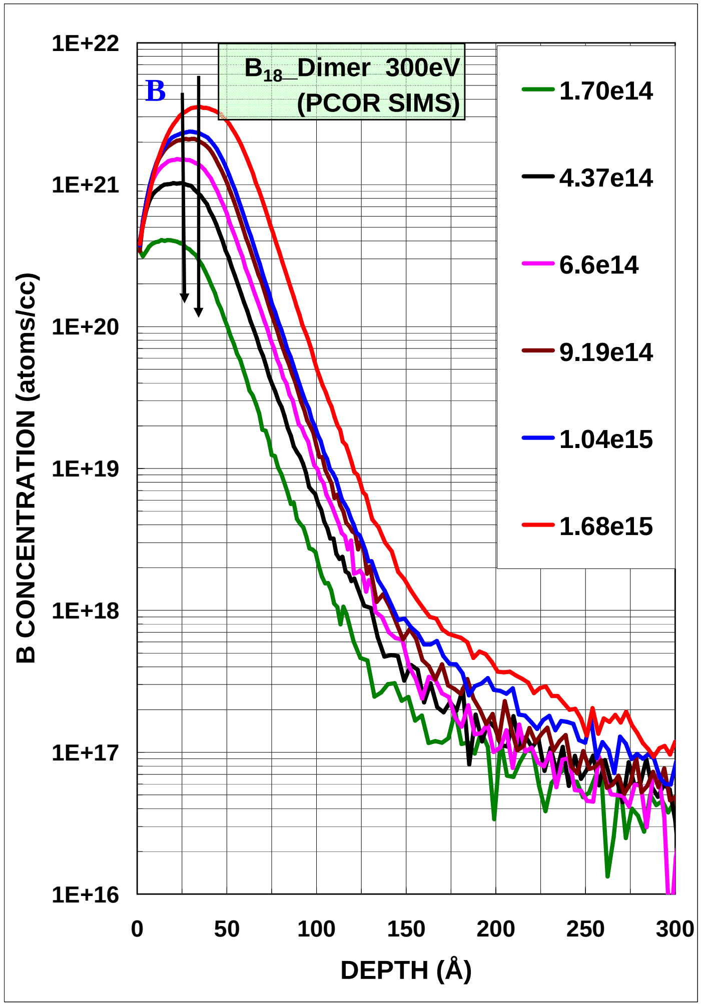
$B_{36}H_x$ – 300eV, 2.33e15 atoms/cm^2 – No EOR defect
Excico Laser Anneal



Expected EOR region.

No obvious extended defects observed even with high boron dose.

$B_{36}H_x$ at 300eV – Dose Sequence SIMS Profile PCOR



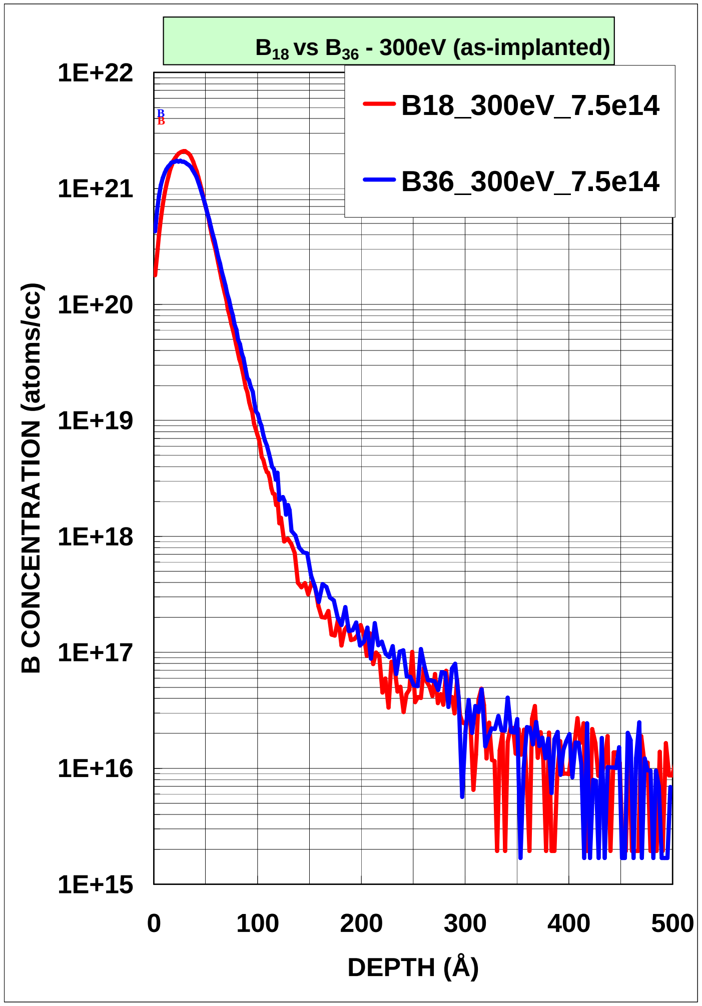
For 300eV dimer B_{36} implant, beyond 7e14 dose, the Rp shifts deeper.

