Junction Scaling Technology for the Sub 90nm Node and beyond

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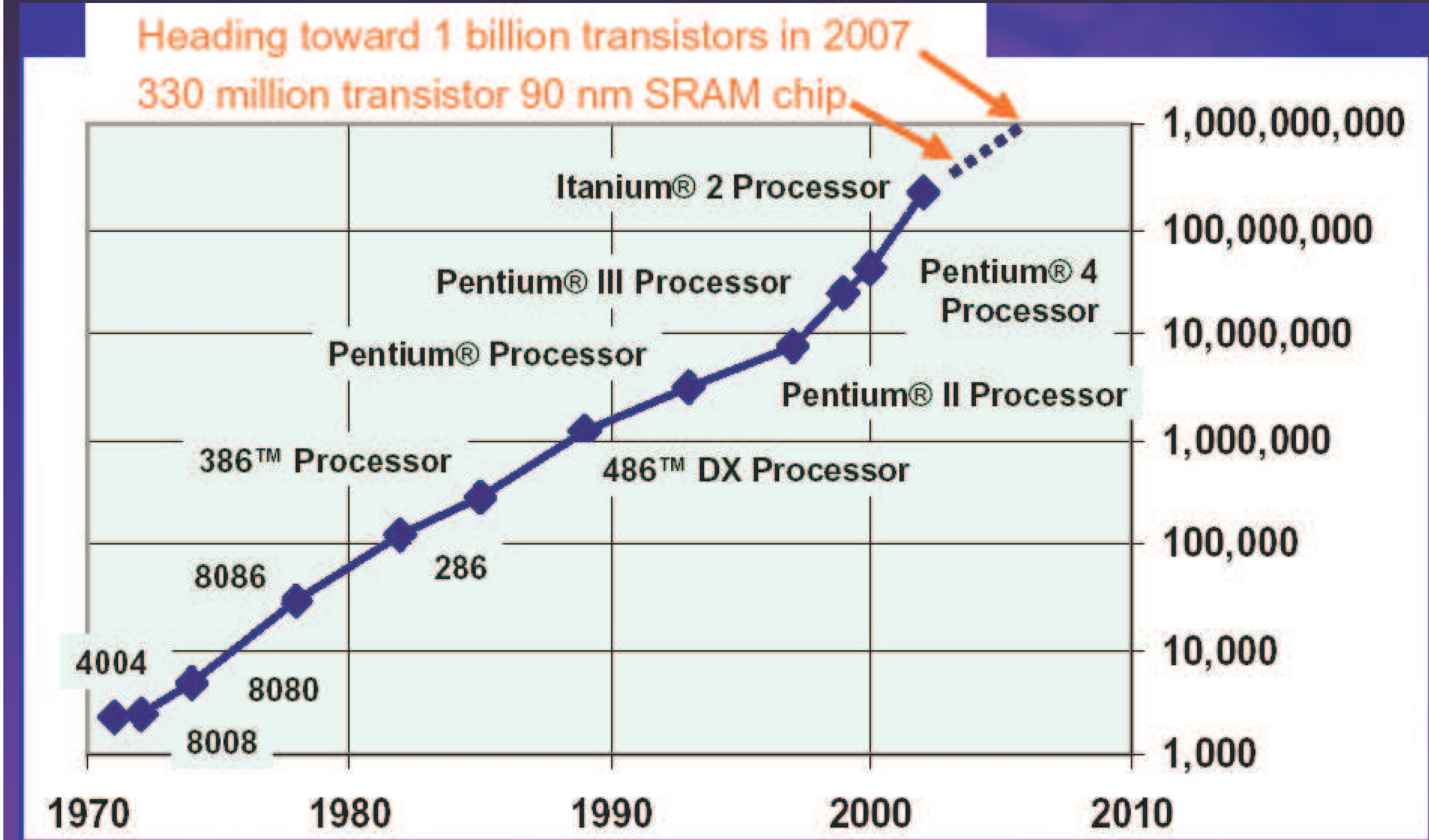
Outline

- Introduction to transistor scaling
- Junction scaling constraints
- RTA developments
- Co-doping effects
- Conclusion

