SemEquip

The Cluster Implant Source

Advantages of Ion Cluster Implantation In CMOS Manufacturing

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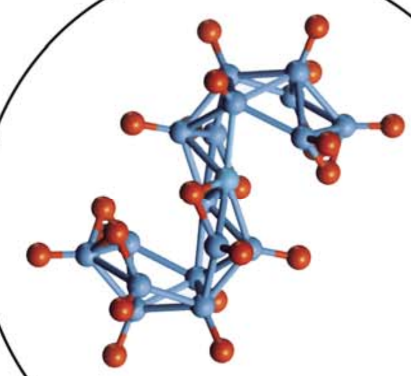
Junction Technology Group

Semicon West, July 19 2007



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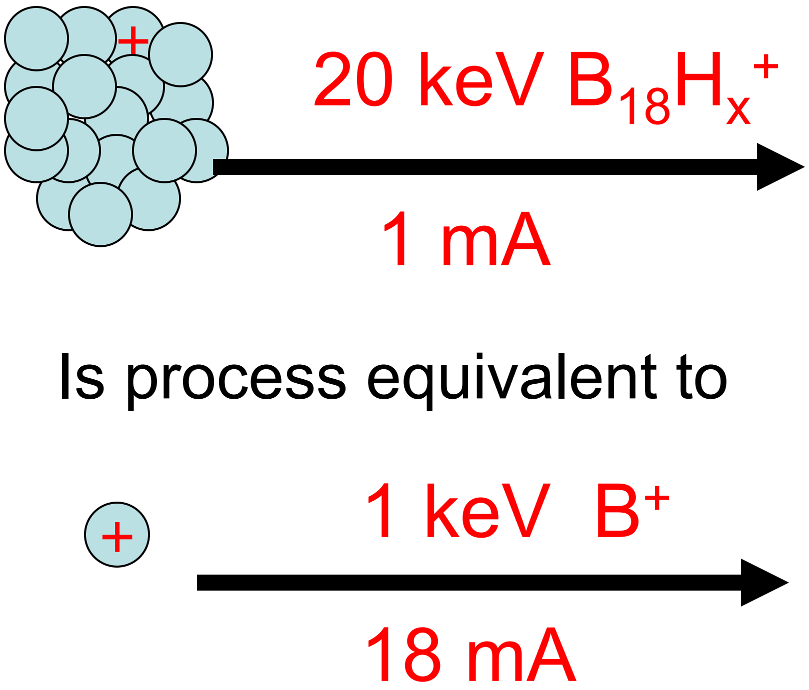
Outline

- Cluster concept
- Types of ion clusters
- Productivity enhancement
- Activation
- Junction leakage
- Defects
- Amorphization; crystal regrowth
- Carbon for diffusion control
- Stress engineering with SiC for NMOS channel mobility enhancement
- Channeling & implant energy control
- Summary

Cluster Concept—Productivity Advantage

- 18 dopant atoms per cluster
- Increases effective dose rate by 18X
- Extract and transport at 20X higher energy
- Reduces net current to wafer by 18X (reduced charging)
- Deceleration is *not* required, eliminating energy contamination
- Enables cost-effective *low energy, high dose* Implants
- Low angular divergence low-energy beams at wafer



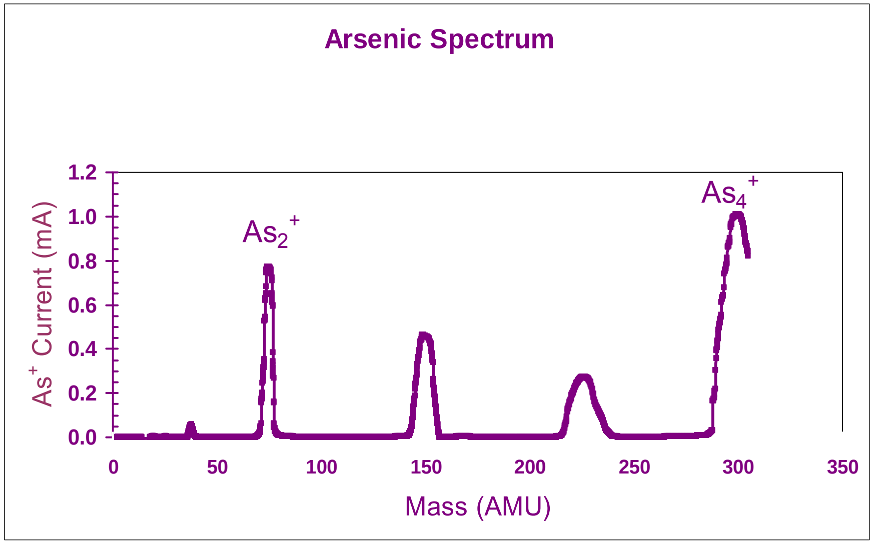
Process Advantages of $B_{18}H_{22}$ Implantation

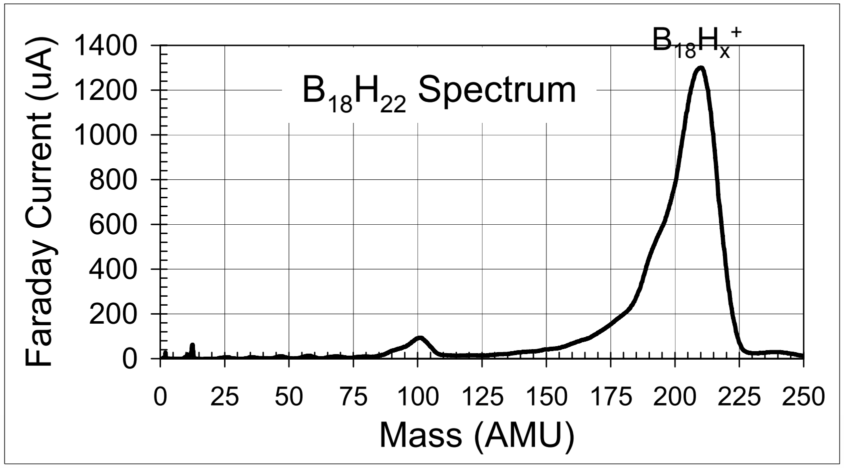
Advanced Logic & Memory

- Higher Throughput
  - Production-worthy throughput for doses up to 3E16cm^{-2}; enabling for dual gate poly doping, contact plug, deep S/D
  - Up to 50mA B even at low (1-4 keV)
  - >100WPH at 200eV PMOS SDE (32nm design rule)
- No Energy Contamination
  - All implants are in drift mode
  - Enables abrupt junctions
  - Reduced risk of V_{th} shifts due to gate punch-through
- Simplified Process Flow
  - No Ge or Si pre-amorphization needed due to self-amorphization property of cluster
  - Shallower as-implanted profiles→ conventional spike anneals can be used for USJ
- Improved Device Characteristics
  - No implanted F, which can promote through-gate dopant diffusion
  - Conventional beam line means tight dose & energy control
  - Low angular divergence at wafer leads to abrupt junctions, reduces V_{th} variation due to shadowing
  - Improved dopant activation at low thermal budget due to self-amorphization
  - Lower leakage because there are no end-of-range defects (perfect re-crystallization is possible)
  - Much reduced angular divergence and improved spatial uniformity for MC and serial HC compared to low-energy monomer beams
  - Enables high tilt, under-the-gate implants (*e.g.*, Halo)

Cluster Species Available with ClusterIon® Source

- $B_{18}H_{22}$, $B_{10}H_{14}$
- $C_{16}H_{10}$, C_7H_7
- As_4, P_4





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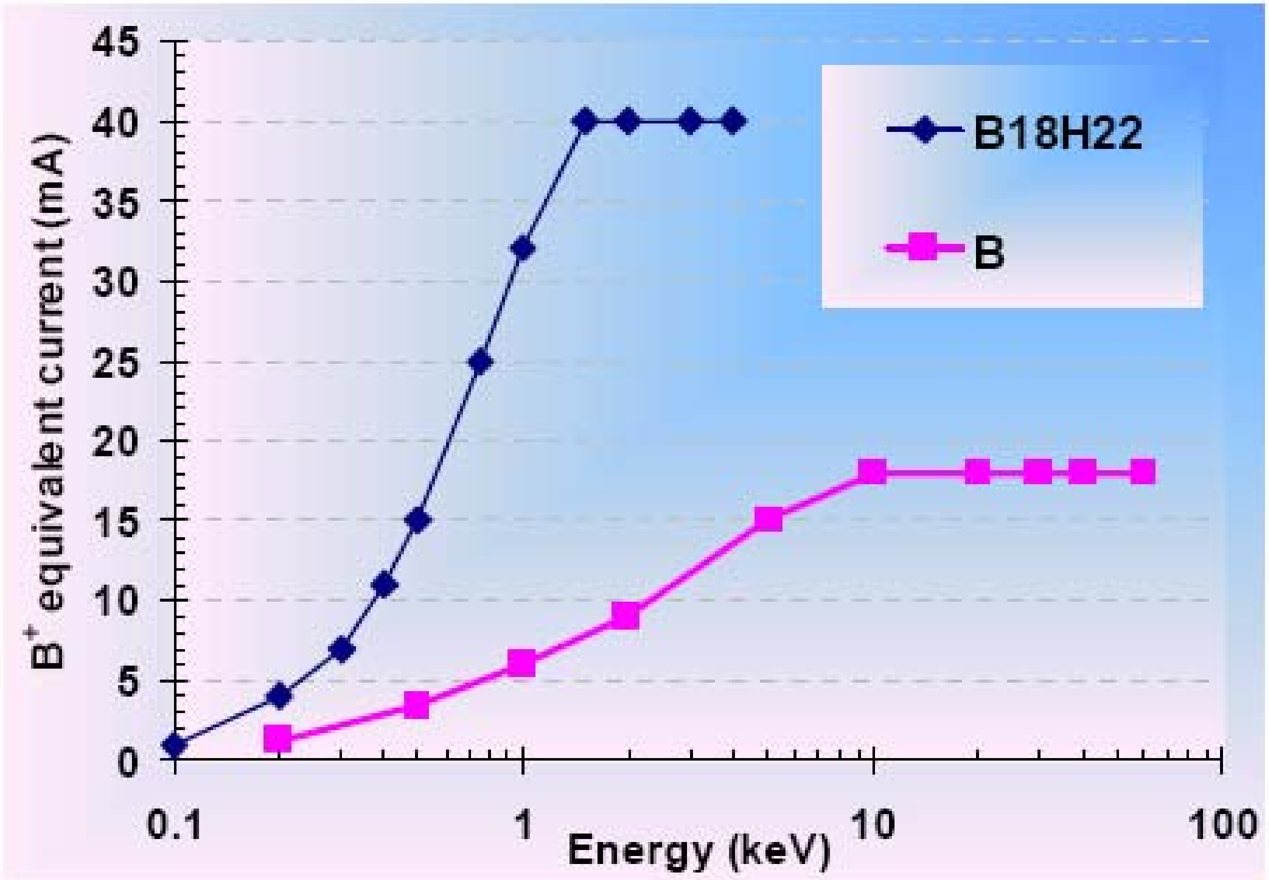
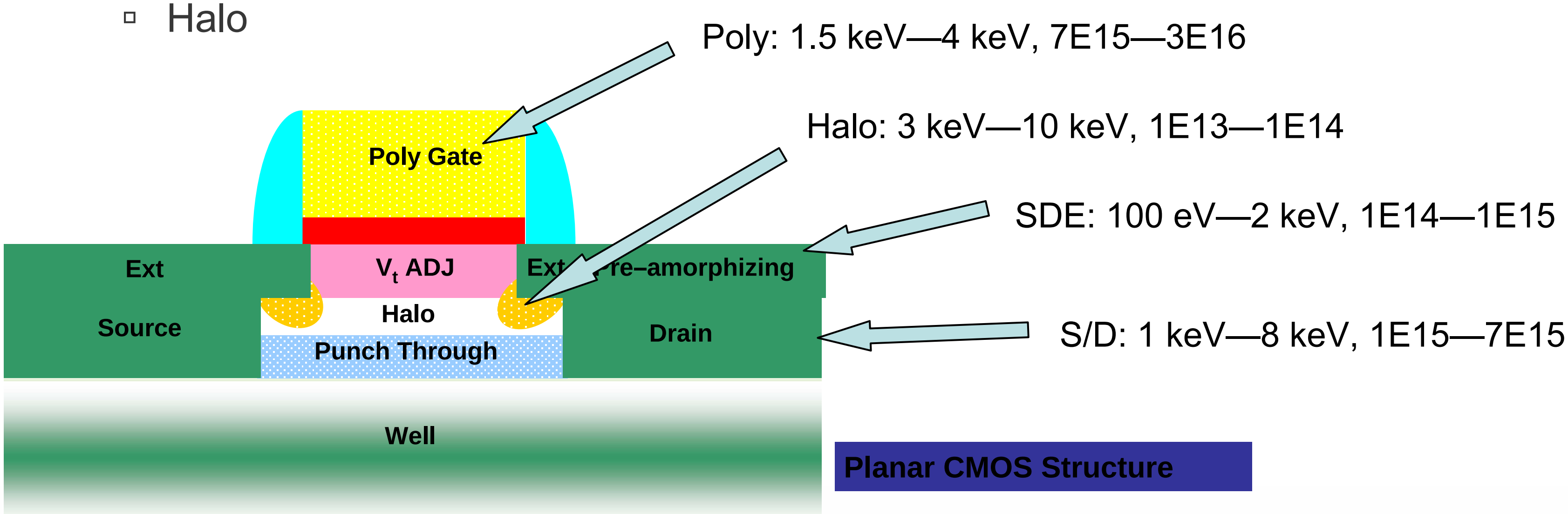
L. Rubin *et al.*, IWJT2007 (Axcelis)
HC Drift Mode Performance of Optima Implanter



What implants can be better done with Clusters?

