Ion implantation challenges and opportunities for next generation SiC devices

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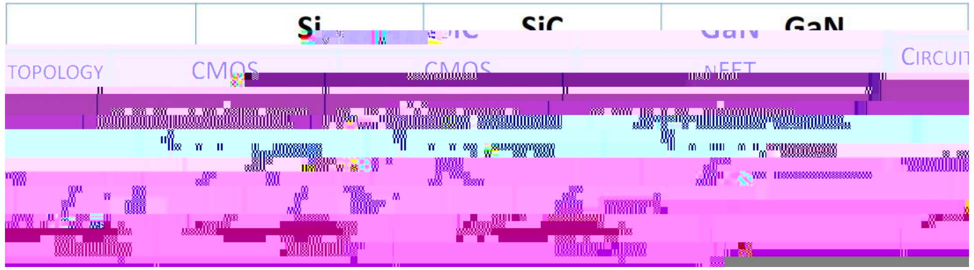
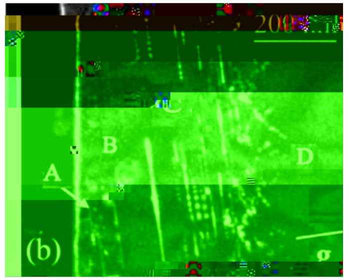
SiC next step for maturity and massive diffusion
Implant for Performances, Reliability and Costs

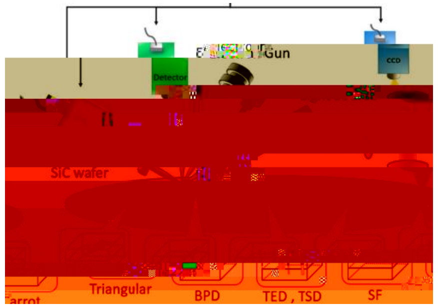


Iannaccone, G. et al. IEEE Access, 9, 139446-139456.(2021)

Reliability



R. Nipoti et al. Mater. Sci. Proc. (2017).



Chen, Po-Chih, et al. Nanoscale Res. Lett. 17.1 (2022): 30.

Continue effort to control defectivity/reliability. Implant to local

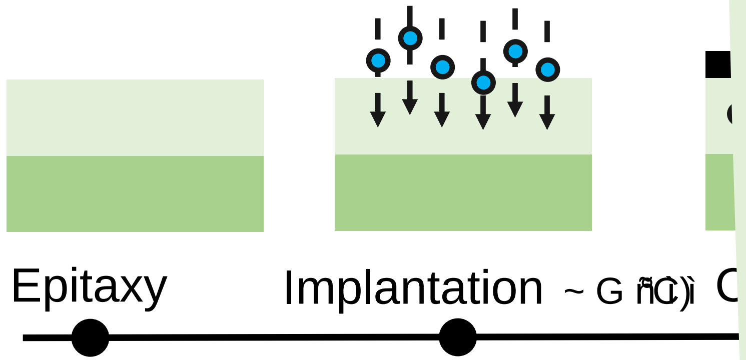
Agenda

{ Path for ultra

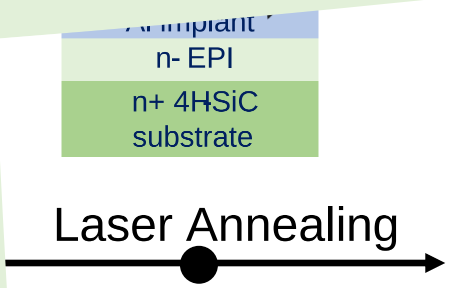
Extend Doping capability - Ultra-low resistivity Junction manufacturing process limit