Xj ranges from 8nm to 12.5nm for dose range from 2e14 to 2e15 atoms/cm^2

Knock-on Effect :

- **V.I.Shulga and P.Sigmond , Nucl. Instr. and Meth B, Vol. 47, p.236, (1990).**
- **Matsuo et al MRS (1998)p.17 (at cluster size > 10, Rp is larger than monomer)**

B_{18} vs B_{36} – 300eV @ 7.5e14 atoms/cm^2



SIMS profile for B_{36} is slightly deeper than B_{18}. At a boron concentration of 5e18 atoms/cm^3, the difference in Xj between B_{18} and B_{36} is around 5Å.

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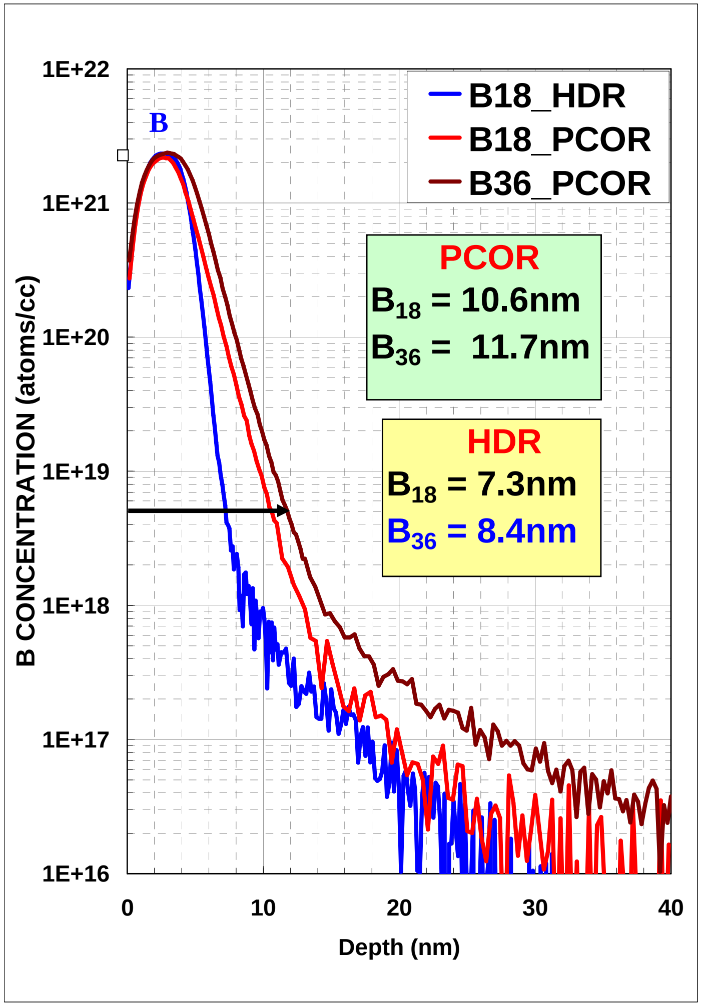
$B_{18}H_{22}$ & $B_{36}H_x$ @ 300eV _1e15
HDR & PCOR protocol