- **$B_{18}H_{22}$** , **P_4** and **As_4** can be used for USJ n+ and p+:
  - Source/Drain Extension
  - Deep Source/Drain
  - Poly Gate
  - Halo

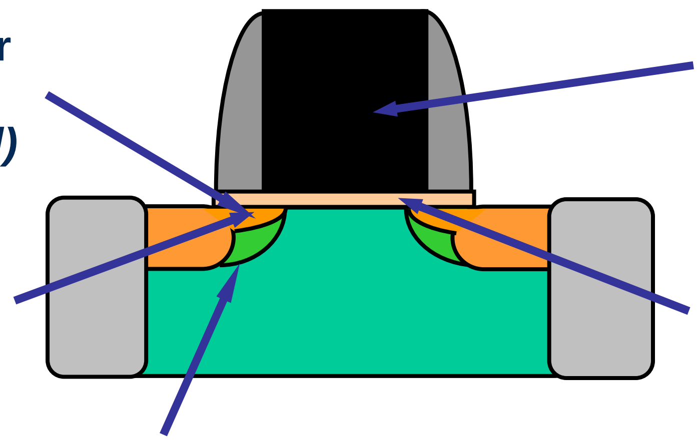


Scaling Challenges

Advanced Logic 65nm & 45nm

DRAM Development 90nm & 70nm

Precision dopant placement is critical for source drain extension implants *(angle control)*



Poly implants requiring lower energies and higher doses; < 5keV, ≥ 1.0E16

Repeatable implant profiles require *ZERO energy contamination*

Zero tolerance for energy contamination in gate oxide

HALO implants requiring higher dose, lower energy to improve electrical performance in the channel

Slide Courtesy of Axcelis Technologies

L. Rubin et al., IWJT2007 (Axcelis)

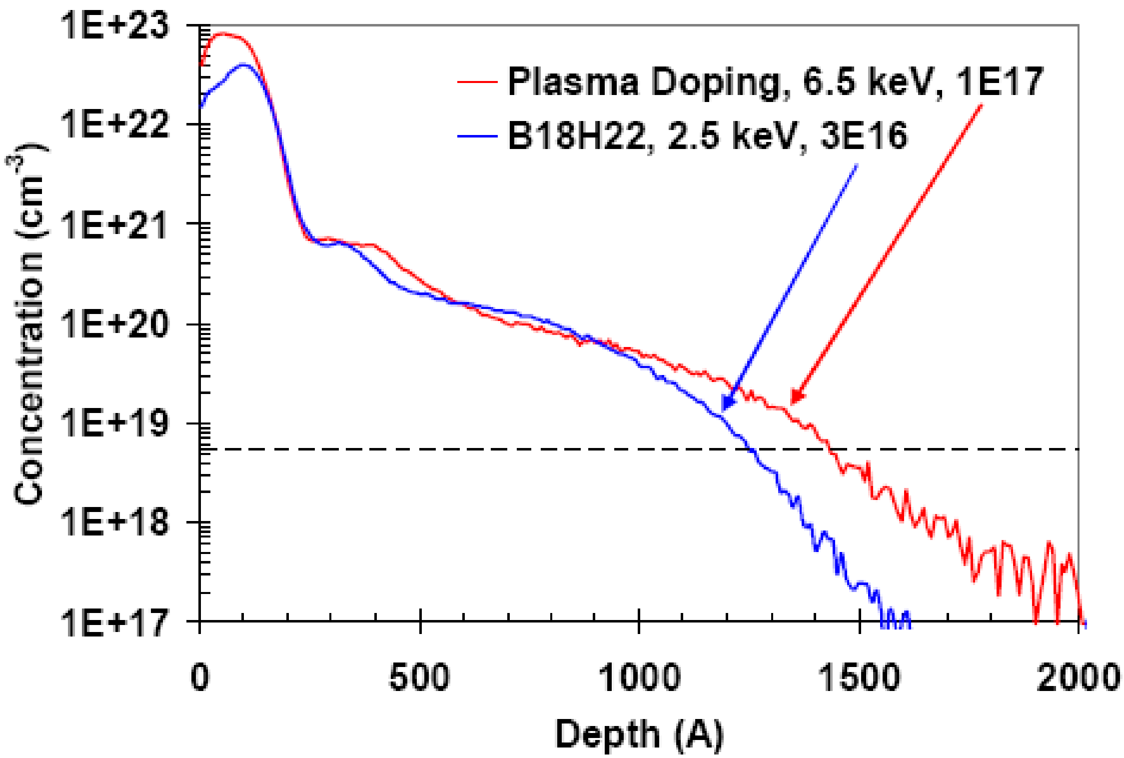
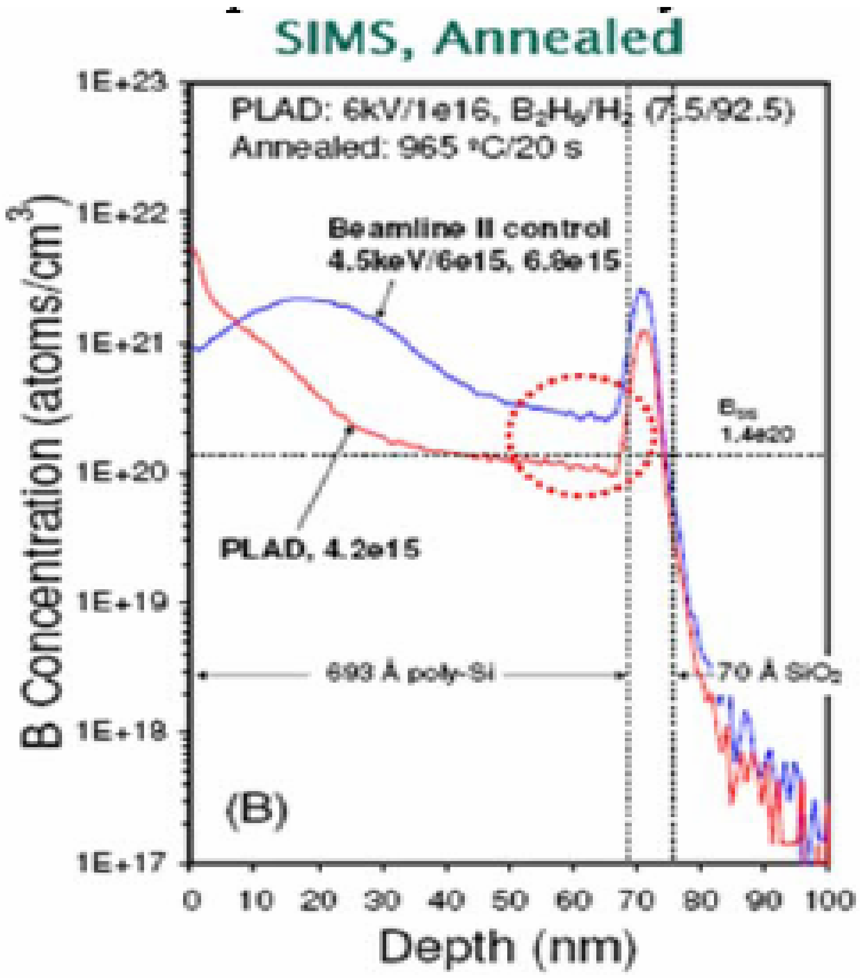
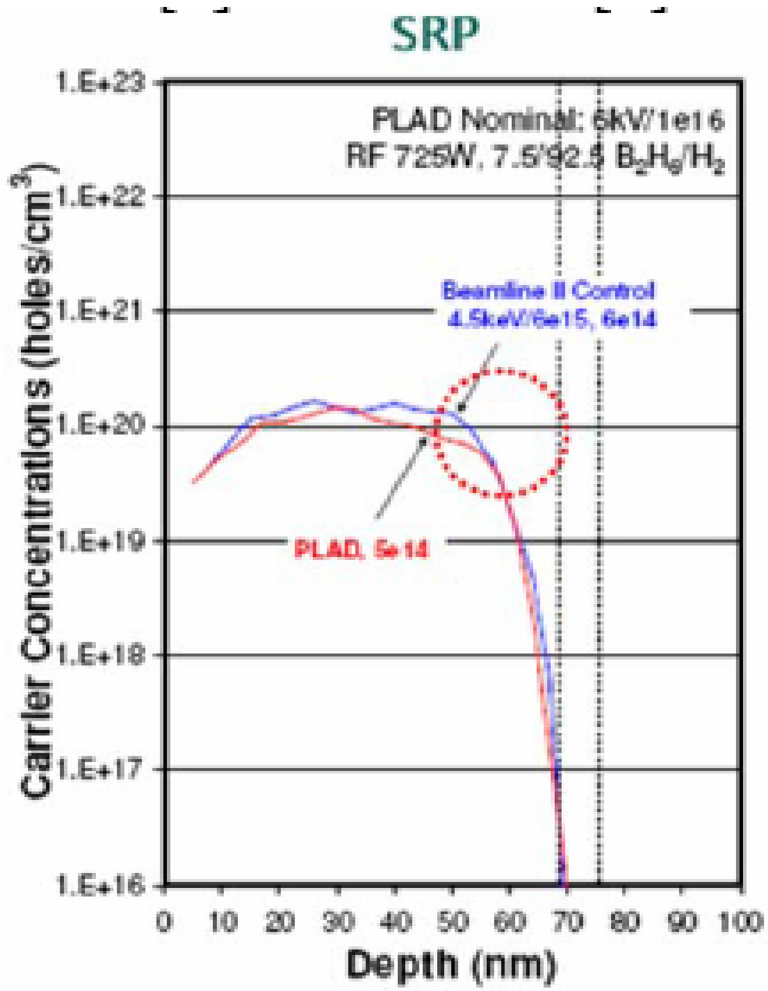


Fig. 9. Comparison of poly doping implants using $B_{18}H_{22}$ and plasma doping. Samples were annealed 30 seconds @ 1000°C.

Comparison of PLAD & Beamline Doping
J. Borland et al, IWJT2007





Akira Mineji *et al.*, IWJT2007 (NEC, NIC, JOB) 750 eV, 1E15 B SDE

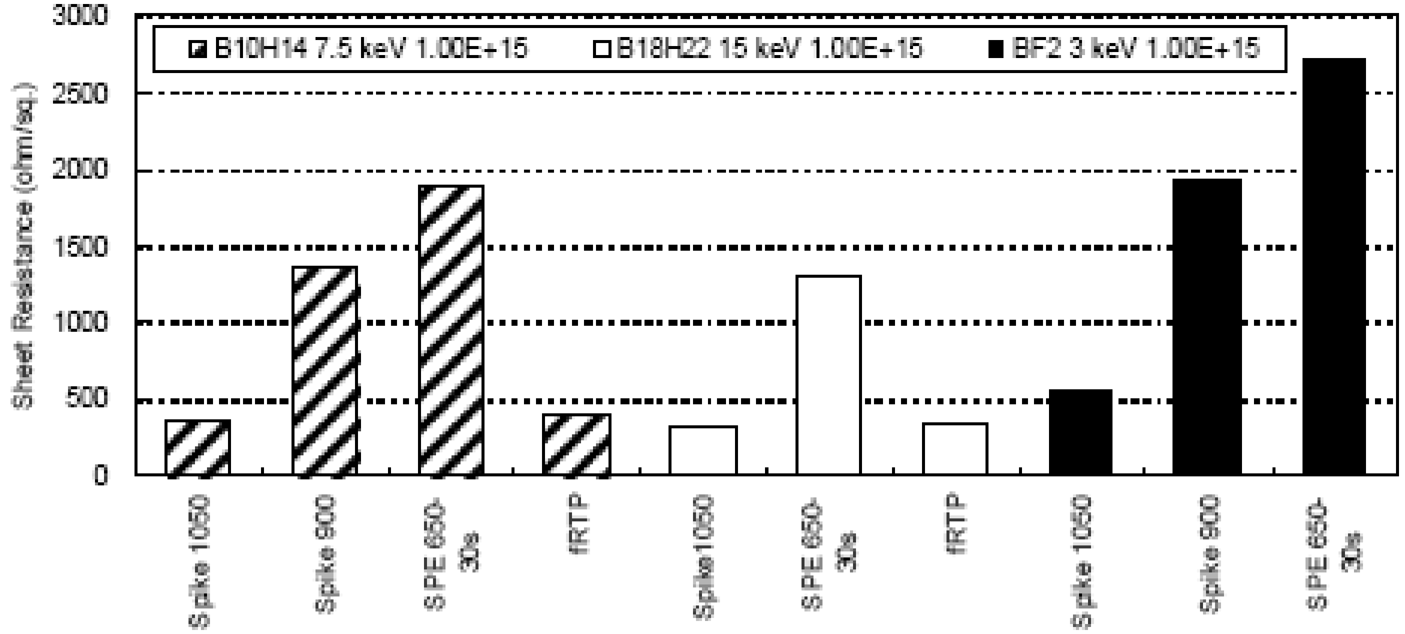


Fig. 3: Boron Rs for pSDE implants and anneals.