Moores Law

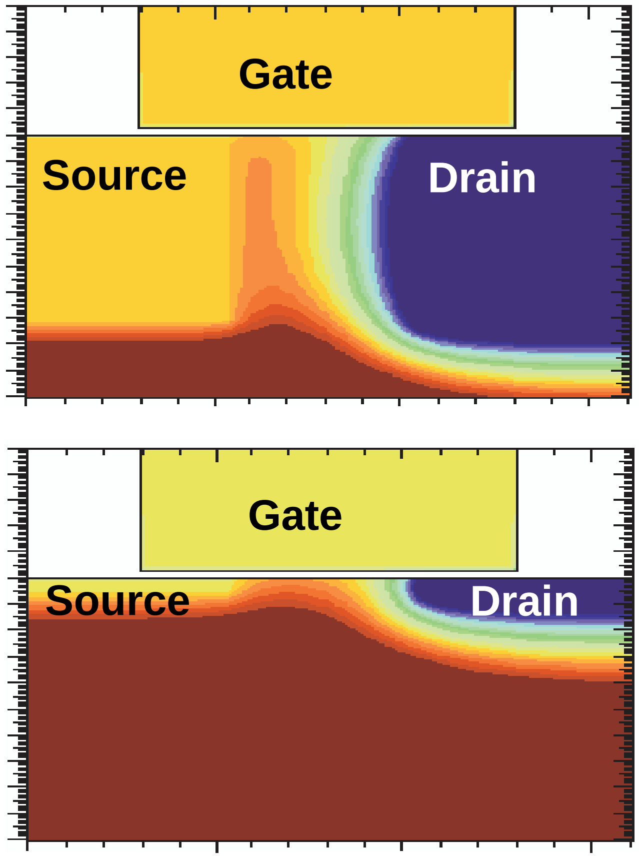


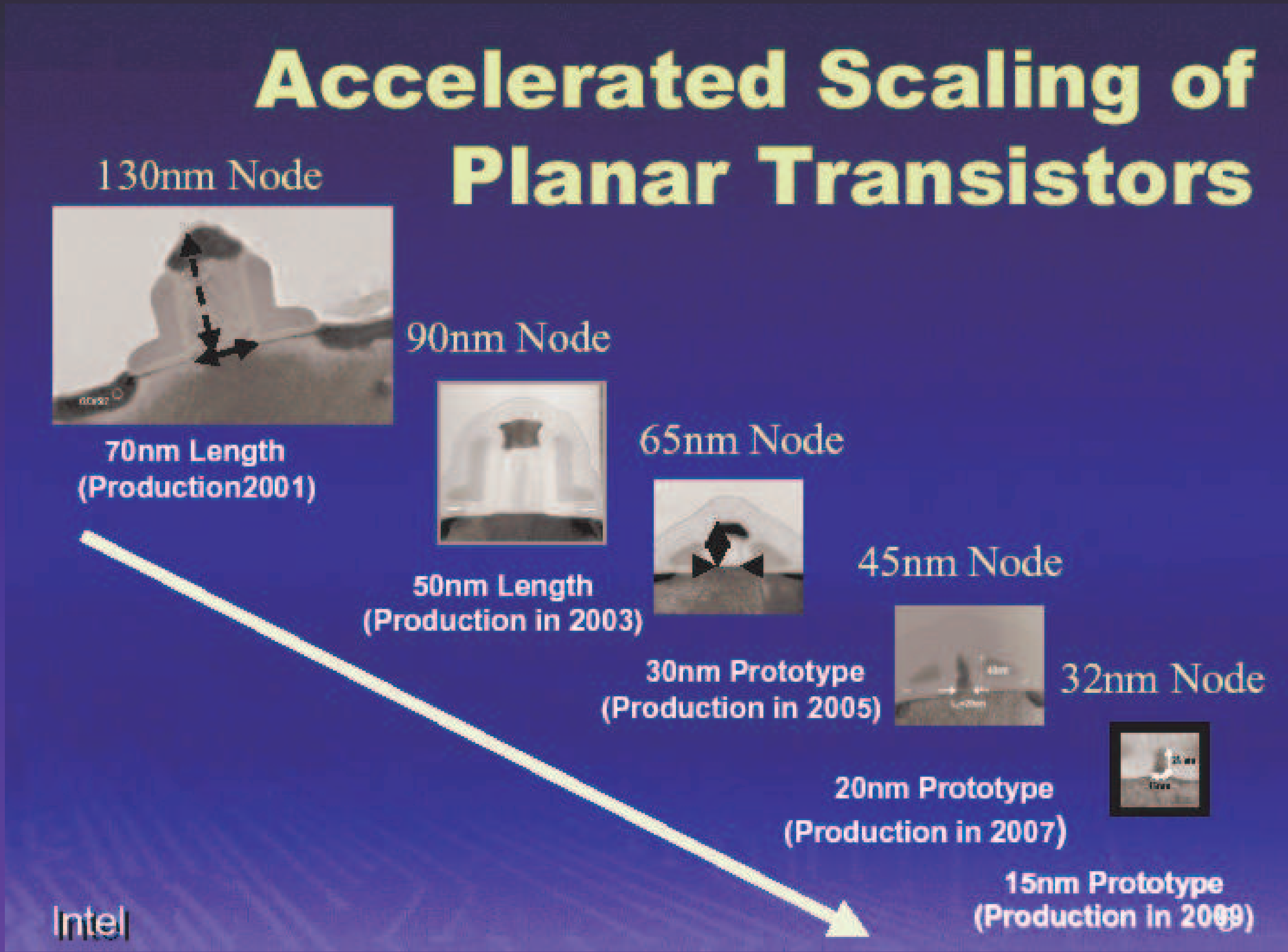
M. Bohr, Intel Developer Form 2002

Scaling MOS Transistors

- MOS scaling theory requires scaling of all geometric dimensions
- Active dopant concentrations must be increased to maintain resistance
- Limits are being pushed in this area

Voltage Potential Contours



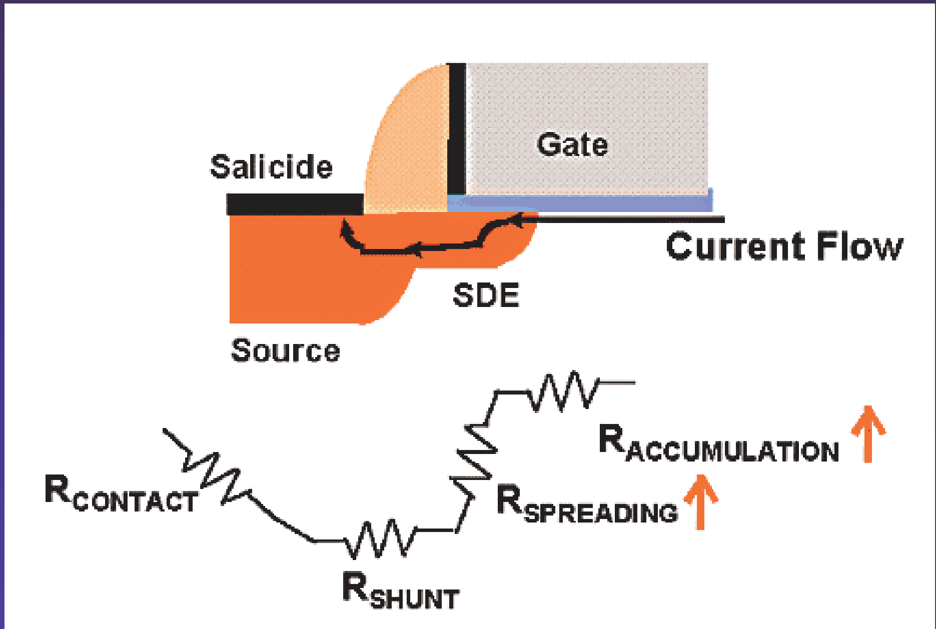


Junction depth Xj needs to scale with Lg 0.7X/node

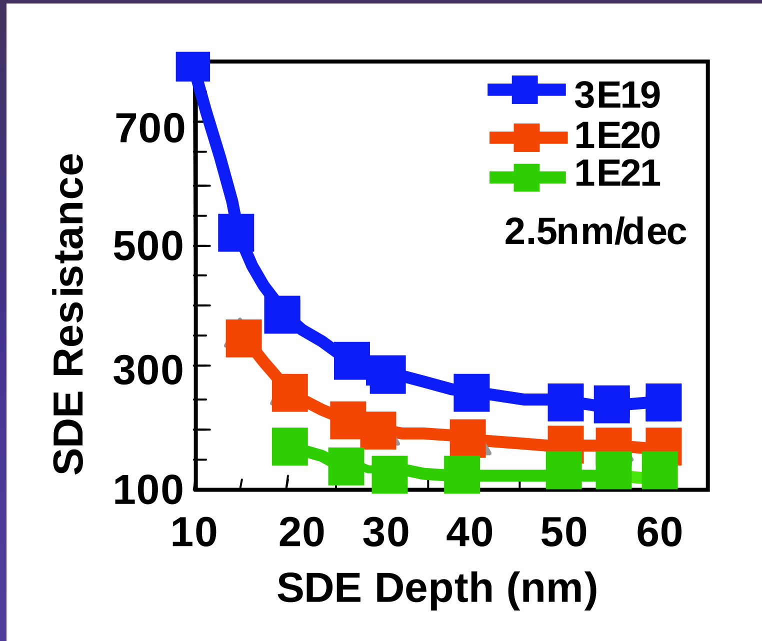
G. Marcyk, Tri gate announcement, Sept 17, 2002 www.intel.com/research/silicon

2004 WCJT meeting, Portland, OR

Why Is High Activation Important?