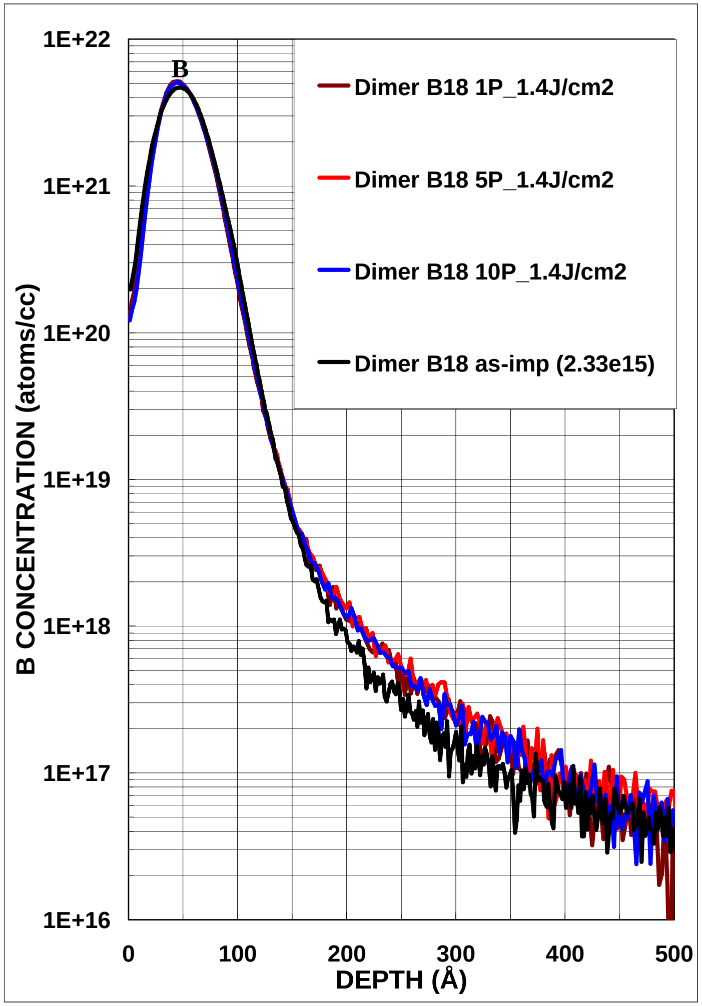
SIMS profile for HDR protocol is shallower than PCOR protocol.

At concentration of 1e18, the difference in Xj is about 4nm.

The Cluster Implant *Source*

$B_{36}H_x$ – 300eV, 2.33e15 atoms/cm^2

Excico Laser Anneal



Practically no change in Xj after anneal at 5e18 atoms/cm^3.

Rs , Xj and Abruptness :

B_{18} vs B_{36} – 300eV, 9e14 atoms/cm^2

	Rs (Ohm/sq)				Xj (5e18 atoms/cm^3)_HDR			
Species	as-imp	1P_ 1.5J/cm^2	5P_ 1.4J/cm^2	5P_ 1.5J/cm^2	as-imp	1P_ 1.5J/cm^2	5P_ 1.4J/cm^2	5P_ 1.5J/cm^2
B_{18}	x	1075	942	1088	86	92	92	x
B_{36}	x	759	671	780	96	100	101	x
Rs % diff.		29	29	28	ΔXj	8	9	x