Borland et al., IWJT2007

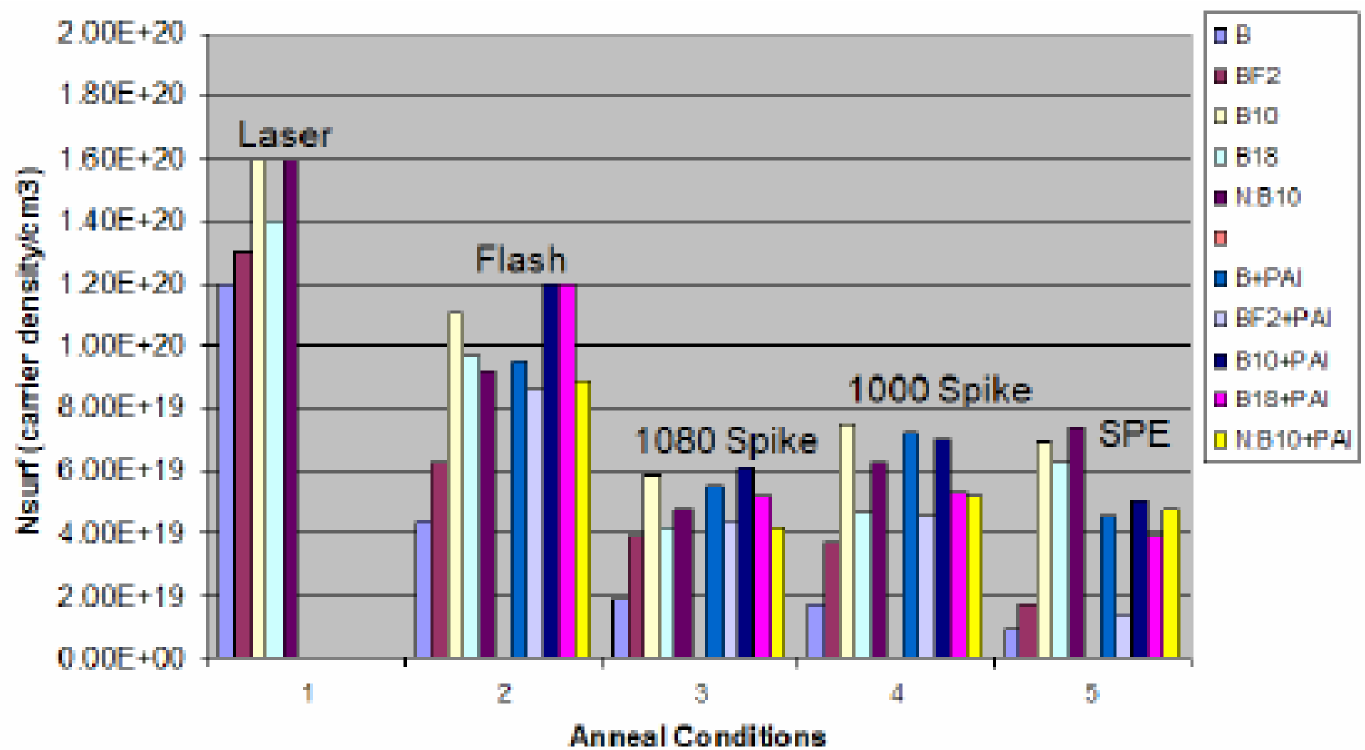


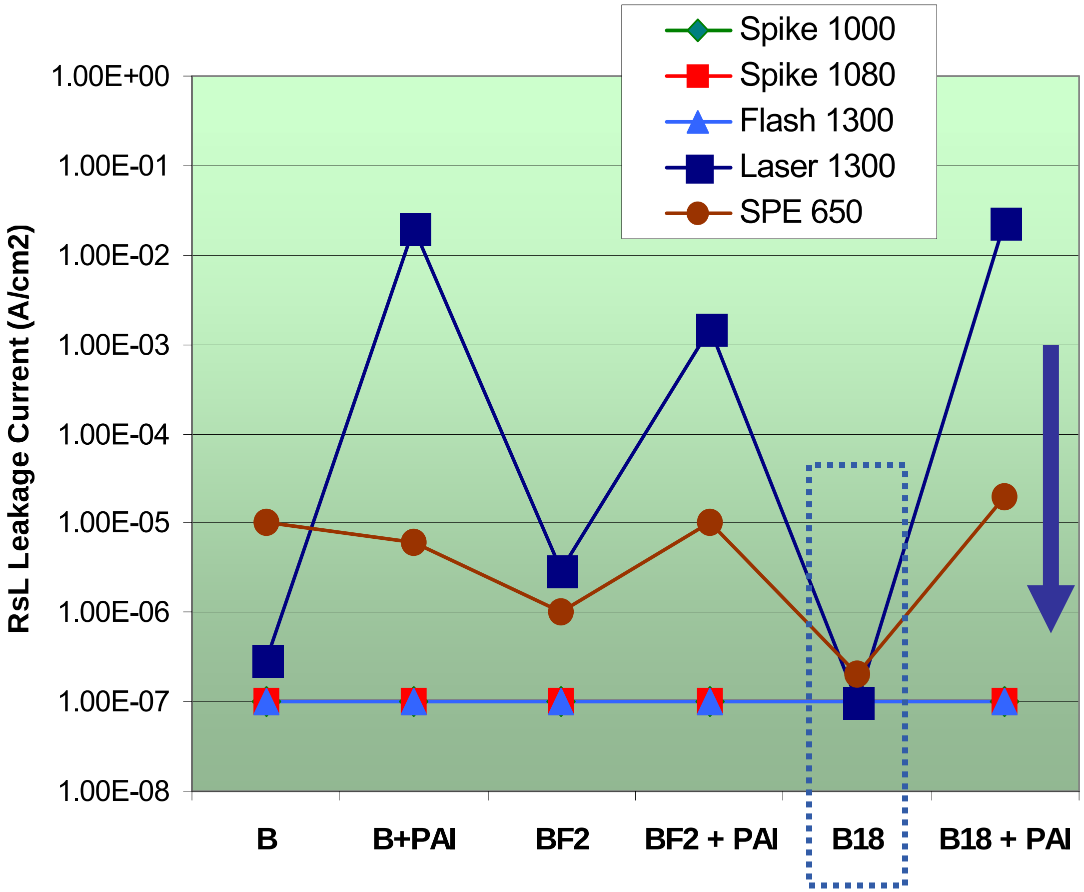
Fig. 4 : Enhanced dopant activation with $B_{18}H_{22}$.

Summary of RsL and PLi Metrology Results
John Borland *et al.*, IWJT2007 (Selete, Nanometrics)

Implant	Anneal	Rs	%	Leakage	PLi	Global [%]	Local [%]
B 500eV	1000 Spike	532	2.6	1.0E-07	1630	10.7	1.0
B 500eV	1000 Spike+FLA	535	2.8	1.0E-07	1623	7.4	1.1
B 500eV	900 Spike + FLA	1248	6.2	1.0E-07	1310	8.9	0.8
B 500eV	FLA	2013	8.5	1.0E-07	488	23.6	3.7
Ge+B	1000 Spike	552	1.8	1.0E-07	1715	13.6	0.8
Ge+B	1000 Spike+FLA	564	1.9	1.0E-07	1650	15.1	0.8
Ge+B	900 Spike + FLA	1211	4.9	1.0E-07	852	92.1	0.3
Ge+B	FLA	498	2.1	1.2E-04	279	1.2	0.2
Ge+B	SPE	898	9.8	1.9E-04	282	1.9	0.4
B18	1000 Spike	588	2.9	1.0E-07	2164	13.0	0.4
B18	1000 Spike+FLA	597	2.9	1.0E-07	2108	16.0	0.4
B18	900 Spike + FLA	1098	2.3	1.0E-07	2165	9.6	0.4
B18	FLA	751	4.2	1.0E-07	1029	38.3	4.7
B18	SPE	1245	1.8	1.0E-07	657	12.3	0.2

(SPE at 650C)

Junction Leakage Current

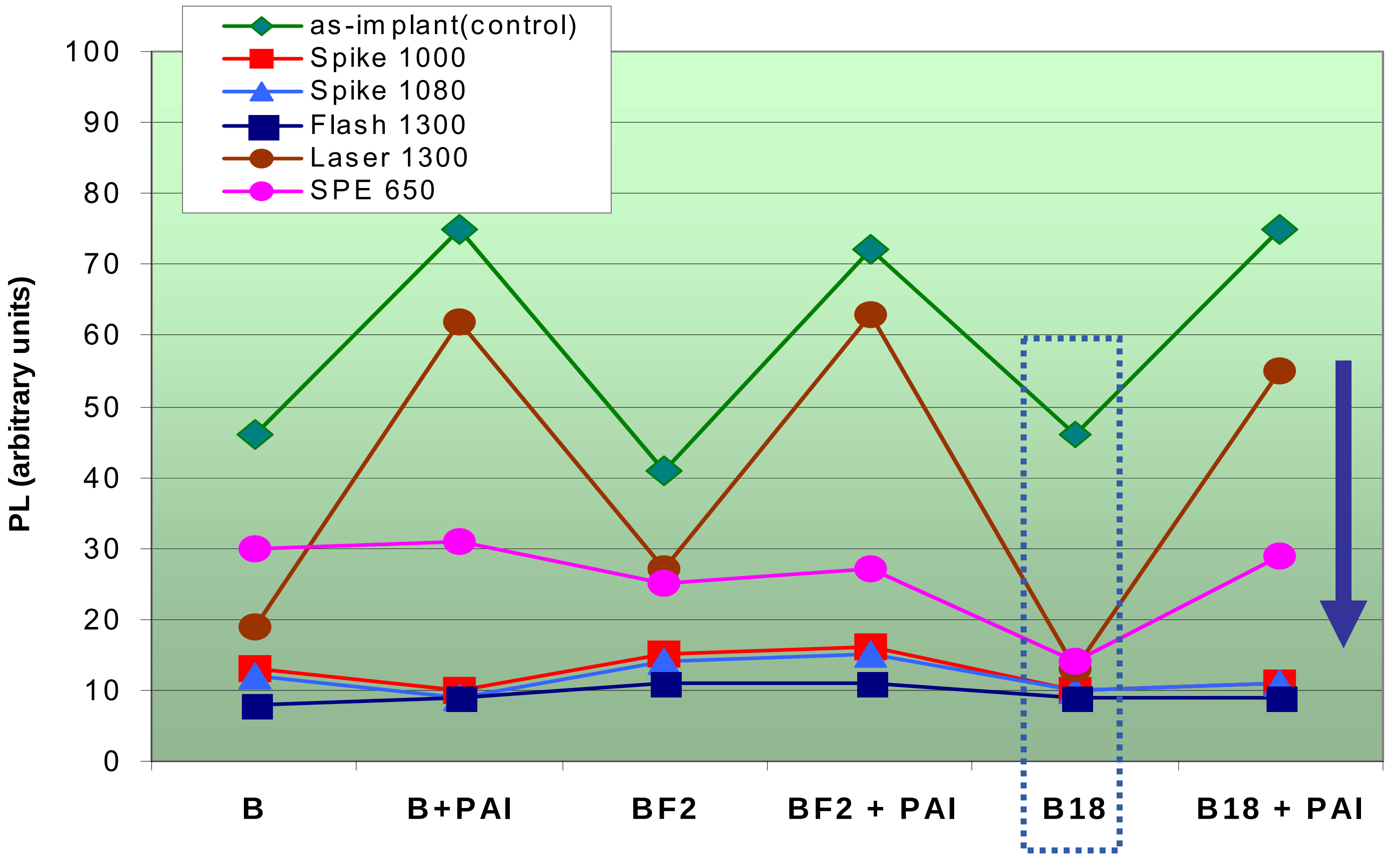


- Non-PAI B_{18} has > 2 orders of magnitude lower junction leakage current using diffusion-less laser and SPE anneals
- This is consistent with low damage junction in PL results

After John Borland *et al.*, IWJT2006, May 15—16, 2006, Shanghai, China, pp. 4—9.