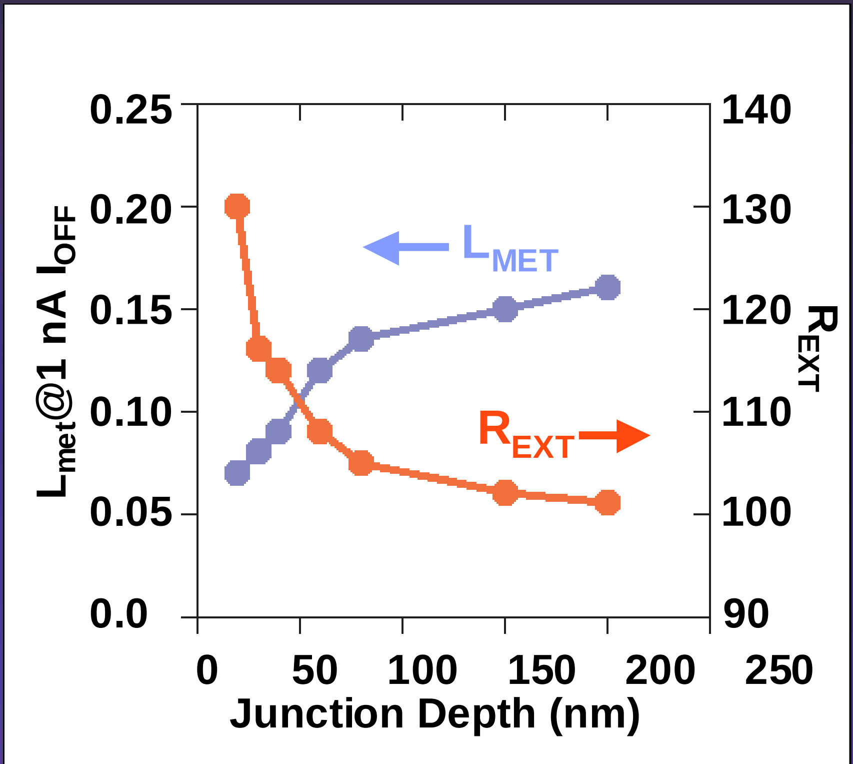
S. Thompson, VLSI Symp. 1998

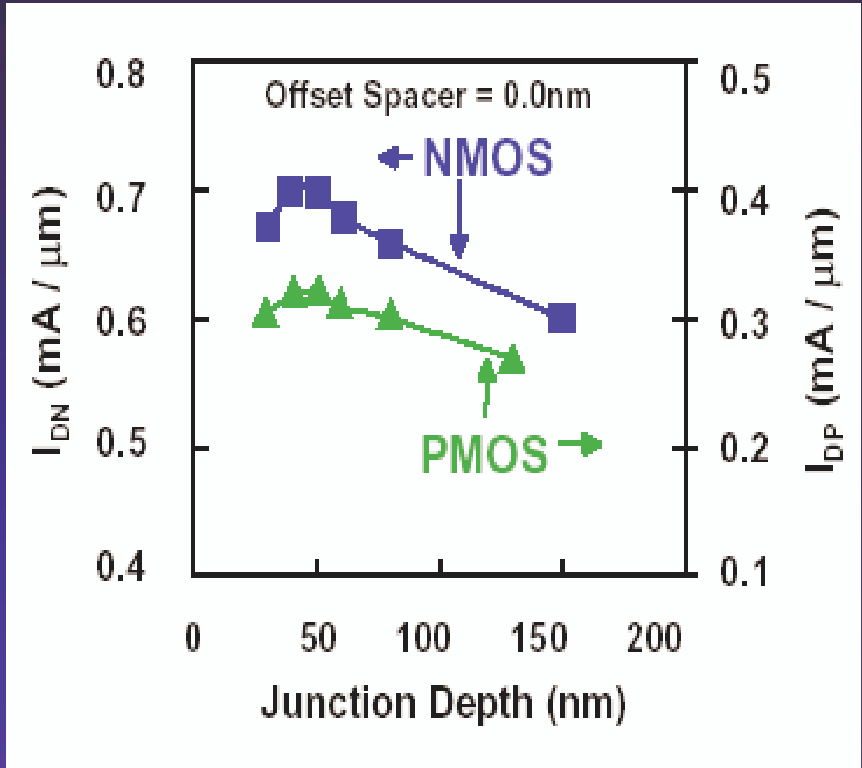


T. Ghani, VLSI Symp. 2000

- SDE resistance is a strong function of doping concentration
- SDE resistance will increase significantly at junctions below 35 nm.

Drive current and R_{ext}





Thompson et. al, Intel Technology Journal, Q3'98

- As junction depths are decreased, short channel effects improve showing gains in I_{dsat} for fixed I_{off}.
- However, R_{EXT} increases very rapidly below 30-40 nm resulting in I_{dsat} degradation.

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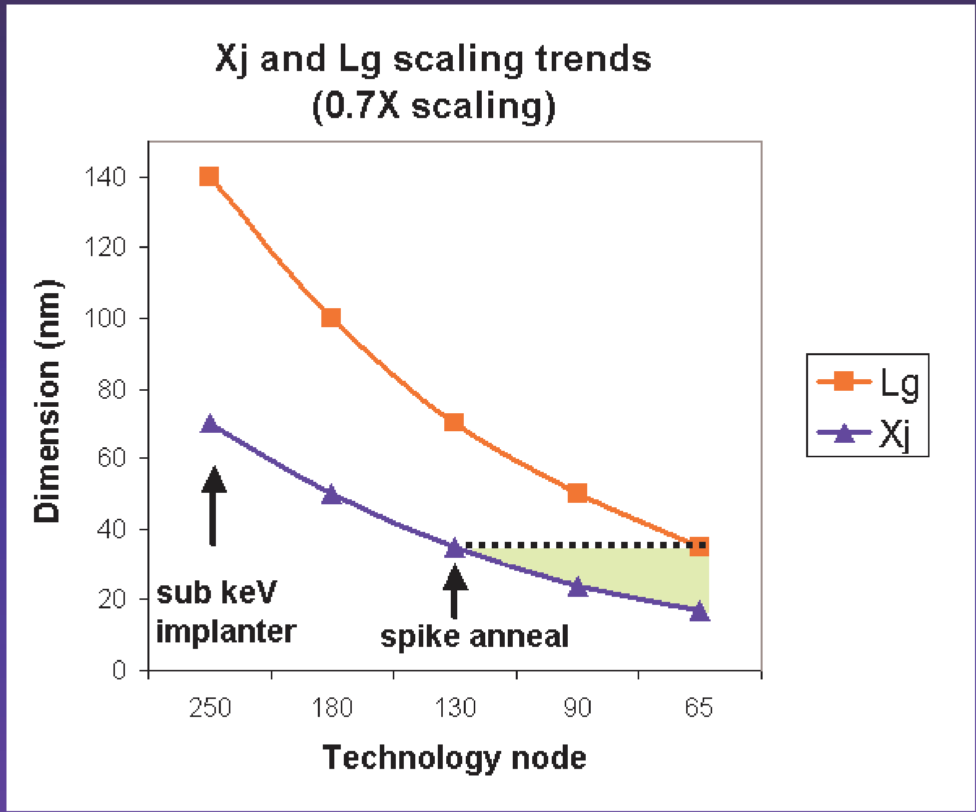
RTA and implant have been the traditional drivers for junction scaling

Known factors that control R_{ext} for 0.7X junction scaling:

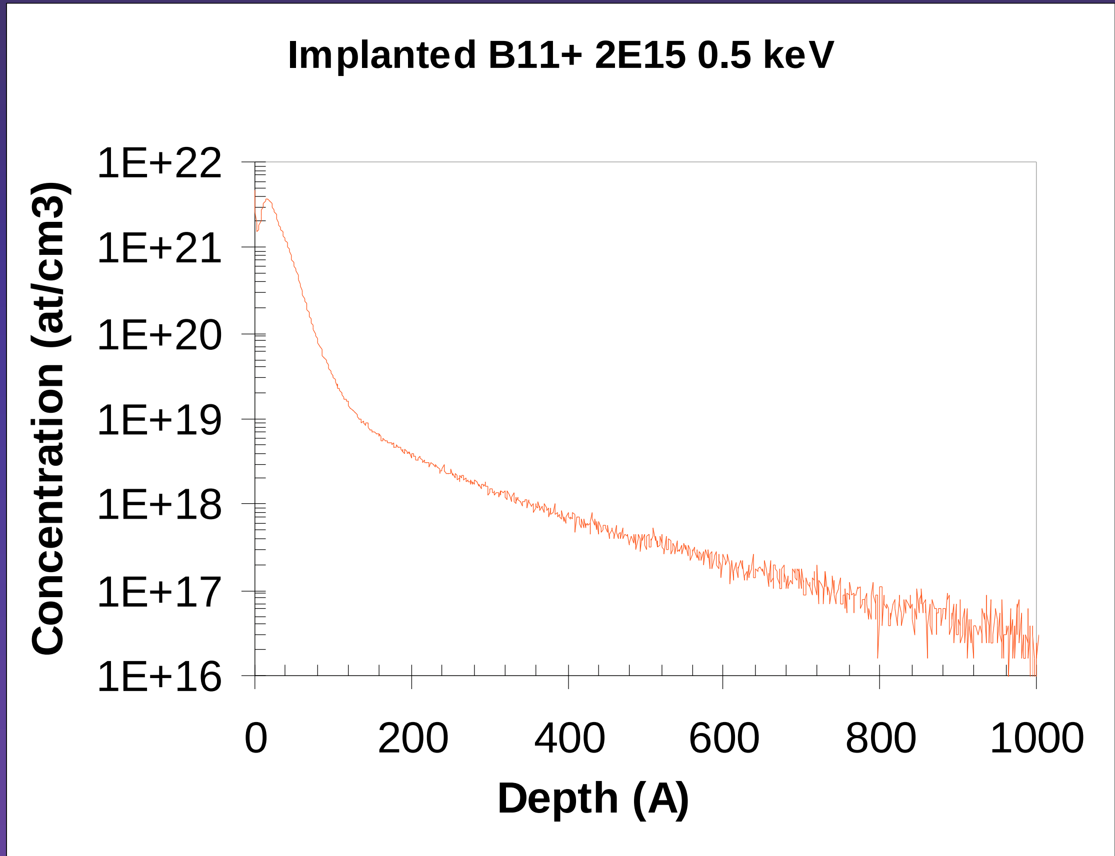
- Low energy implant
- Faster RTP
- Co-impurity addition
- Junction abruptness
- SDE underdiffusion