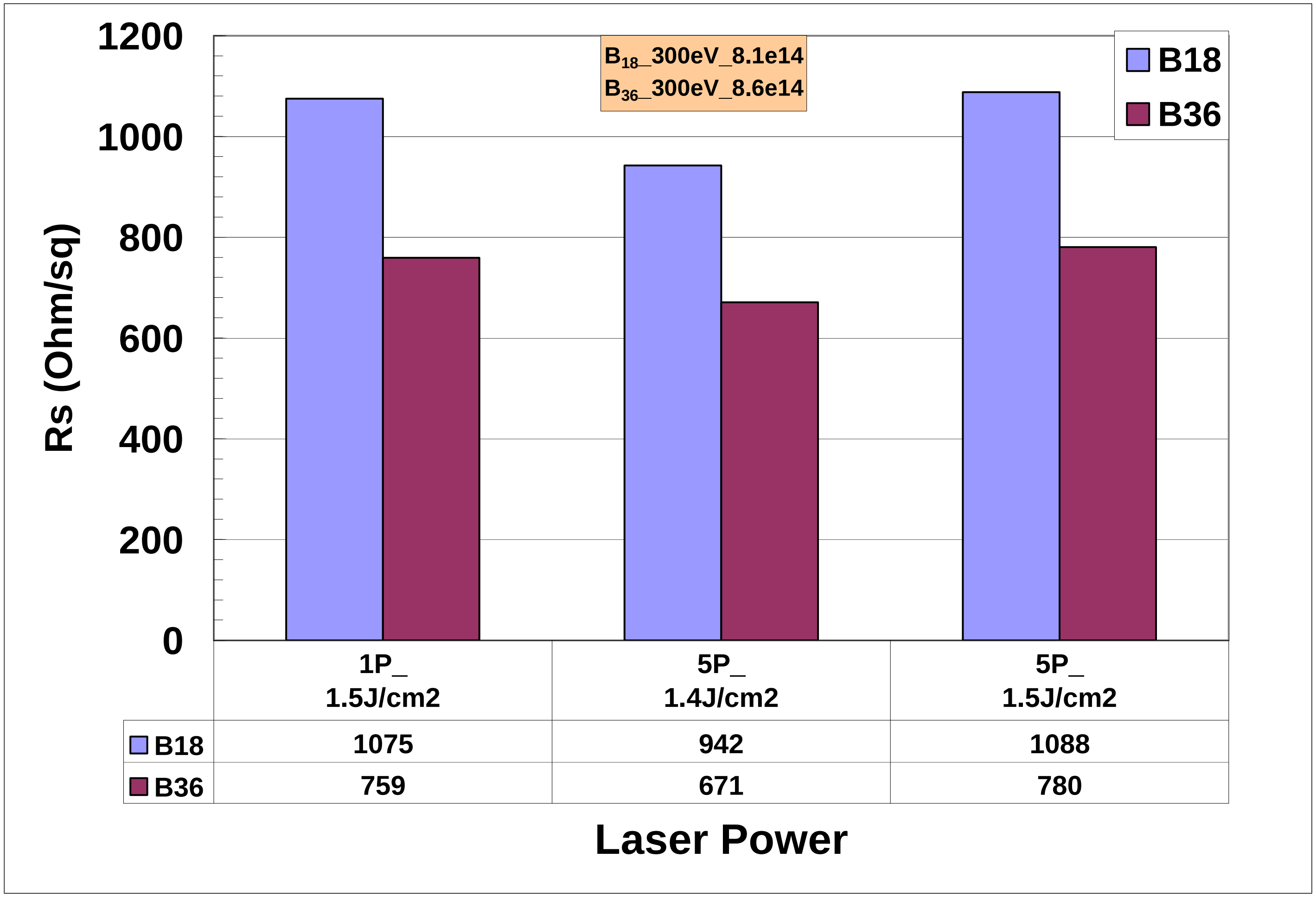
	Abruptness				SIMS Dose (atoms/cm^2)			
	as-imp	1P_ 1.5J/cm^2	5P_ 1.4J/cm^2	5P_ 1.5J/cm^2	as-imp	1P_ 1.5J/cm^2	5P_ 1.4J/cm^2	5P_ 1.5J/cm^2
B_{18}	1.75	1.90	1.96	x	8.00E+14	7.94E+14	8.05E+14	x
B_{36}	x	x	x	x	x	x	8.60E+14	x

30% better Rs with B_{36}. The difference in Xj between B_{18} & B_{36} is < 10Ǻ. Abruptness < 2Ǻ

The Cluster Implant *Source*

Rs Results:

B_{18} vs B_{36} – 300eV, 9e14 atoms/cm^2

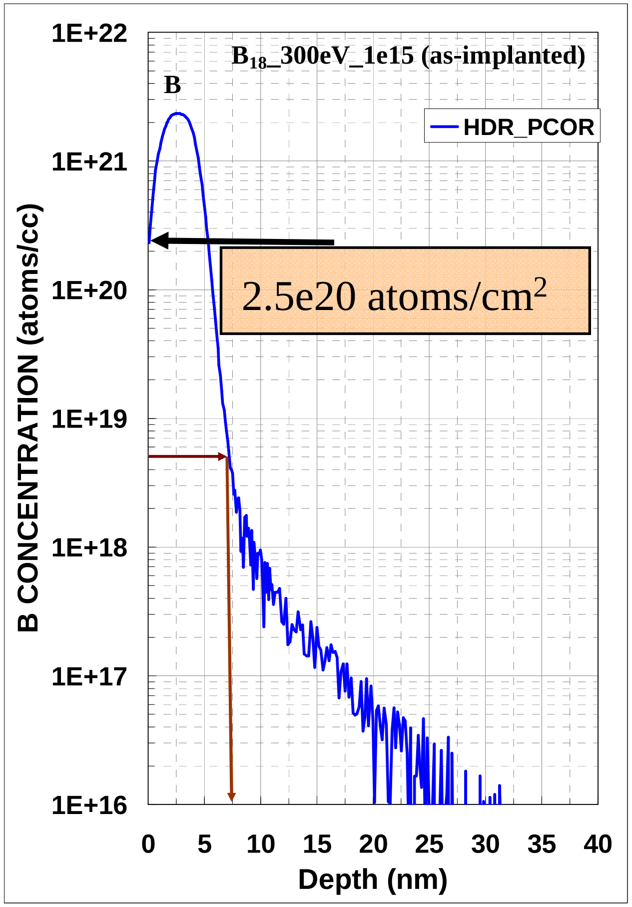


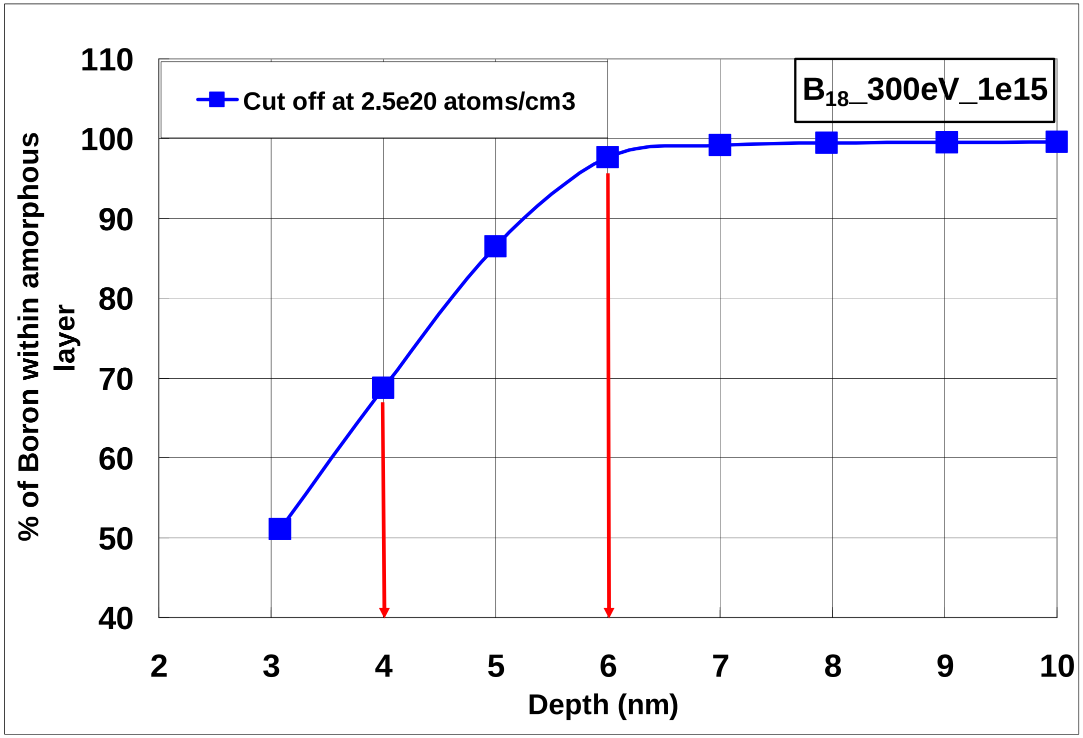
B_{18}_300eV_8.1e14
B_{36}_300eV_8.6e14

	1P_ 1.5J/cm2	5P_ 1.4J/cm2	5P_ 1.5J/cm2
B18	1075	942	1088
B36	759	671	780

30% better Rs in the case of B_{36}.