Silicon Crystal Lattice Damage

(JOB & NEC, IWJT2006 & SST2006)

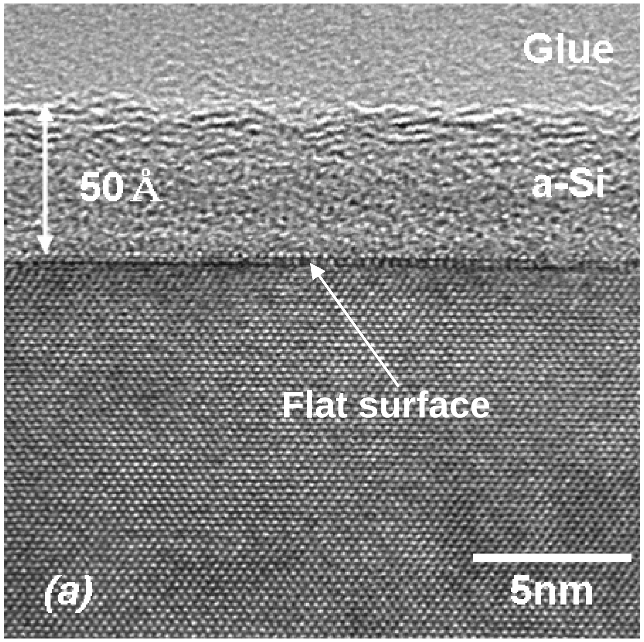


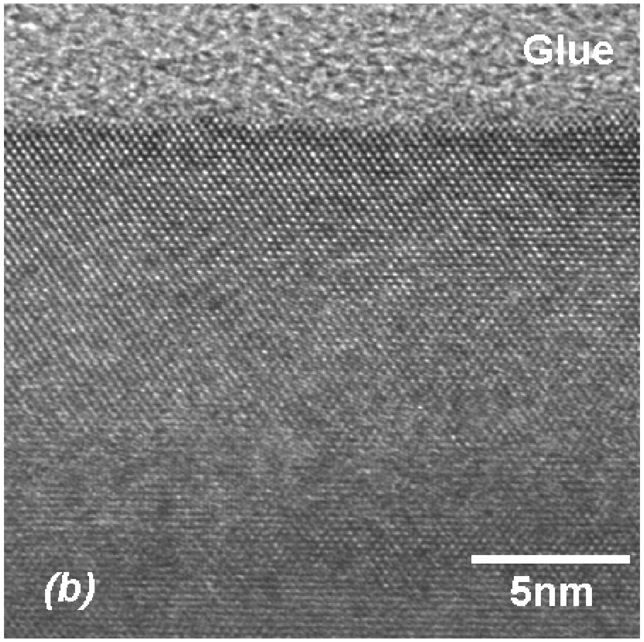
B18 has lowest Junction damage with various annealing techniques

X-TEM of Self Amorphizing with $B_{18}H_{22}$
(GIST IWJT2006)

as-implanted 250eV 1E15 B equiv.

after excimer laser anneal

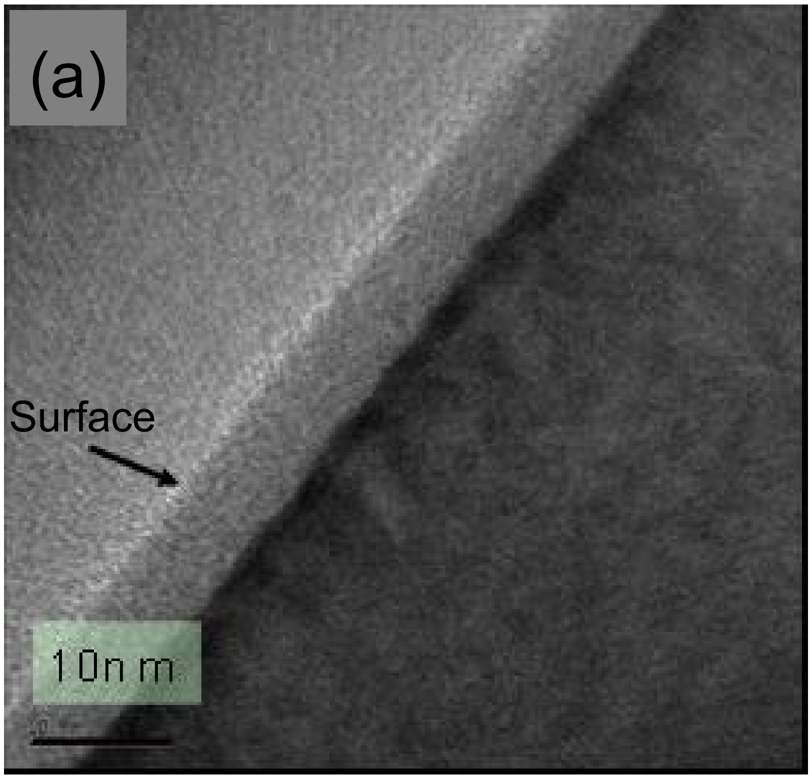




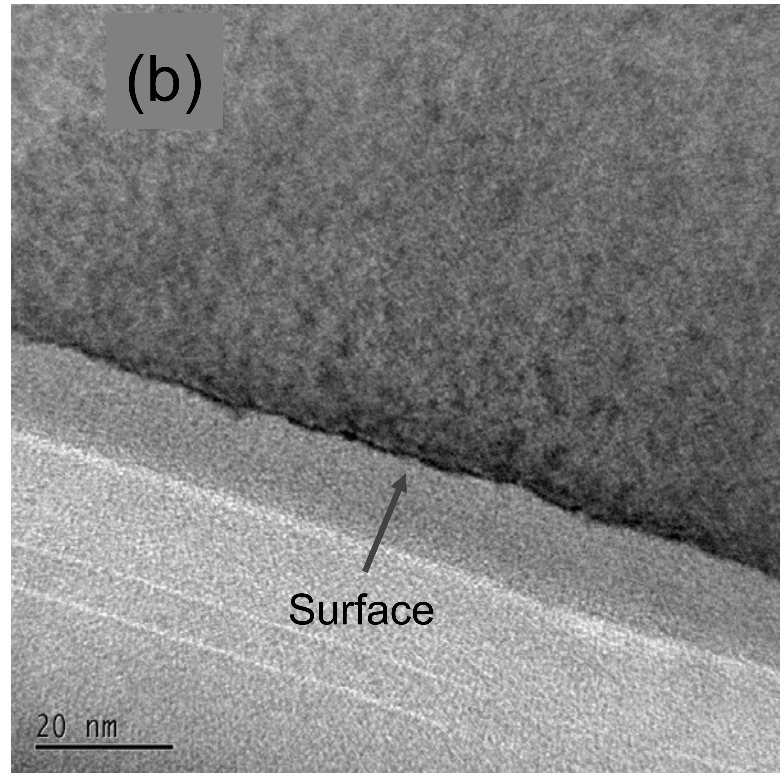
(a) Uniform Si interface at amorphous layer;

(b) Post-anneal Si re-crystallization without defects

Amorphous Layers Created by 1E15 implants of $B_{18}H_x^+$ and $C_{16}H_x^+$ Ions



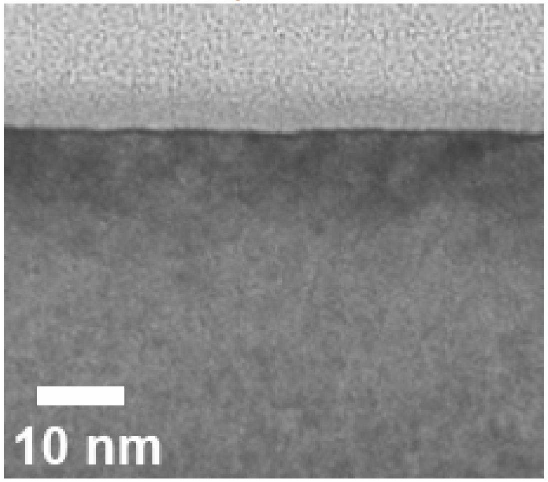
(a): X-TEM of a 1e15, 500eV per boron $B_{18}H_x$ implant yielding a 6.2nm amorphous layer



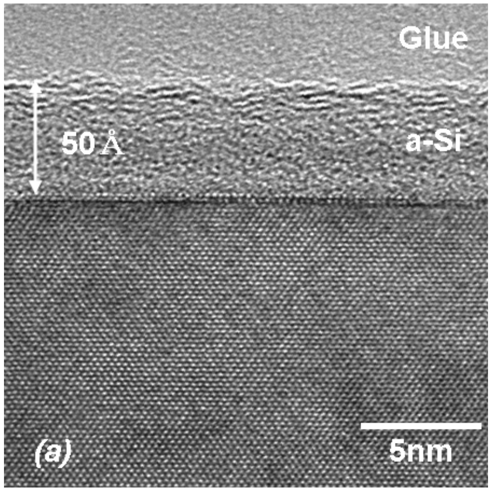
(b): X-TEM of a 1e15, 3keV per carbon $C_{16}H_x^+$ implant yielding a 14nm amorphous layer

X-TEM of as-implanted
(Fujitsu IWJT2006)

$B_{10}H_x$

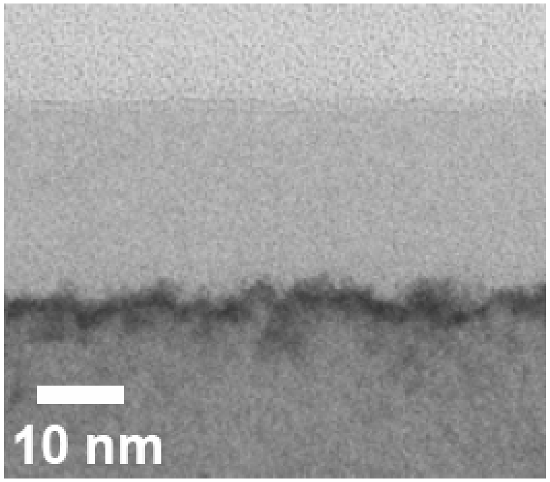


$B_{18}H_x$



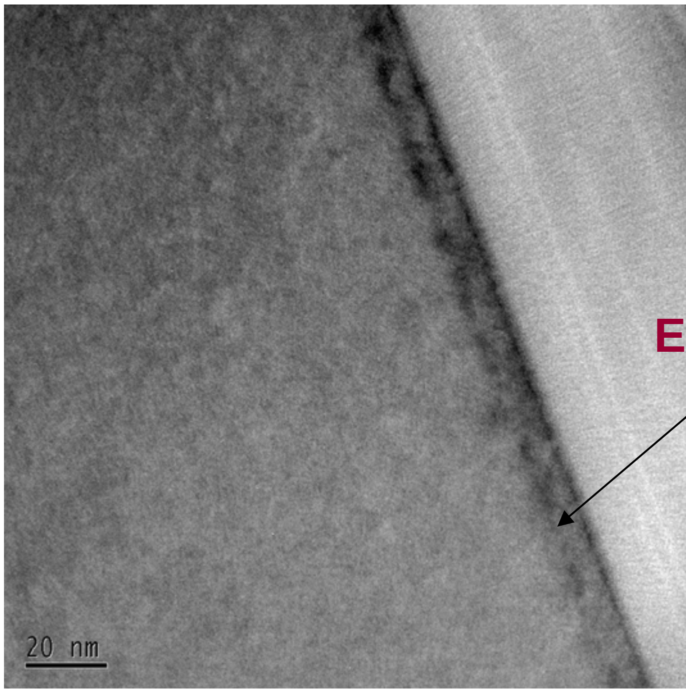
(GIST, IWJT2006)

B w/ Ge-PAI

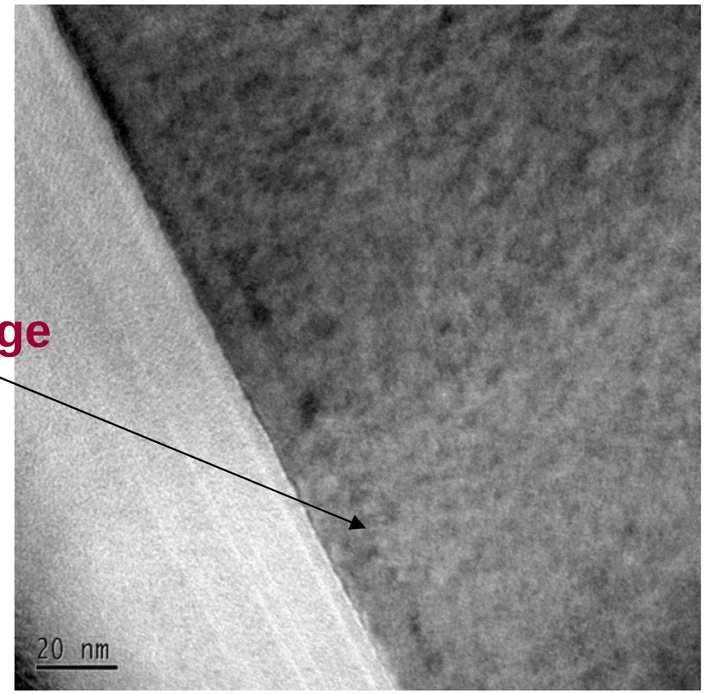


Amorphous-silicon crystal interface of B_{10} and B_{18} cases are smooth while Ge-PAI indicate rough interface and small defects are observed.