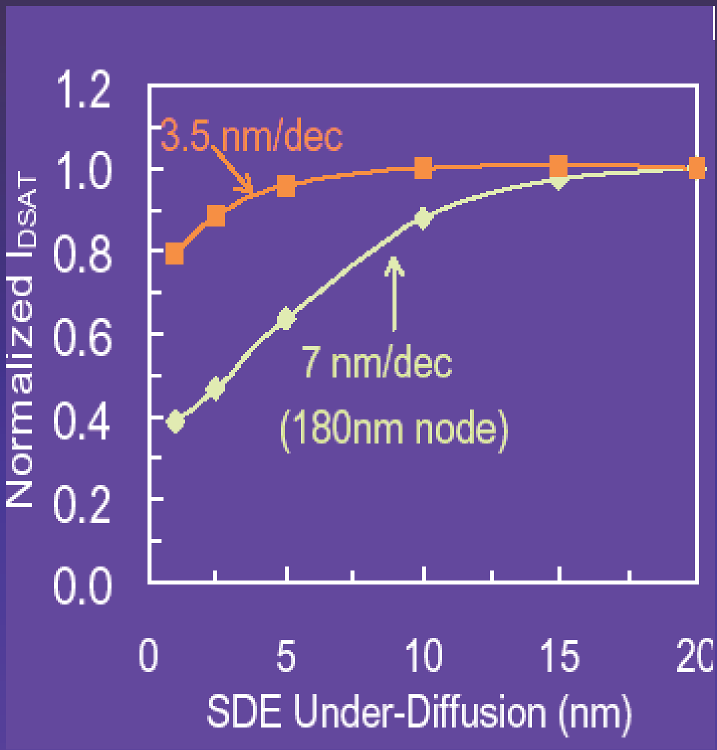
Junction targets for 65 nm is still TBD

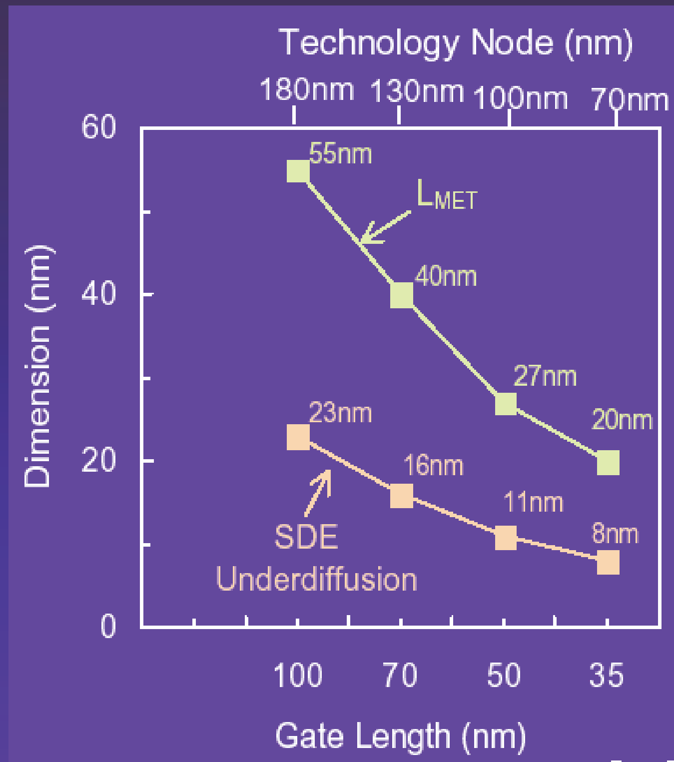
Aggressive scaling at 65nm allows for little dopant diffusion

- 0.7X junction scaling at 65 nm node requires 17 nm Xj.
- Xj for Implanted 0.5 keV B11 implant is 13 nm Xj for 1E19 conc.
- How much farther can Xj be scaled?
- Other constraints?



No diffusion poses challenges for SDE underdiffusion (XUD)





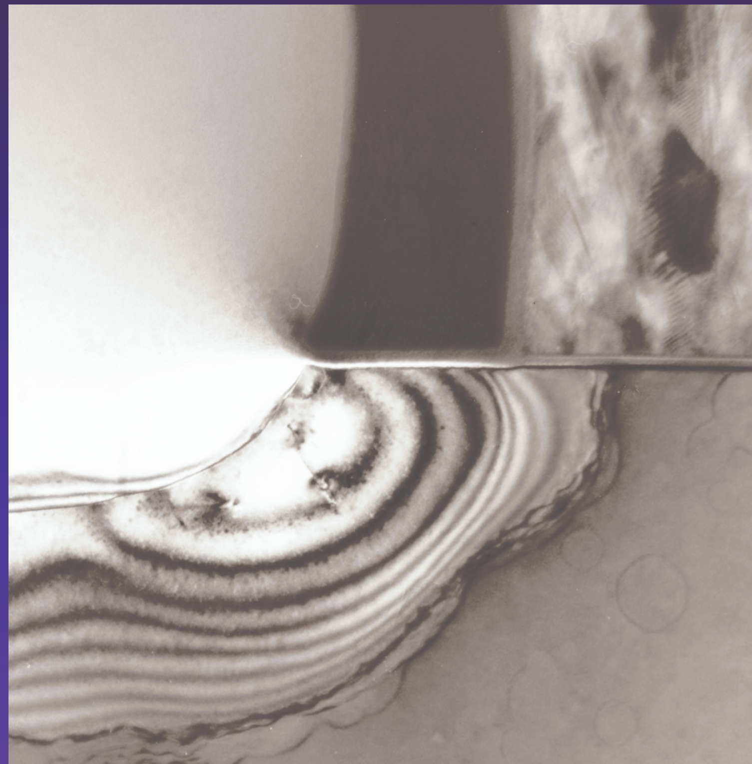
T. Ghani, et al., VLSI symposium 2000

- **SDE dimensions are scaled by 0.7X to meet Lgate target.**
- **Applying 0.7X scaling at 65 nm requires a 8nm XUD vs. 17 nm Xj -> Lack of diffusion may make it difficult to optimize Xj and XUD for transistor performance.**

2D junction profile

Possible solutions for XUD
- Improve junction abruptness
- Decouple XUD from Xj. Xj is not adequate to fully characterize the system.

2D dopant profile techniques can help assist the optimization of the junction.