% of Boron within α-Si layer
HDR (300eV, 1e15 atoms/cm^2)



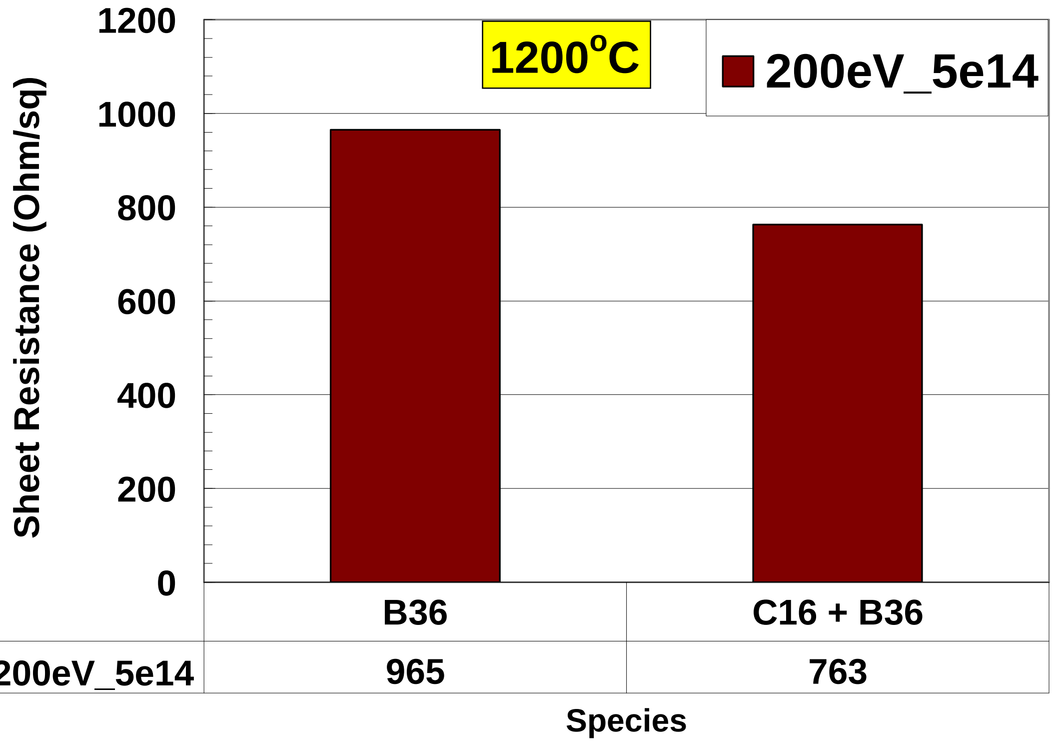


40Ǻ α-Si ~ 70% boron within the α-layer

60Ǻ α-Si ~ 98% boron within the α-layer

B_{36} vs C_{16} + B_{36} – 200eV, C_{16}_3keV

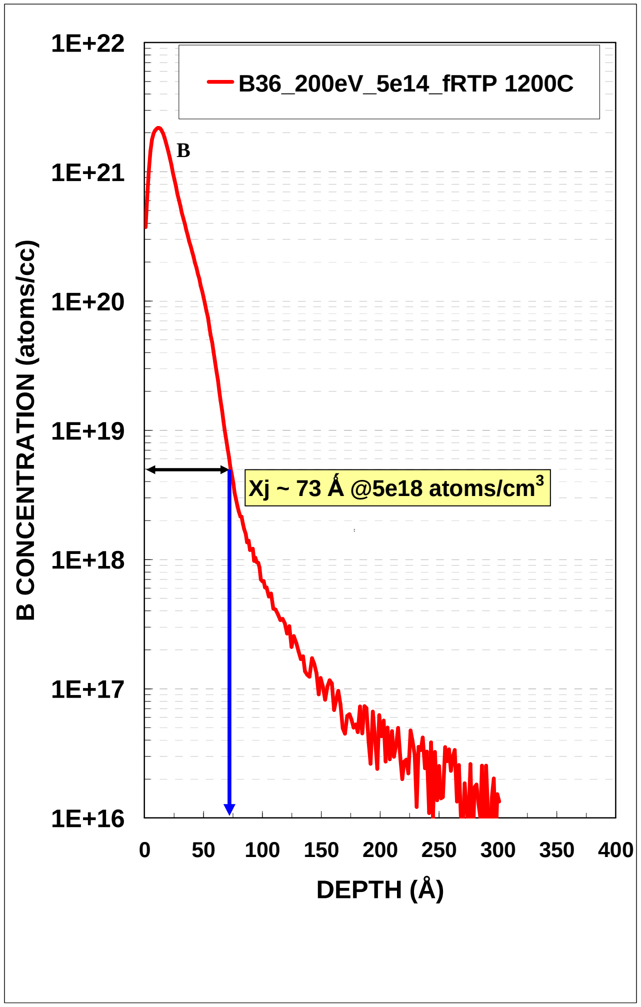