BF_2 EOR Damage - TEM



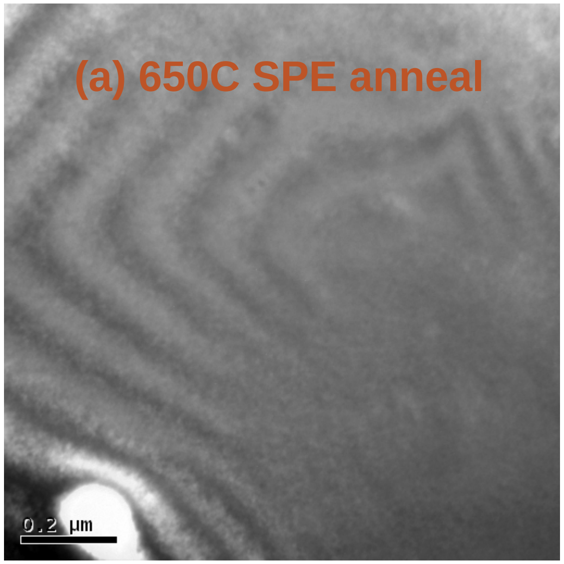
EOR damage

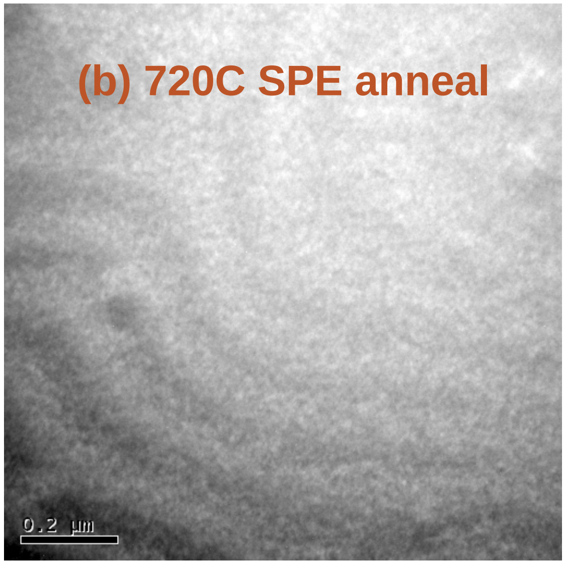


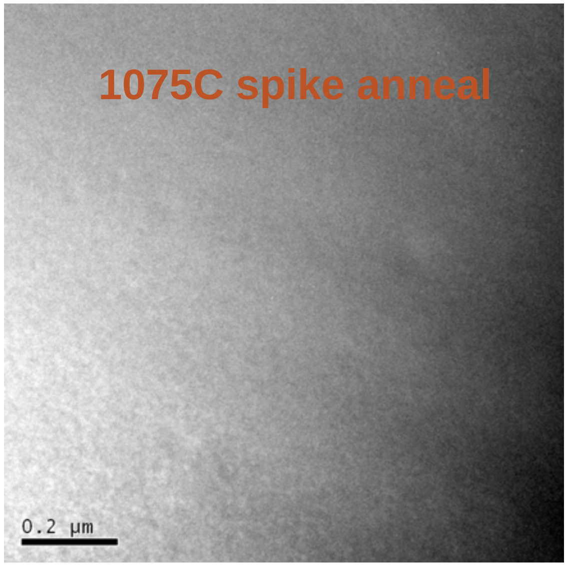
Laser anneal

SPE anneal

Plan View TEM's of $B_{18}H_{22}$-implanted samples after various anneals



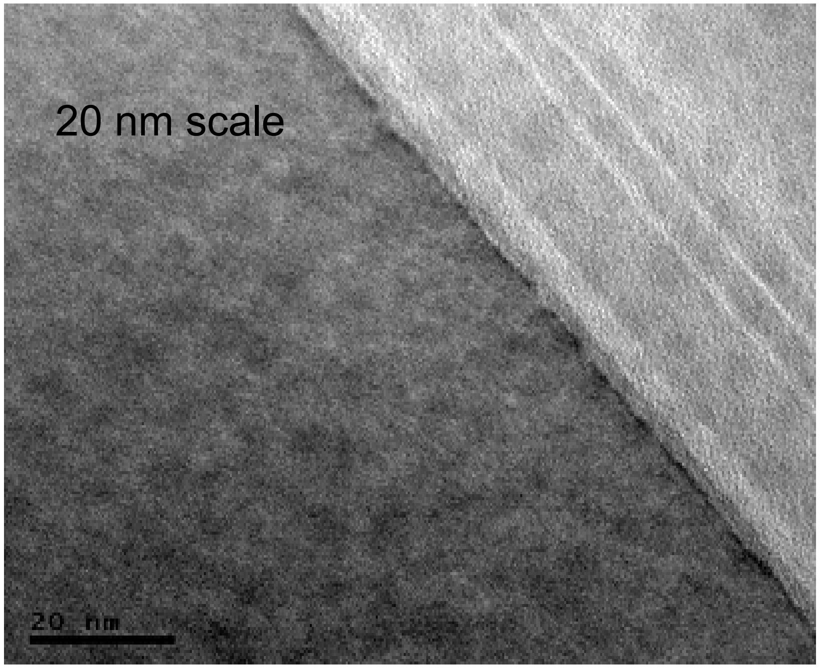


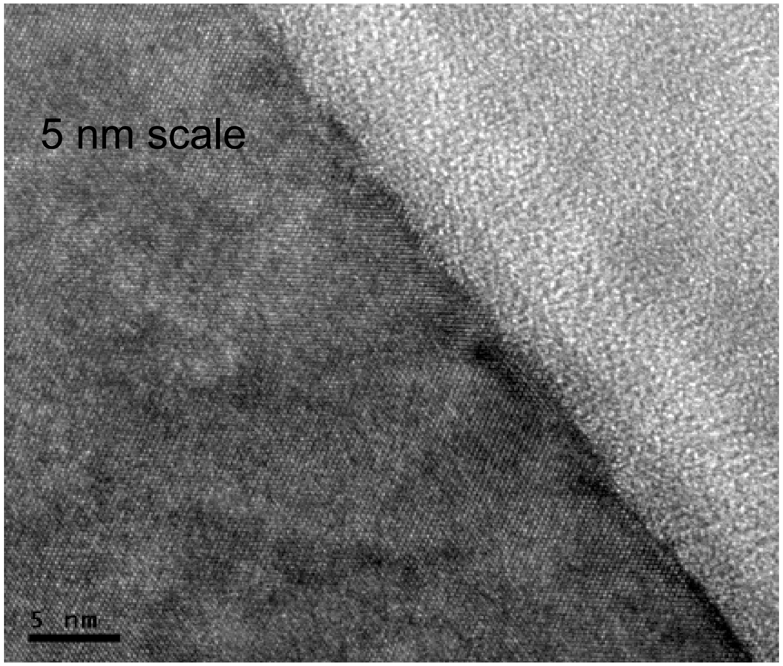


No EOR Defects Visible

Klaus Funk, Einladung zum RTP- & Ionenimplantations-Nutzergruppen-Treffen,Villach, Austria, September 25-26, 2006.

X-TEM of 950C, 5s Annealed Samples after $B_{18}H_x^+$ and $C_{16}H_x^+$ Co-Implants showing no EOR Defects

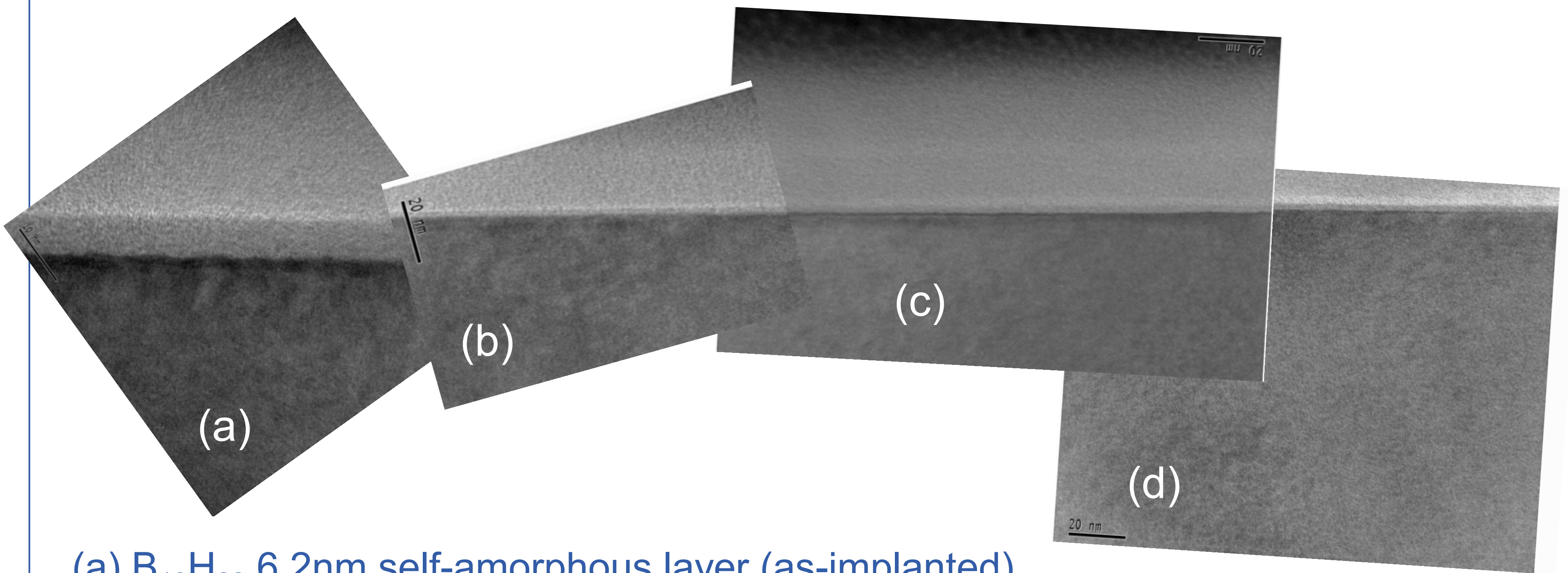




X-TEM images after 1e15 cm-2, 3keV $C_{16}H_x^+$ + 0.5keV $B_{18}H_x^+$ implants followed by a 5s, 950C spike anneal.

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

(JOB & NEC, IWJT2006 & SST2006)



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

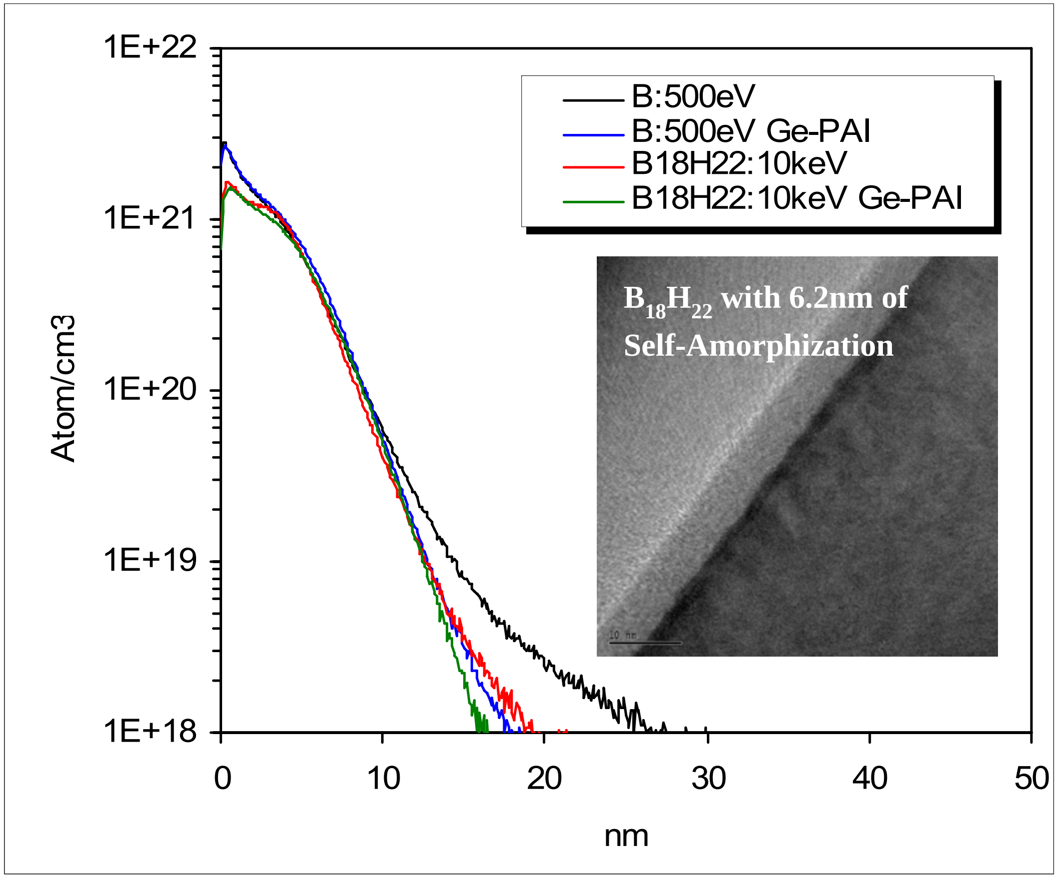
(b) SPE with no EOR damage

(c) Laser with no EOR damage

(d) Flash with no EOR damage

SIMS Boron Depth profile

Boron 500eV 1E15/cm^2 equivalent (PAI: Ge 5KeV 5E14/cm^2)