S. Corcoran

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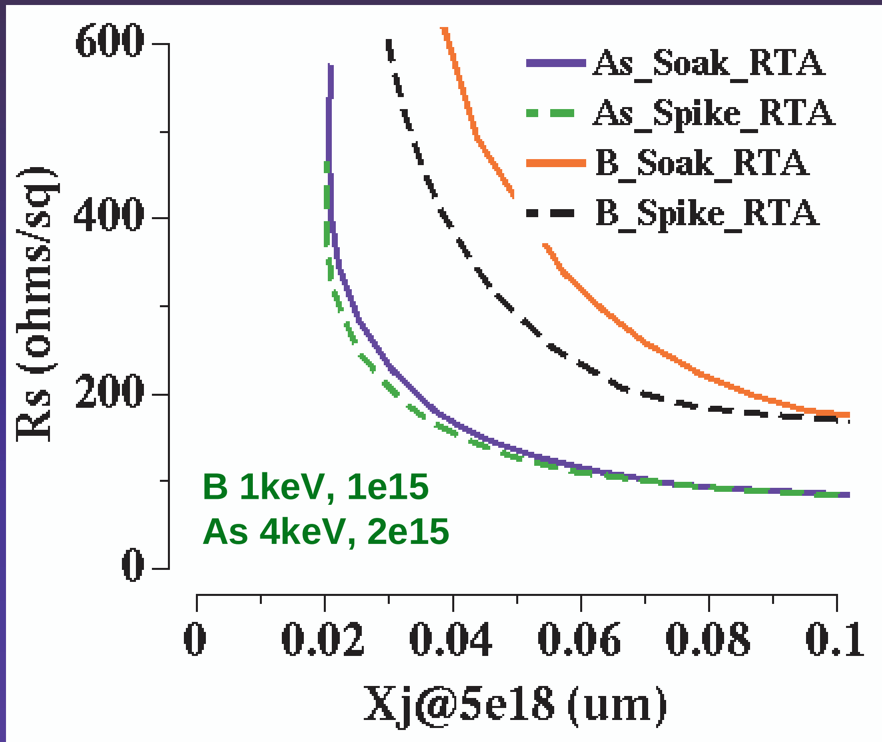
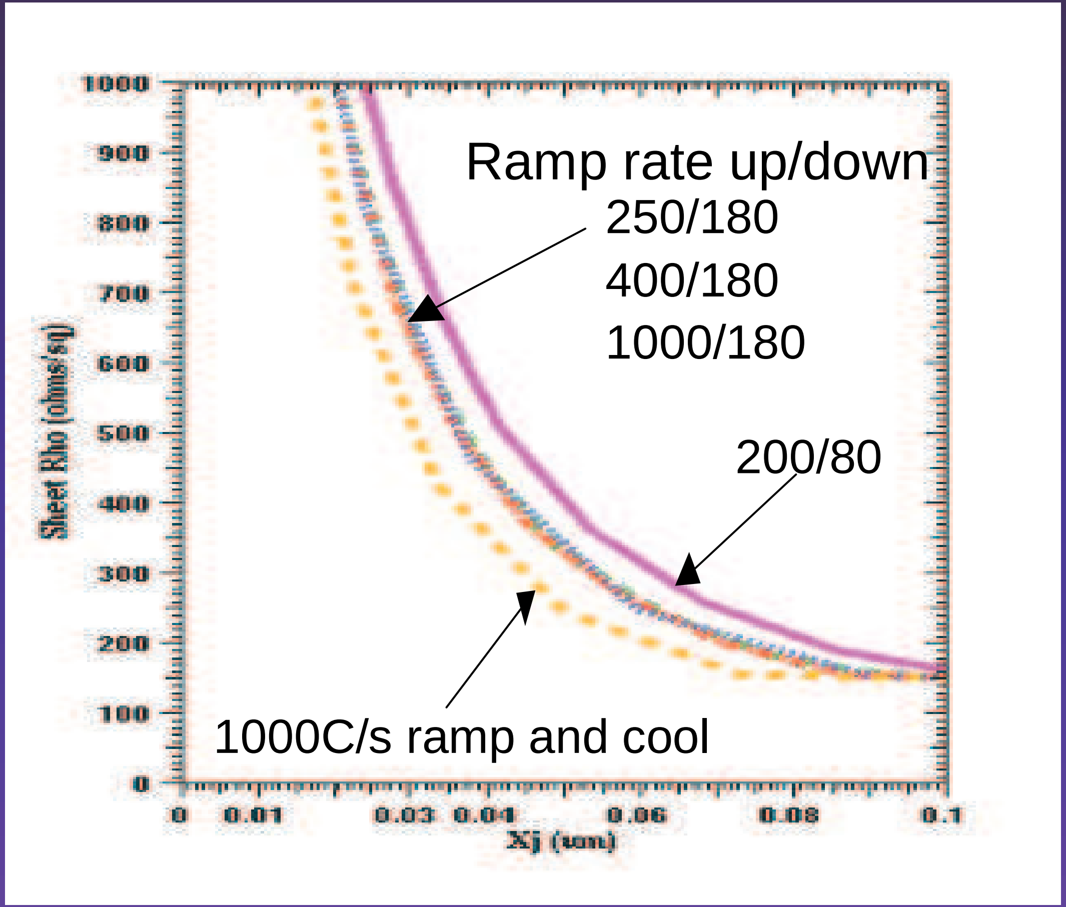
RTA trend - faster is better



Kennel et al. IEDM 2002

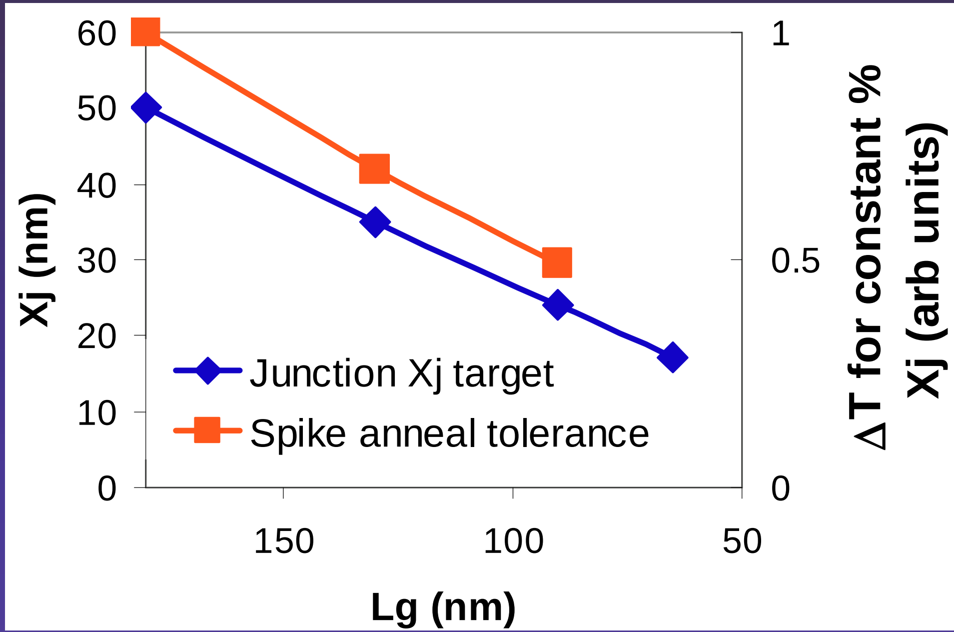
- B Rs-Xj benefits from spike anneal, but As is insensitive
- As (NMOS) may show limited benefits from future RTA developments

Future RTA developments



Tool developments need to focus on improving cooldown rates

0.7X Junction scaling -> 0.7X uniformity scaling



- Simulated ΔT for % Xj control of B11 2.0E15 0.5 keV implant.
- Any spatial temperature non-uniformity reduces number of die with optimal performance.
- The 65nm technology anneal solution will be evaluated based on performance and uniformity

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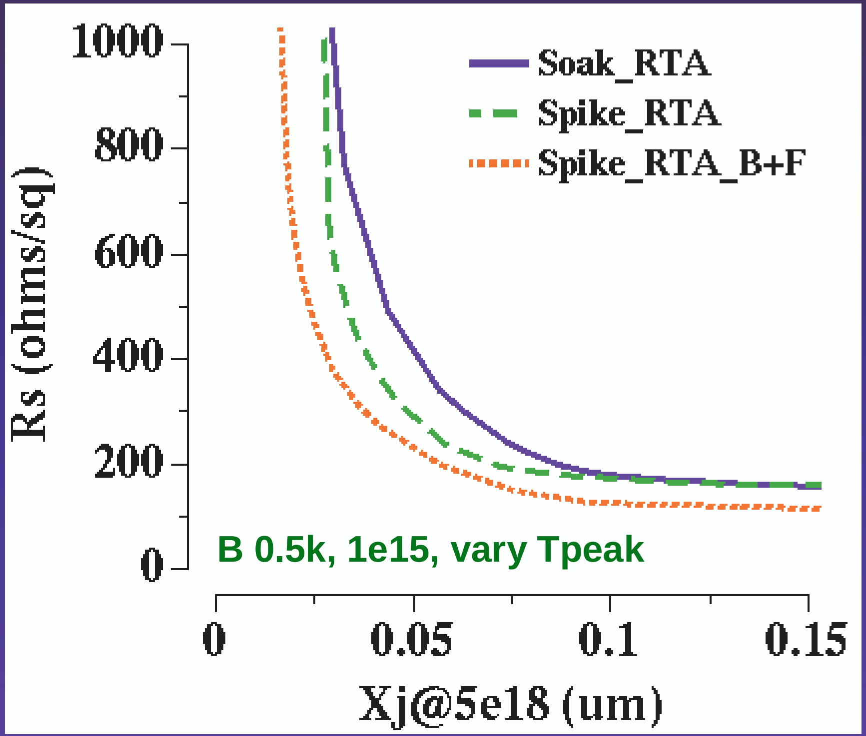
Spike anneal and co-doping effects