Flash Anneal co-implant effect



Using B_{36} or C_{16}+B_{36} one can get to low sheet resistance with millisecond anneal with Xj < 10nm

B_{36} – 200eV, C_{16}_3keV

Flash Anneal SIMS - Xj



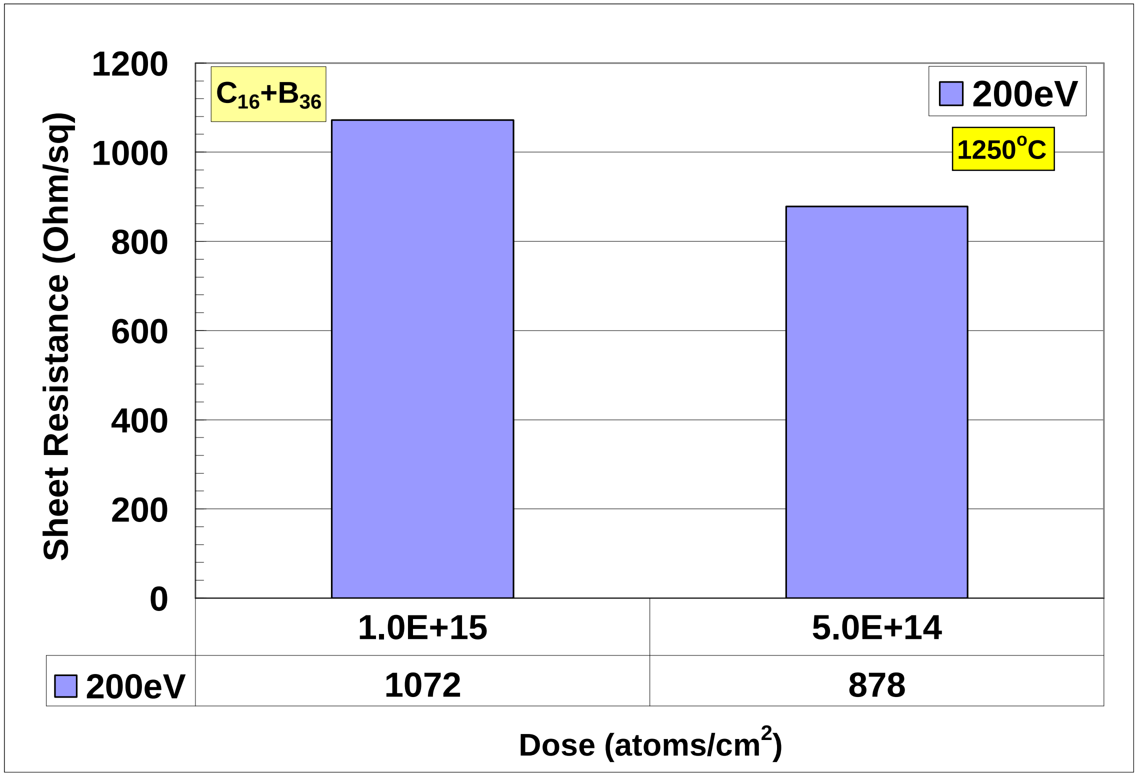
Using B_{36} only without any PAI

Xj ~ 7.3 nm.