- Xj @1E18
  - B 25.2nm
  - B_{18} 19.1nm
  - B + PAI 17.8nm
  - B_{18} + PAI 16.1nm
- B_{18} Self-Amorphization helps to make Shallower Junction and Eliminate the need of Ge-PAI

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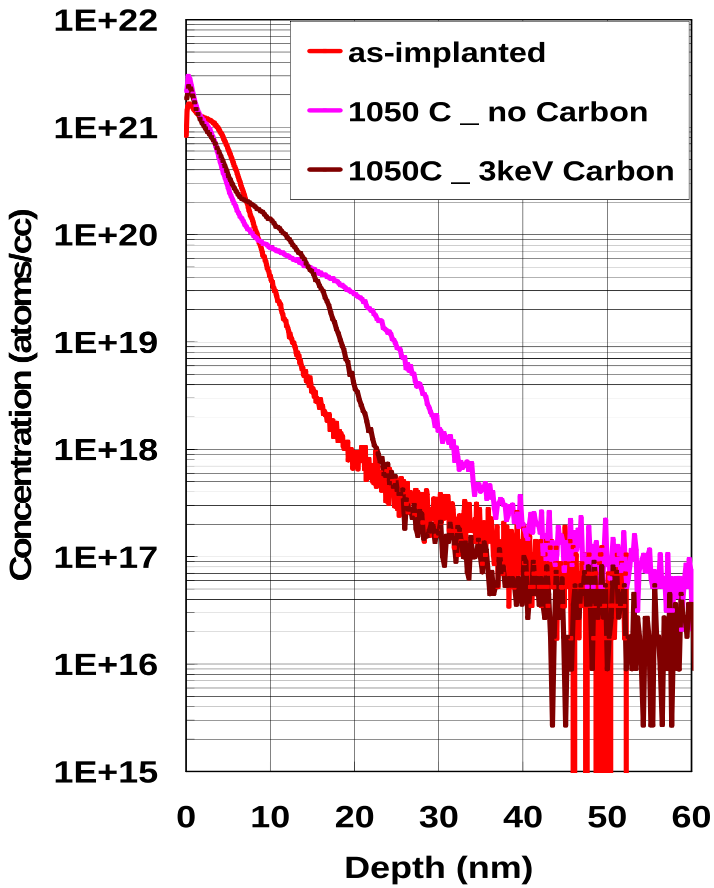
Cabron Cluster Implantation for B Diffusion Control
(SemEquip IIT2006)

- Reduction of boron diffusion during anneal
- Improvement of junction abruptness
- Increase in boron solubility in the active junction volume



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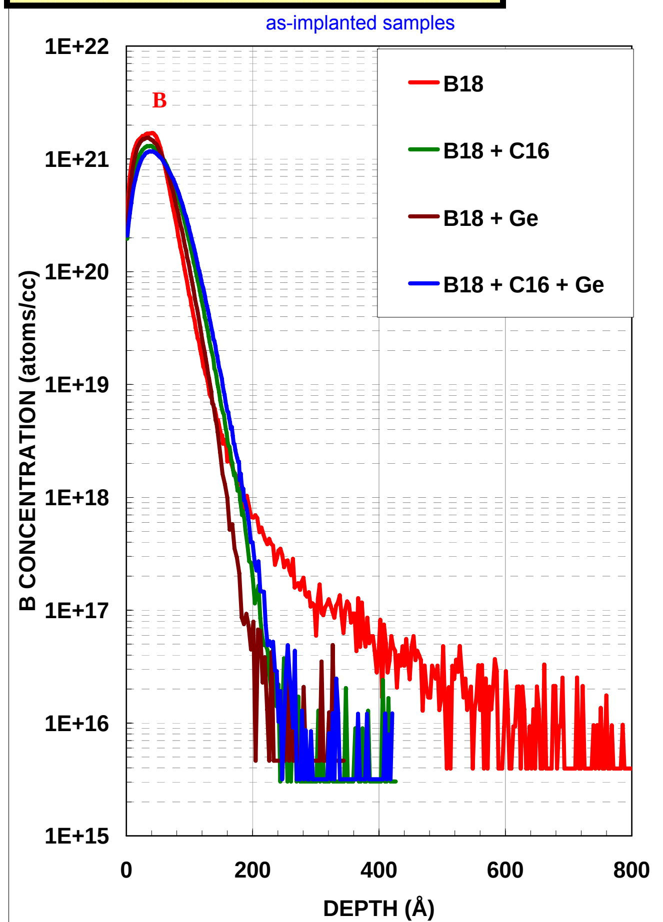
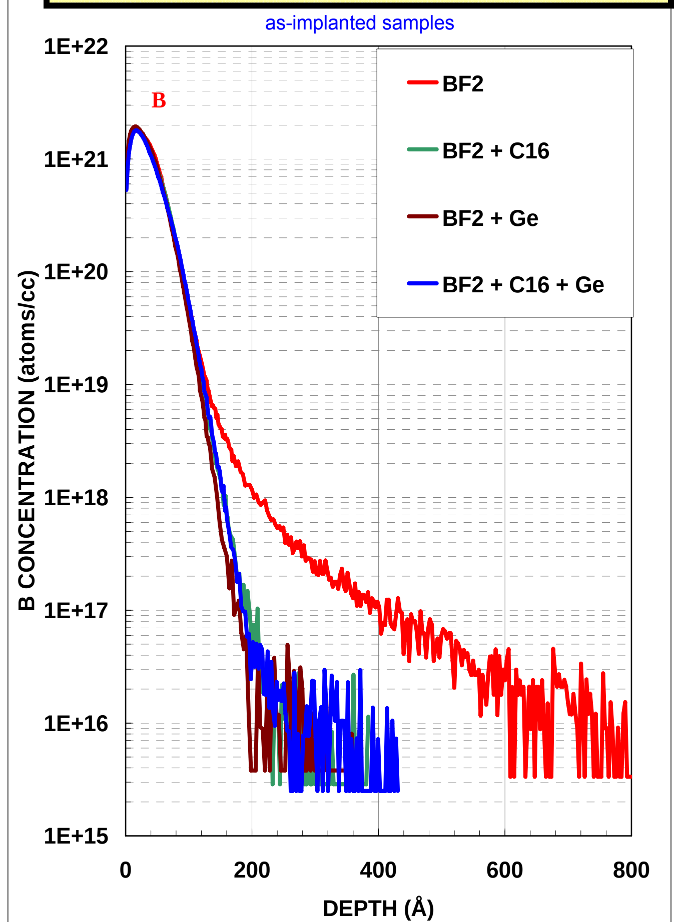
as-implanted SIMS Profiles: C_{16} vs. Ge PAI