Kennel et al. IEDM 2002

Spike anneals better

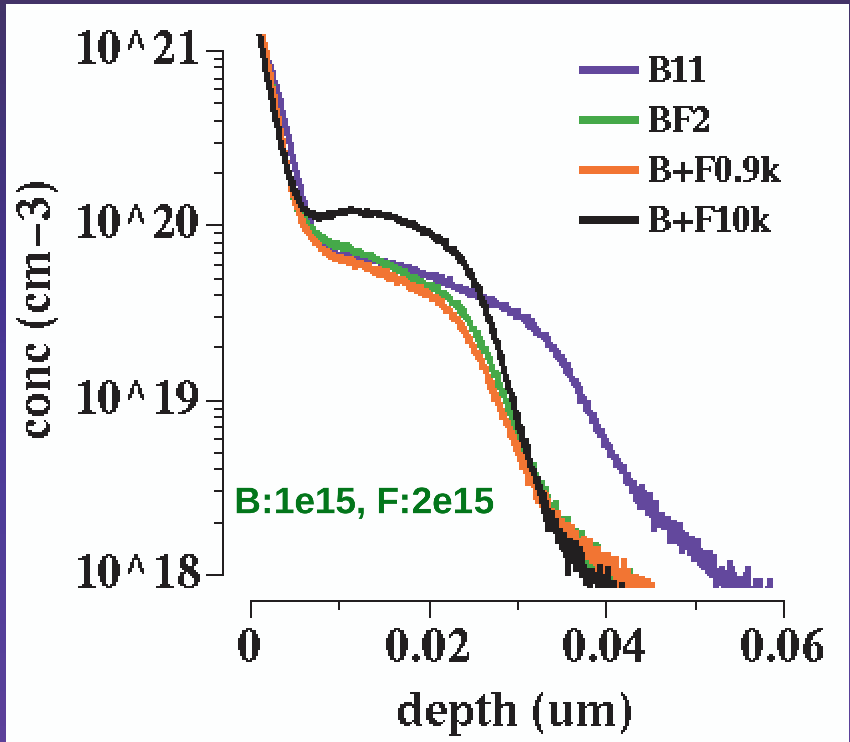
- Higher peak T @ Xj leads to improved solid solubility
- Less TED (higher T)

B+F co-implants show significant Rs-Xj improvement to spike anneal

Co-doping effects can yield comparable Rs-Xj benefits to RTA advances.

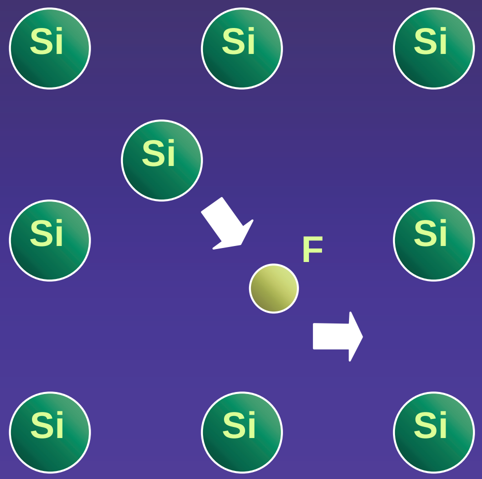
Fluorine co-implant

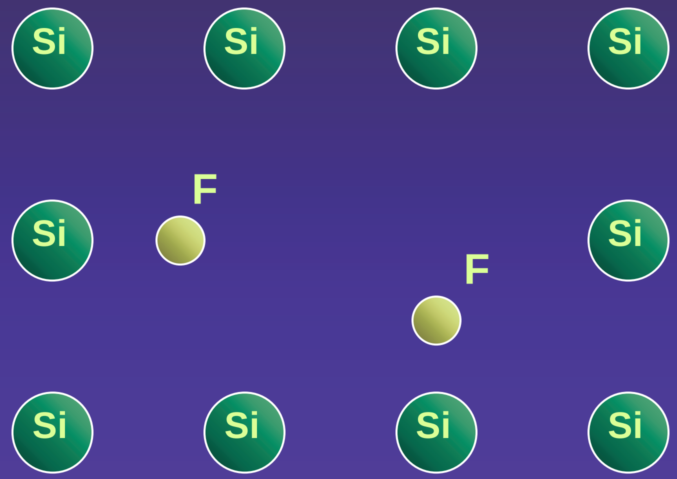
- Location of co-dopant relative to junction is an important parameter.
- Implant F deeper than B for best results.
- Fluorine co-doping improves Junction abrutpnes.
- Plateau is elevated as tail is reduced.
- Co-doping effect is chemical as Si PA control experiment shows little impact on B11 profile.



Review: Robertson IWJT 2001

Fluorine and Point Defects





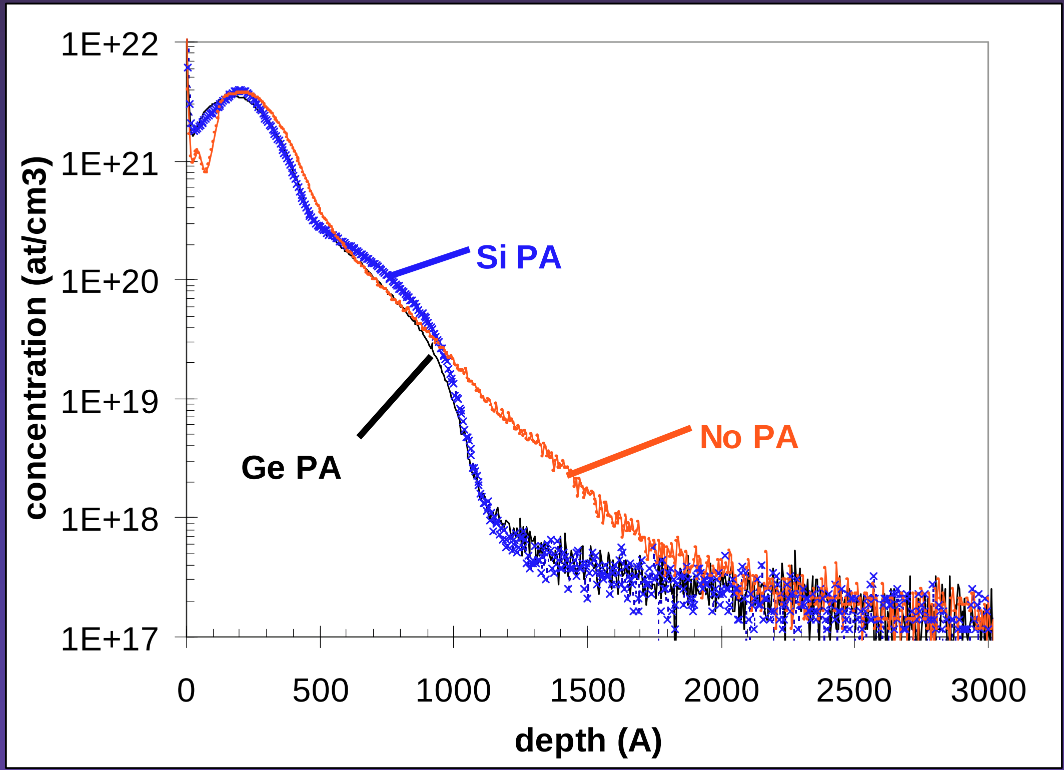
Kickout of Fluorine consumes Ints

Trapping of F by Vac clusters during regrowth

Mechanisms supported by ab-initio physical modeling (Dunham SISPAD 2002, Shano IEDM 2001)

Germanium co-implants

- Effect of high Ge concentration is equivalent to PA for junction profile.
- SPE dominates co-implant effect.
- Effect is physical, not chemical.
- Addition of Ge can produce strain.