Rs ~ 965 Ohm/sq

C_{16} + B_{36} – 200eV , C_{16}_3keV

Flash Anneal DOSE EFFECT



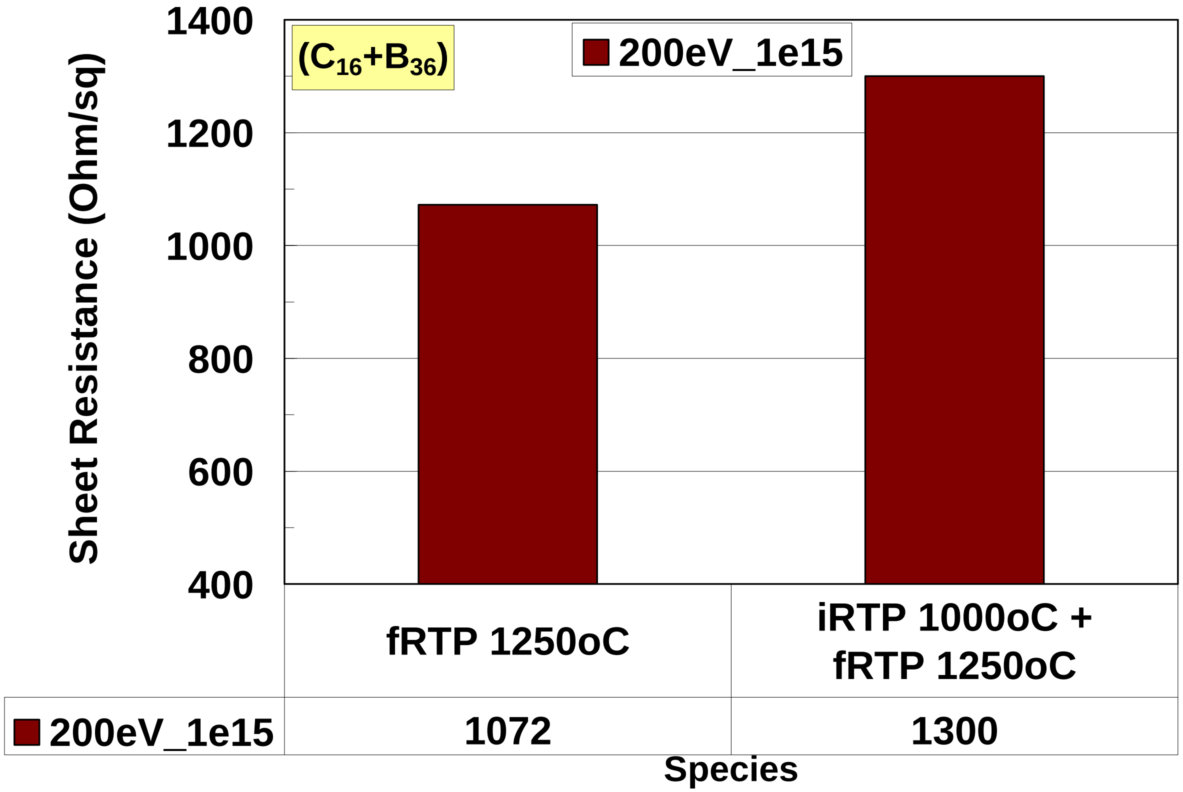
	1.0E+15	5.0E+14
■ 200eV	1072	878

Lower dose provides better Rs. (Formation of Boron complex ending up in deactivation due to higher available concentration)

C_{16} + B_{36} – 200eV , C_{16}_3keV

Flash Anneal

Anneal EFFECT



	fRTP 1250oC	iRTP 1000oC + fRTP 1250oC
■ 200eV_1e15	1072	1300

Higher Rs after impulse spike and flash anneal.

Summary

- Molecular implant has many unique features which provide process solutions for current challenges
  - Amorphization with high productivity
  - Elimination of EOR damage for low leakage junctions
  - Diffusion control for advanced junctions
- ClusterBoron implant enables advanced USJ for 22nm and beyond