B_{18} with co-implant

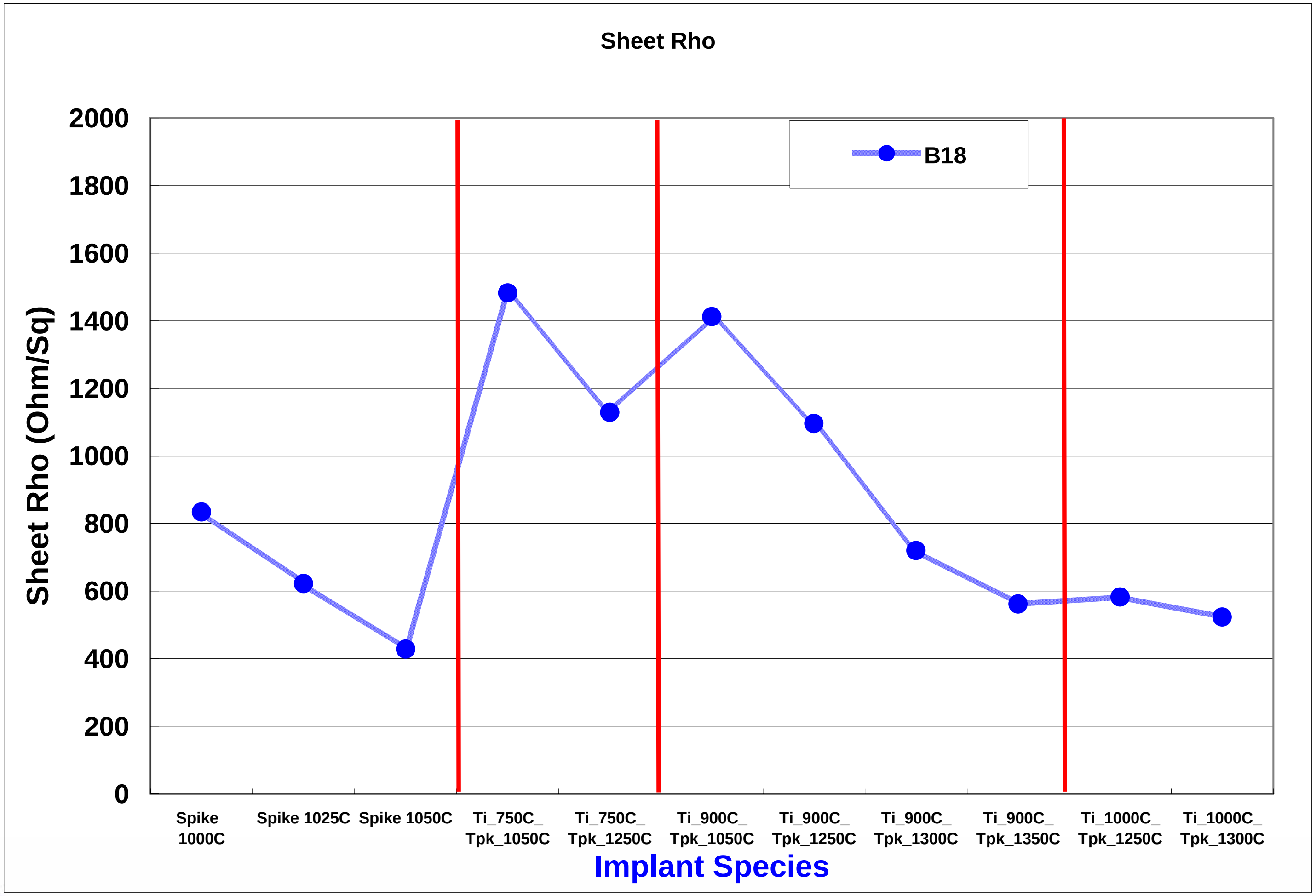


BF_2 with co-implant



Abrupt junction with C_{16} with co-implants

B_{18} – 500eV, 1e15 (FLASH ANNEAL)
SE + J. Gelpey, Mattson



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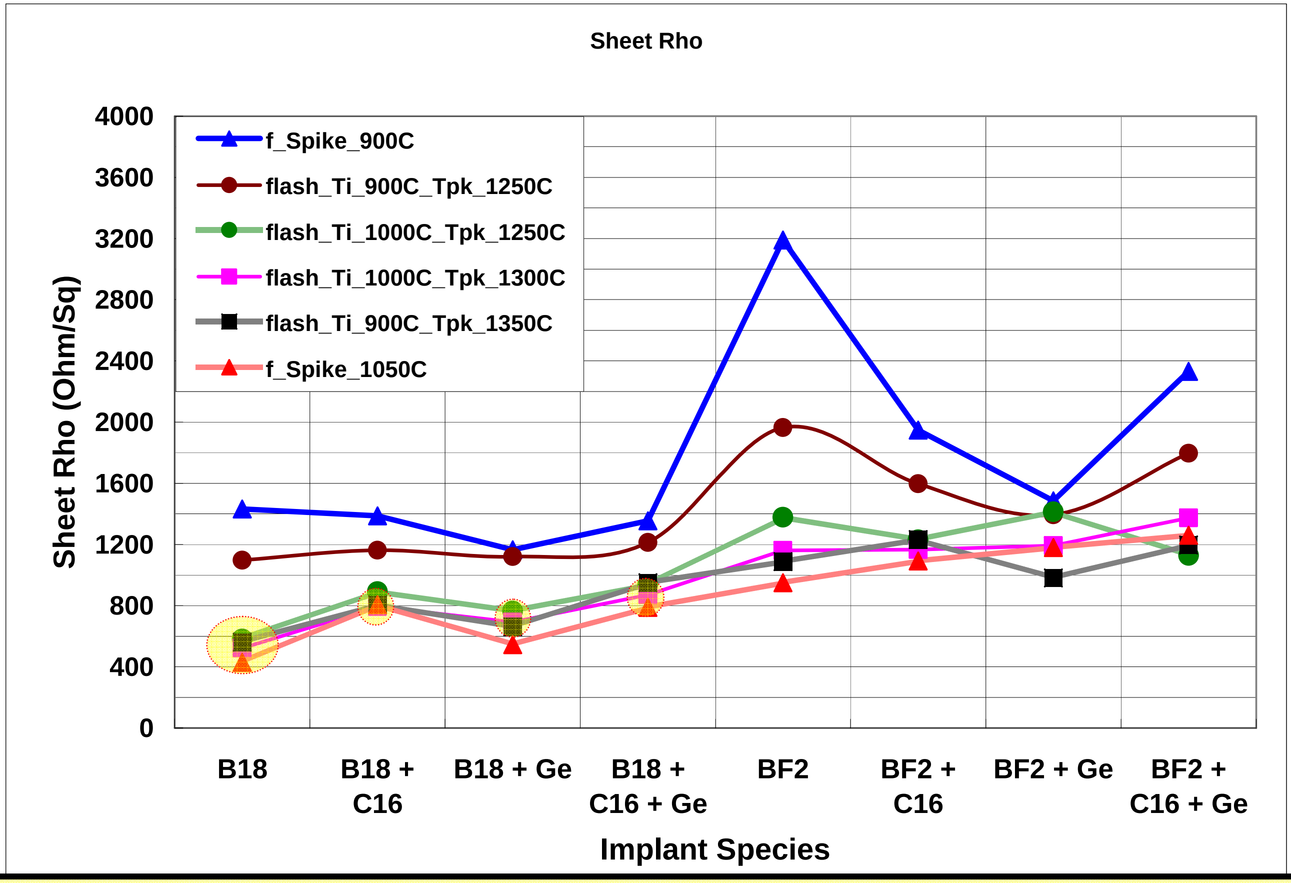
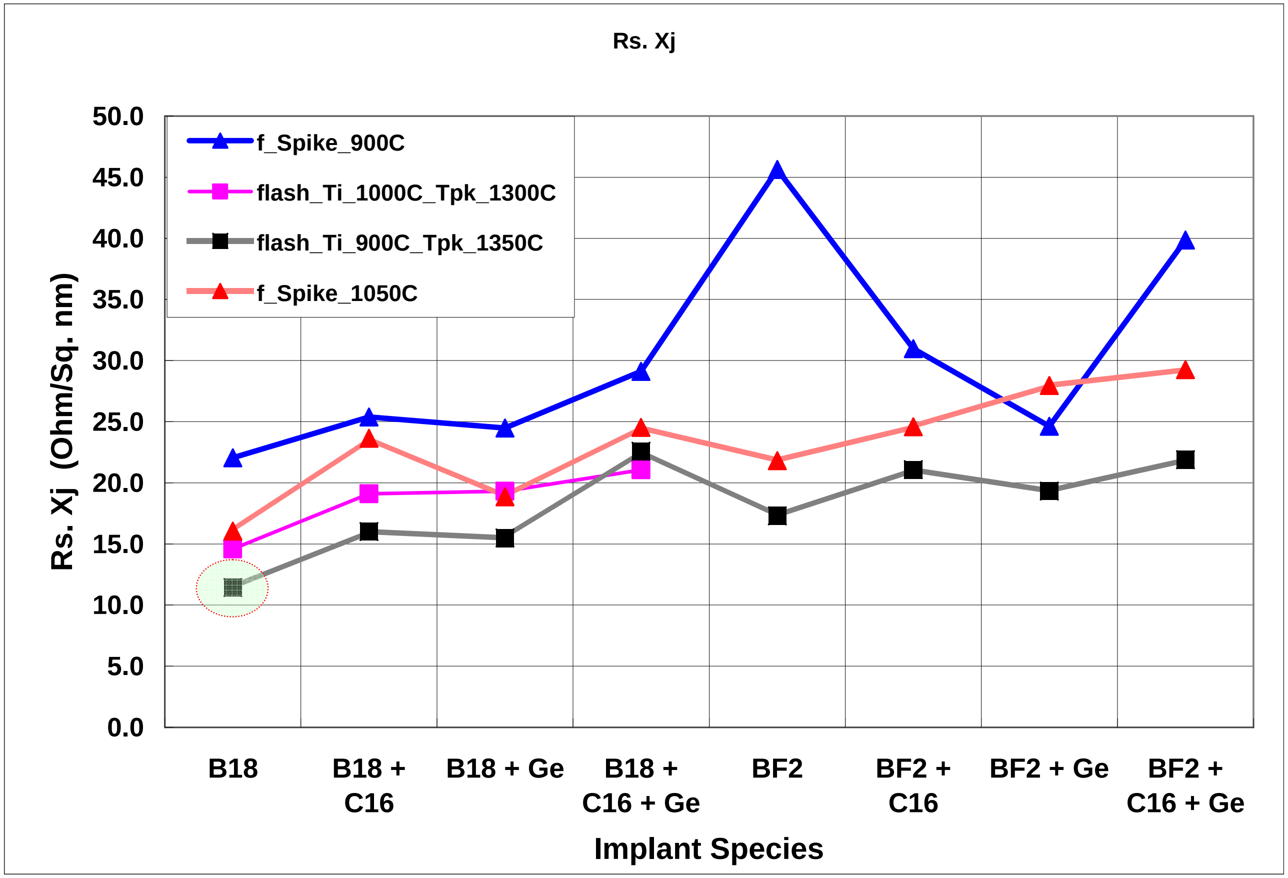
Flash anneal : Rs Results (SE + J. Gelpey, Mattson)



Lower Rs is observed for f-spike 1050C and flash-Ti_900C_Tpk_1350C.

Rs. Xj Product : measure of active carrier concentration (SE + J. Gelpey, Mattson)

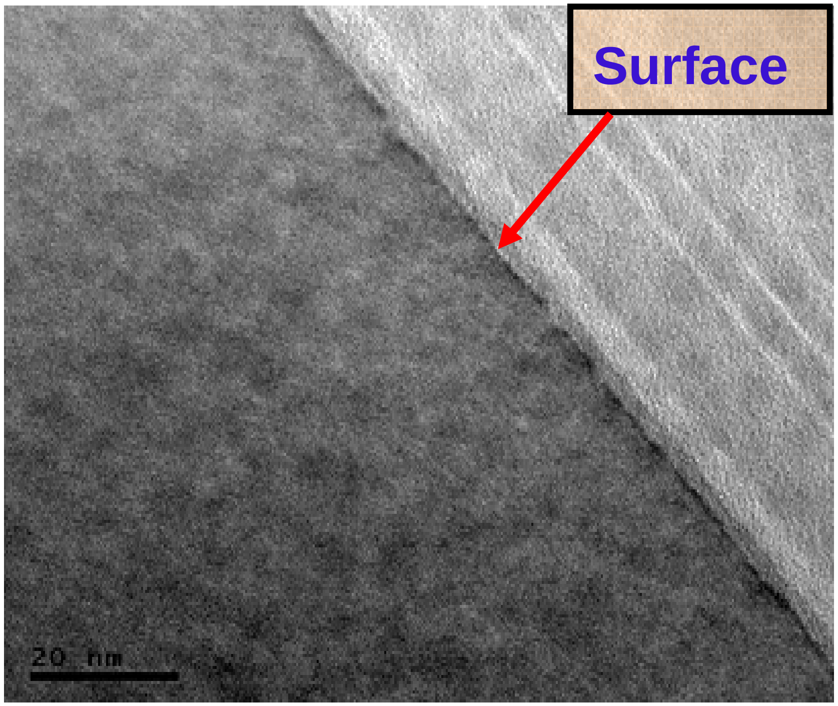


Rs. Xj product (inverse of active carrier concentration) is lowest for B_{18} implant indicating a higher active carrier concentration in the active junction area.

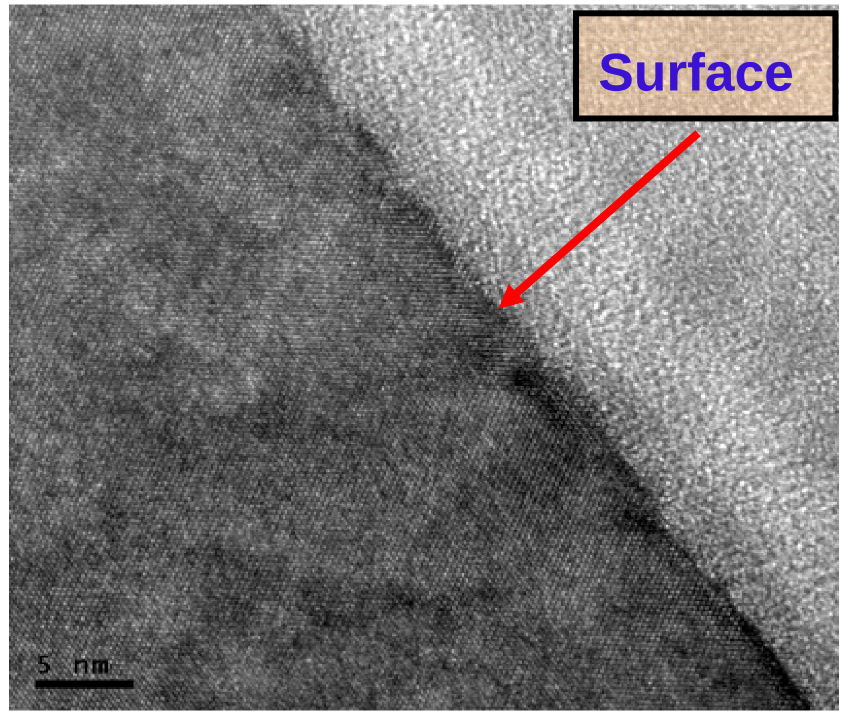
X-TEM C_{16} (3keV) + B_{18} (0.5keV) @1e15 atoms/cm^2

950^{o}C , 5 sec – annealed NO EOR DAMAGE

20nm scale

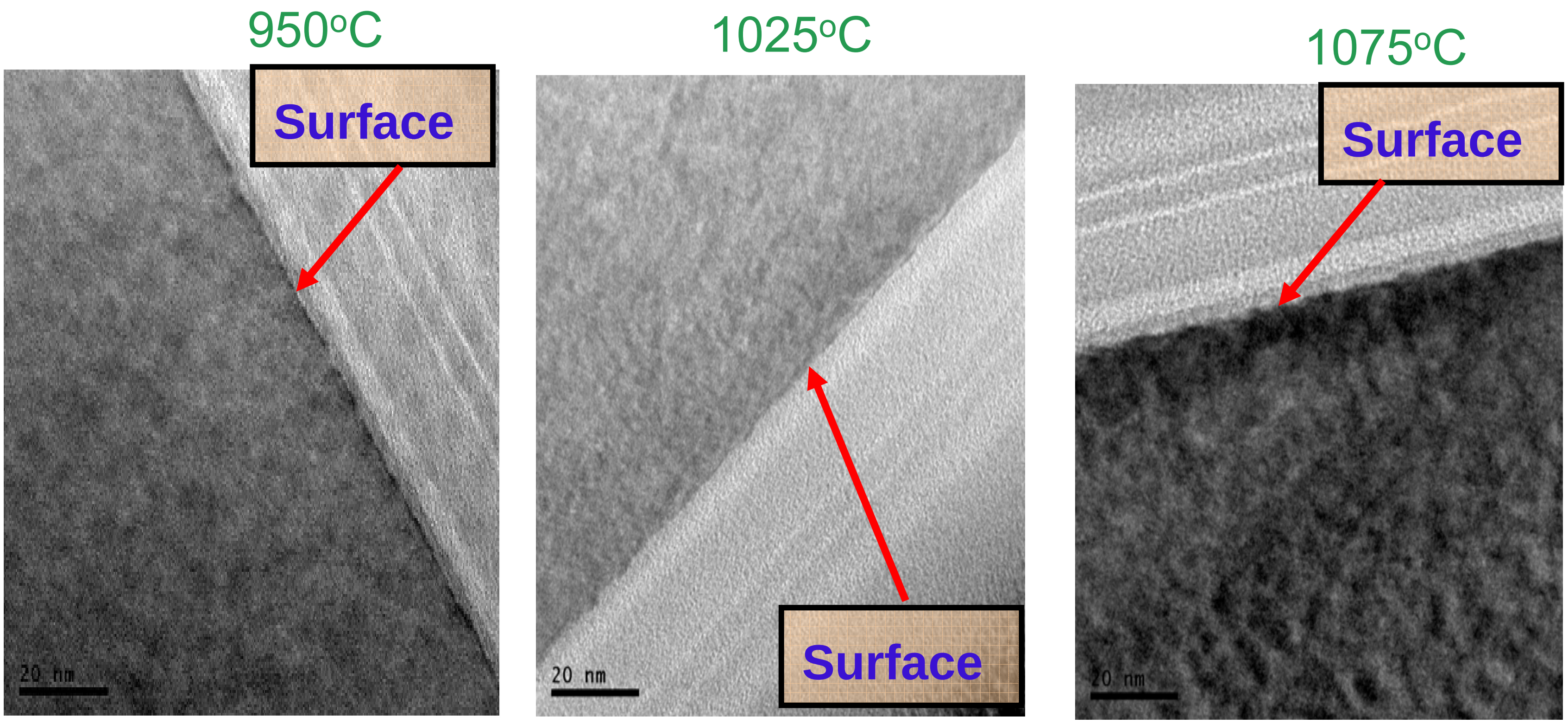


5nm scale



- **No EOR damage is seen with TEM for 950^{o}C 5 sec anneal**

X-TEM C_{16} (3keV) + B_{18} (0.5keV) @1e15 atoms/cm^2
Various Anneal Temperatures : NO EOR DAMAGE