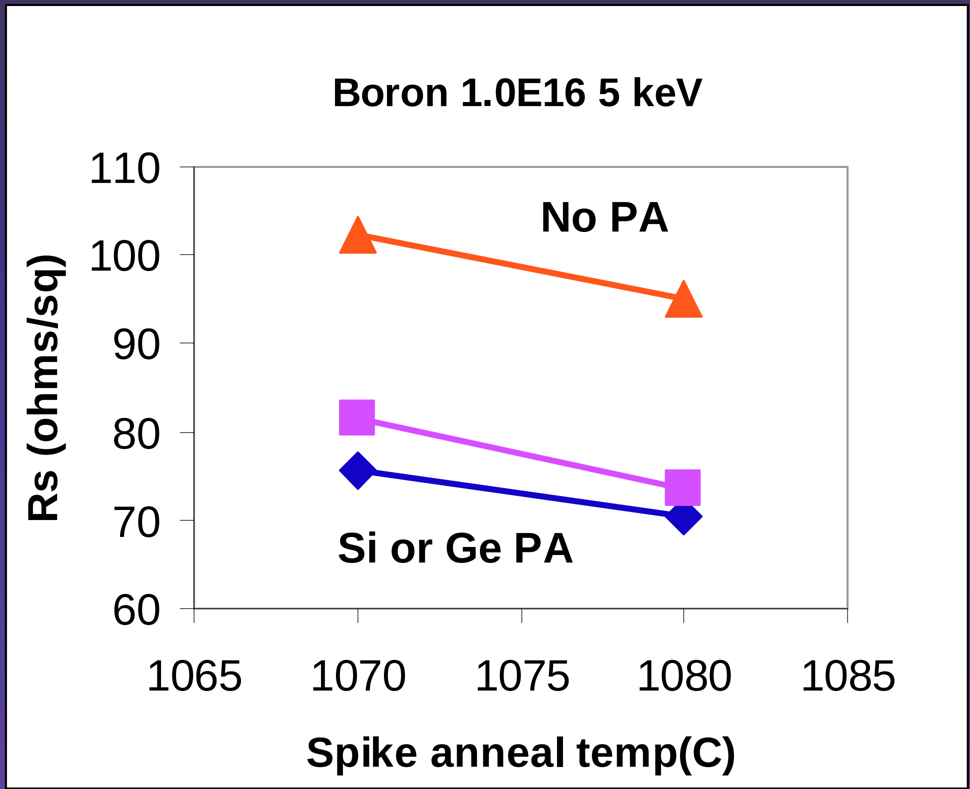


B11+ 1.0E16 5 keV

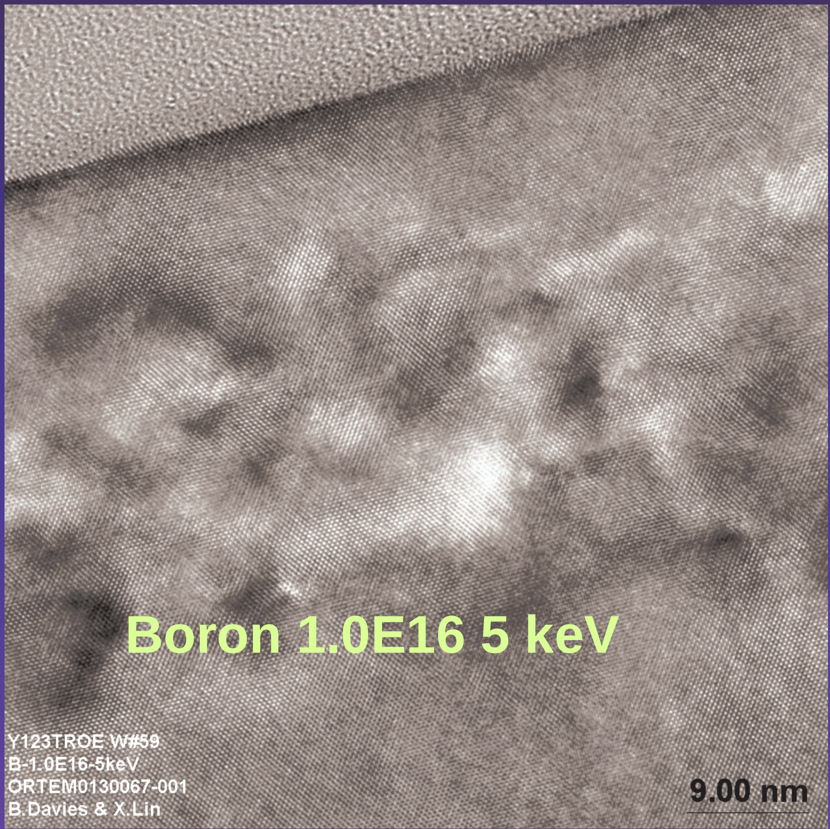
Si PA 2.0E16 25 keV

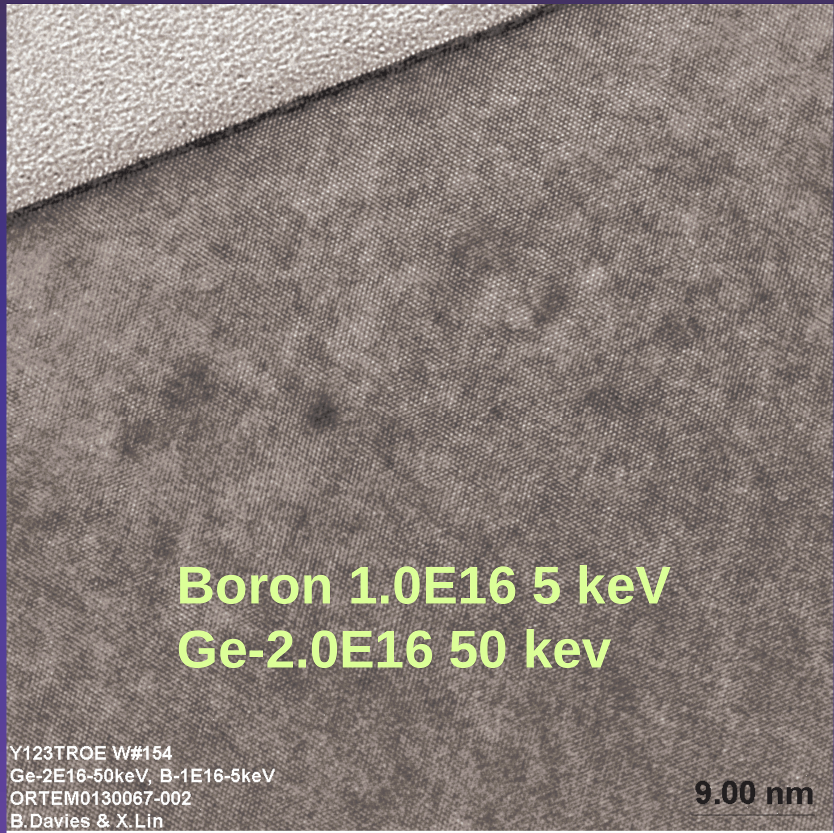
Ge PA 2.0E16 50 keV

SPE effects dominate co-implant effect



Boron implant conditions can not completely amorphize Si

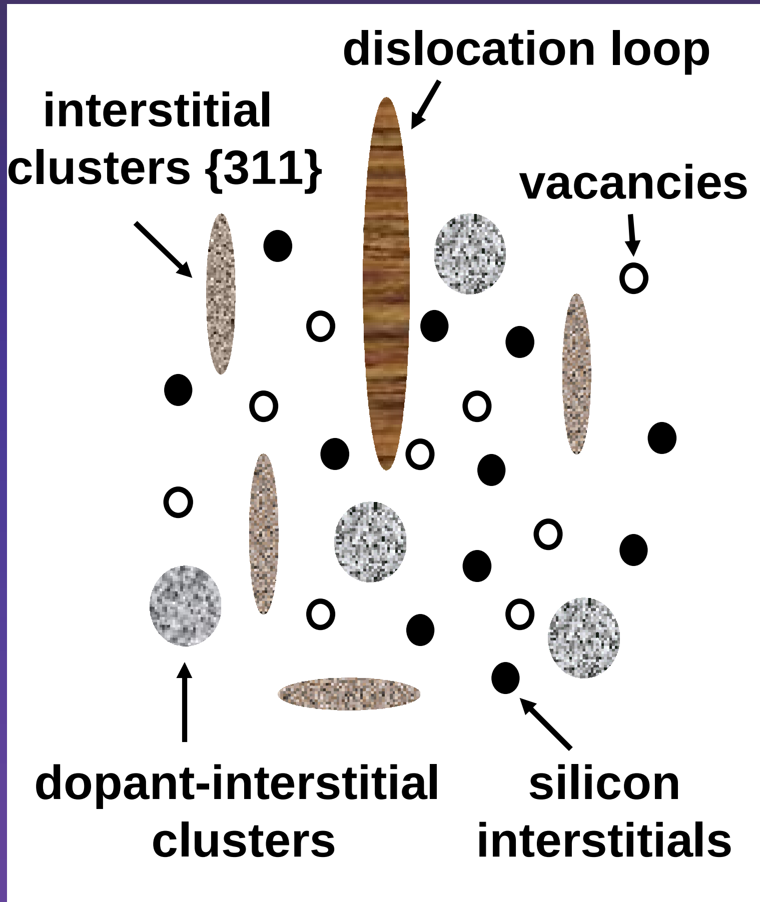




Lack of complete amorphization has significant penalties for dopant activation (TEM is post anneal)

Defect engineering

- During low temperature anneals, extended defects form
- These extended defects may contain dopant atoms
- The growth and dissolution of these defects determines the dopant diffusion.
- Co-doping effects can modulate the evolution of these effects.

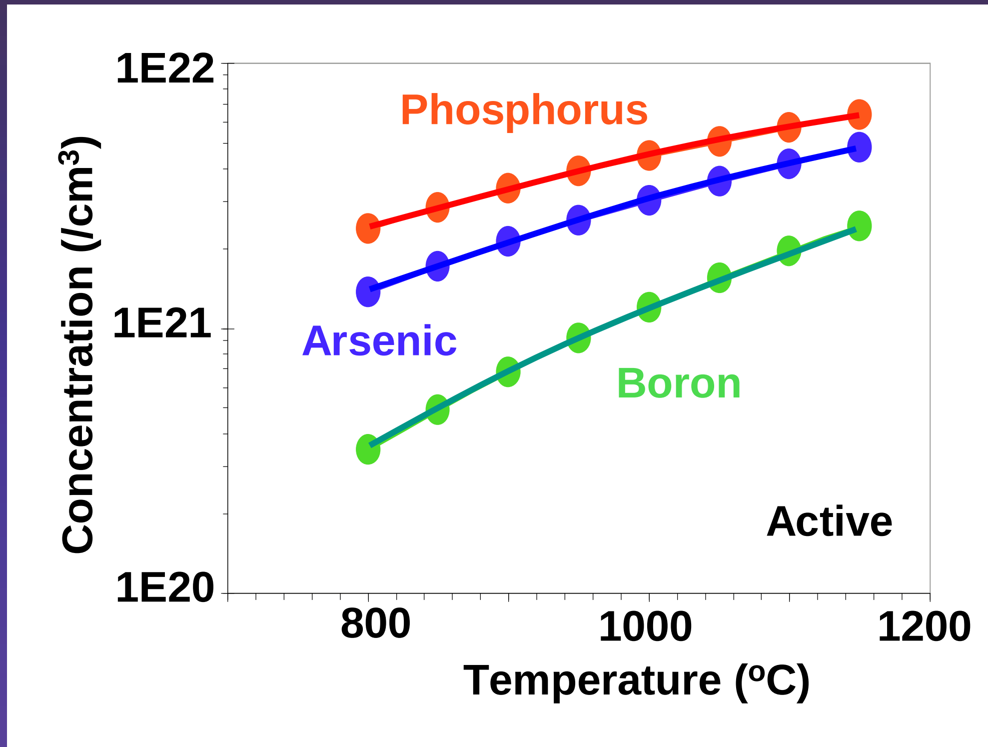


Are there any useful co-doping interactions still to be discovered?

					2 He
5 B	6 C	7 N	8 O	9 F	10 Ne
13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
49 In	50 Sn	51 Sb	52 Te	53 I	54 X3
81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn

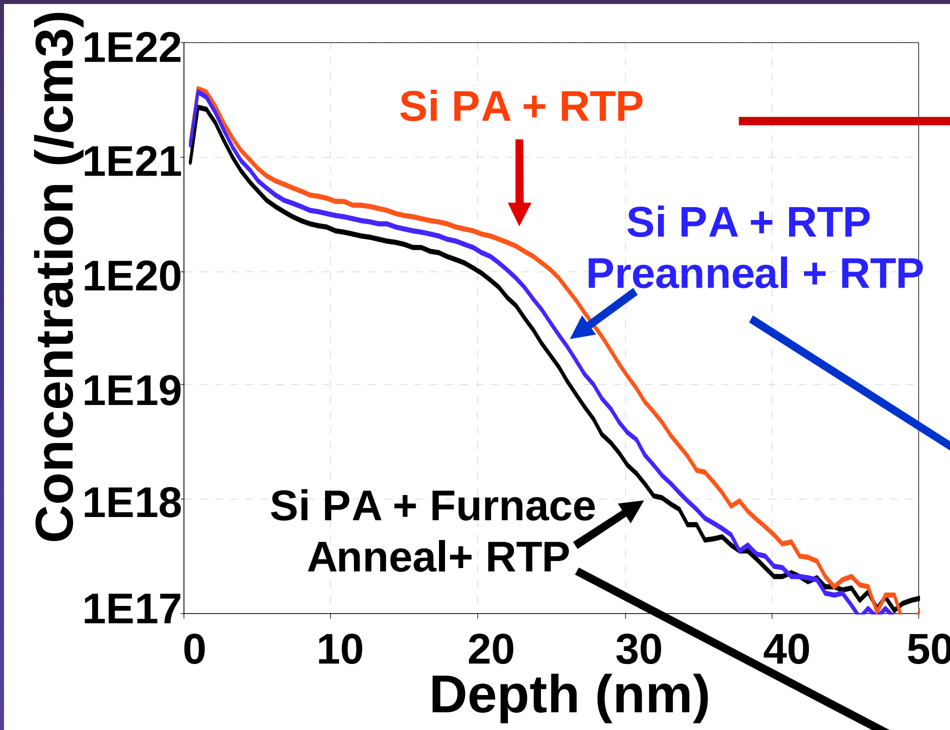
More applications of other co-dopant applications have been documented in the literature.

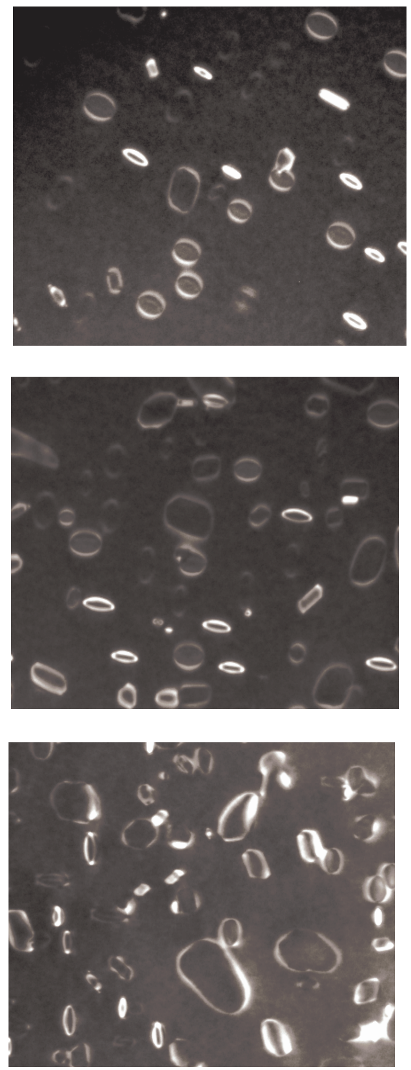
Improving dopant solid solubility



Faster ramp rates and higher temperature to improve dopant solid solubility

Thermal History





- Subsequent low temperature anneals nucleate defects
- Extended defects can act as sinks
- Process needs to be optimized for full thermal process history

Conclusion

- Aggressive scaling of Xj at 65 nm node will present challenges in maintaining adequate XUD for the SDE.
- Future RTA hardware improvements will require higher peak temperatures and faster cooldown rates.
- Junction scaling efforts will require improvements in RTA temperature uniformity.
- Co-dopants effects can be chemical or physical. These effects can show comparable Rs-Xj benefits to recent RTA advances.
- Moores law will continue.

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