- No EOR damage is seen with TEM

Carbon Implant + SPER for e-Si:C in NFETs
Yaocheng Liu *et al.*, IBM (VLSI 2007)

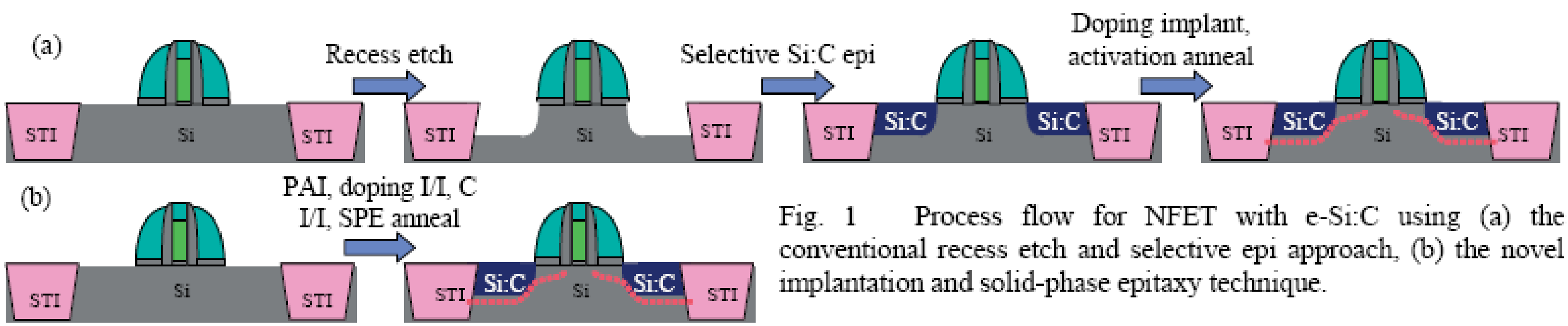
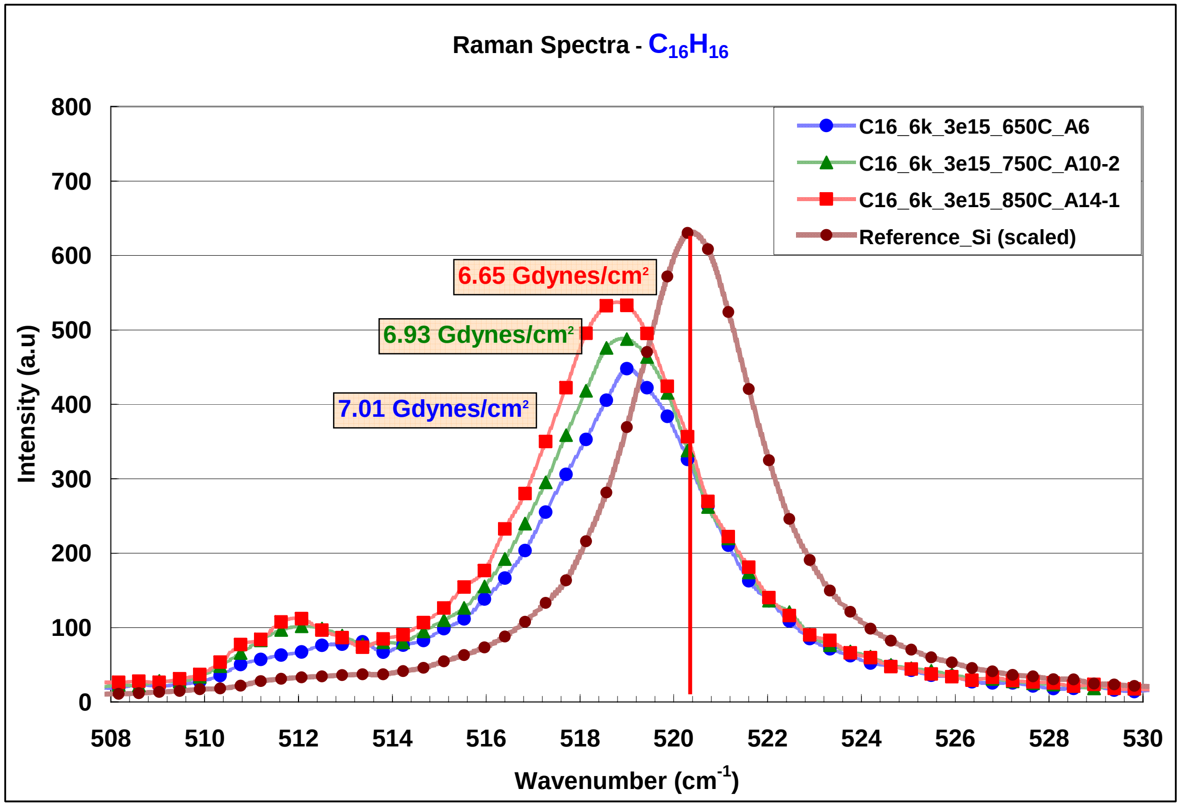


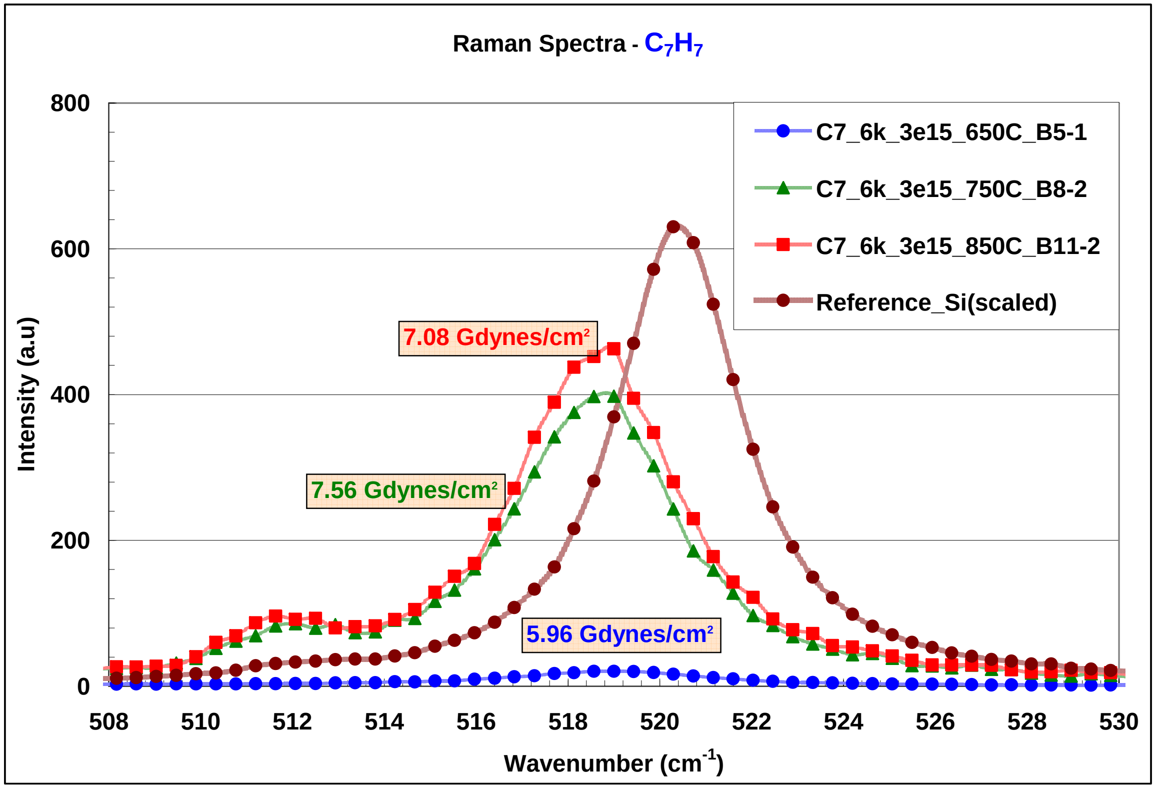
Fig. 1 Process flow for NFET with e-Si:C using (a) the conventional recess etch and selective epi approach, (b) the novel implantation and solid-phase epitaxy technique.

ClusterCarbon for Stress: Raman – $C_{16}H_{16}$ @3e15



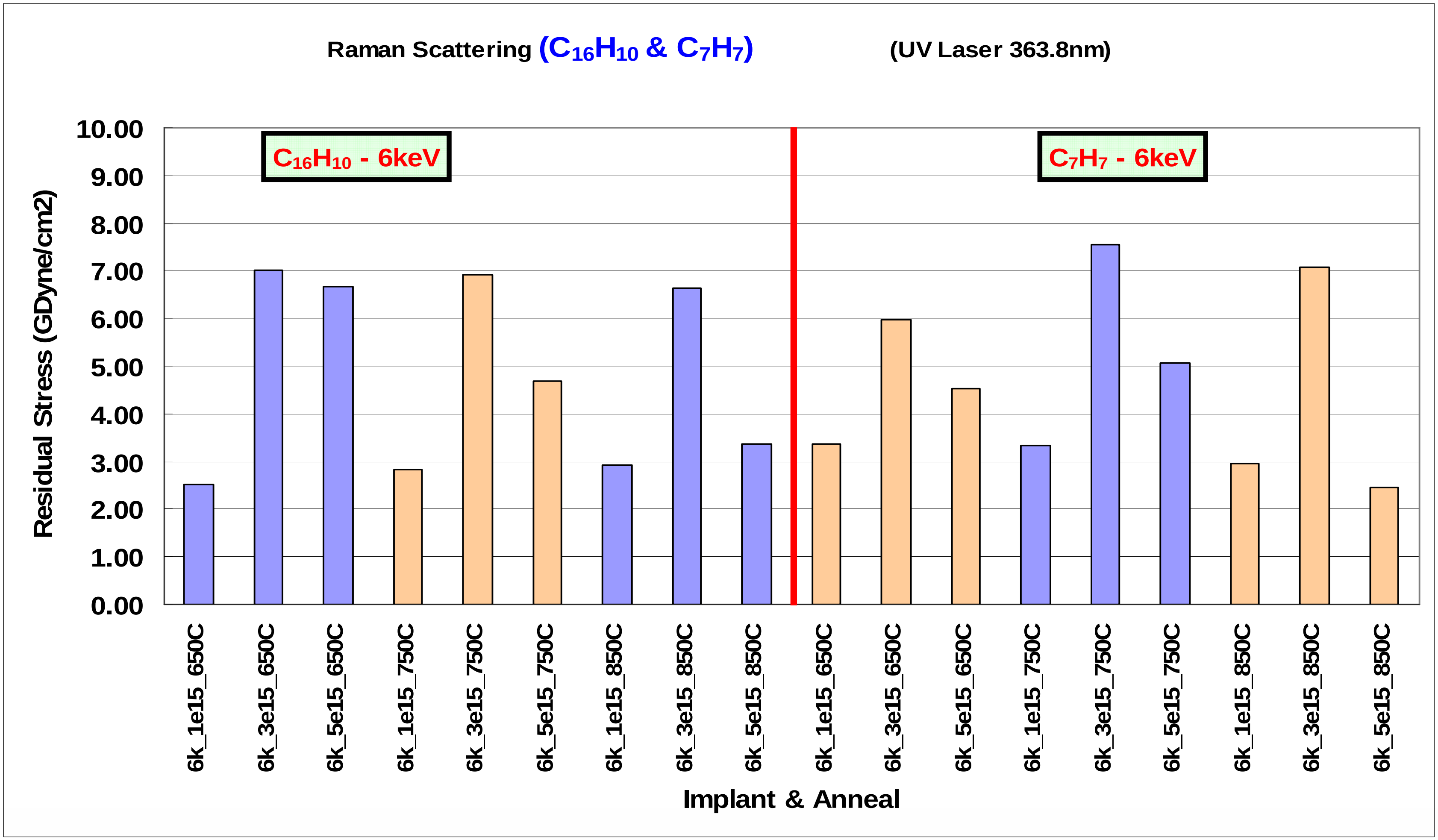
C_{16}@3e15 dose, the avg. stress values for the temp. range more or less remain the same.

ClusterCarbon for Stress: Raman – C_7H_7 @3e15



@3e15 dose, the avg. stress values for the temp. range lie within ± 15% of each other

ClusterCarbon: Stress Data



Summary

- Due to collective effects, amorphization during cluster implantation yields powerful process advantages using low thermal budget anneals:
    - More complete crystal regrowth lowers defect density
    - Lower defect density reduces junction leakage
    - Active carrier concentration is increased
    - Channeling reduction results in shallower, more abrupt junctions without Ge PAI
- 3-5X increase in wafer throughput for high dose, low energy processes without risk of energy contamination
- Carbon clusters are effective at creating e-Si:C with increased activation of substitutional carbon during SPER, resulting in higher tensile stress than achievable with monomer carbon implants

Acknowledgements

- SemEquip: Dale Jacobson, Wade Krull, Bob Milgate, Karuppanan Sekar, Jeff Buda, Brian Haslam
- Mattson: Jeff Gelpey
- Axcelis: Mike Ameen, Mark Harris