Extend Doping capability - Ult
Implant and laser annealing c

Industrial process



New Process

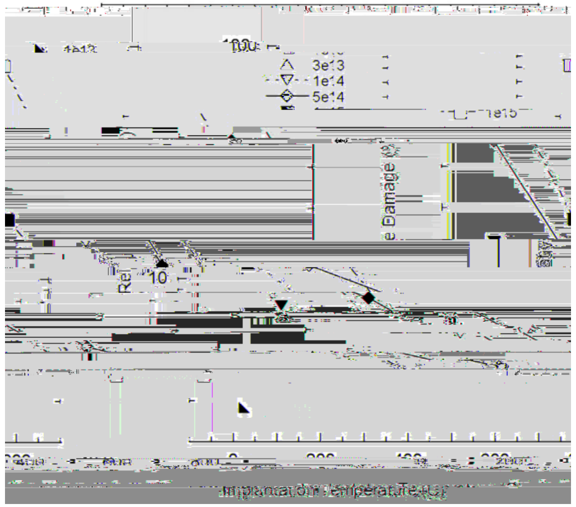


…mize defect level

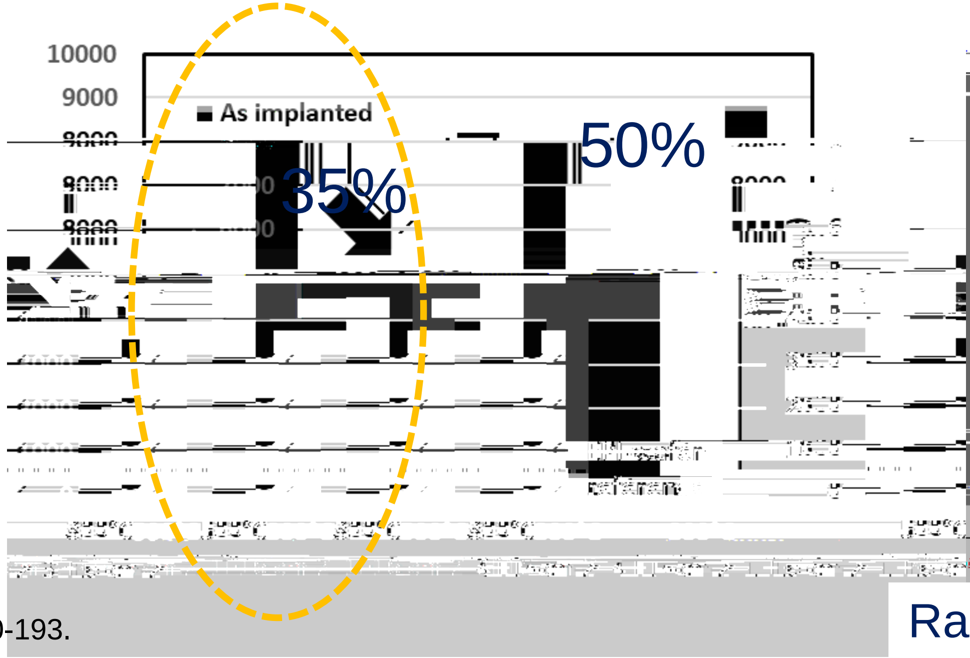
- Avoid capping layer process and to reduce manufacturing costs
- Laser annealing to combine high temperature activation efficiency with no high thermal budget-induced extending defects

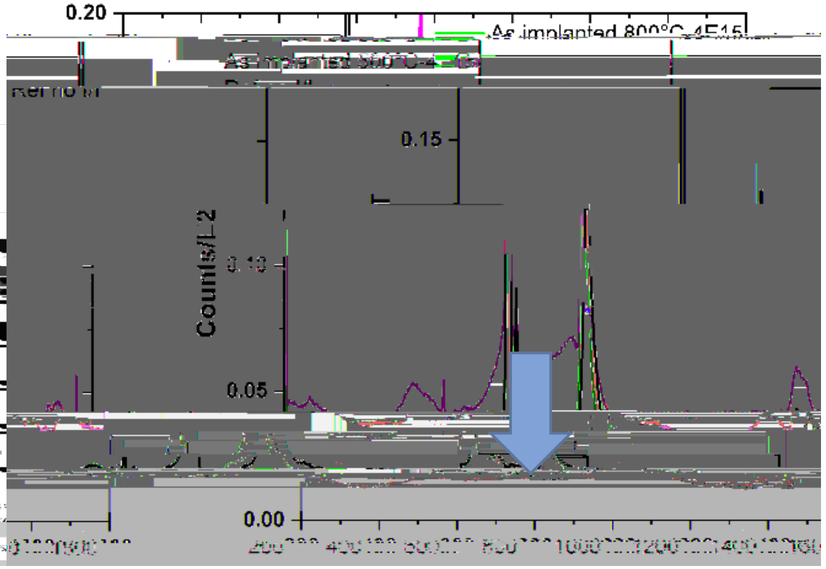
Advance implantation engineering: Defect modulation

- Rising wafer temperature (~500°C) during implantation is successfully implemented for doses 1E15 cm^{-2} and below
- We explore doses >> 1E15 cm^{-2} with a rising wafer temperature to 800°C



Hallén, A., & Linnarsson, M. (2016).
Surface and Coatings Technology, 306, 190-193.

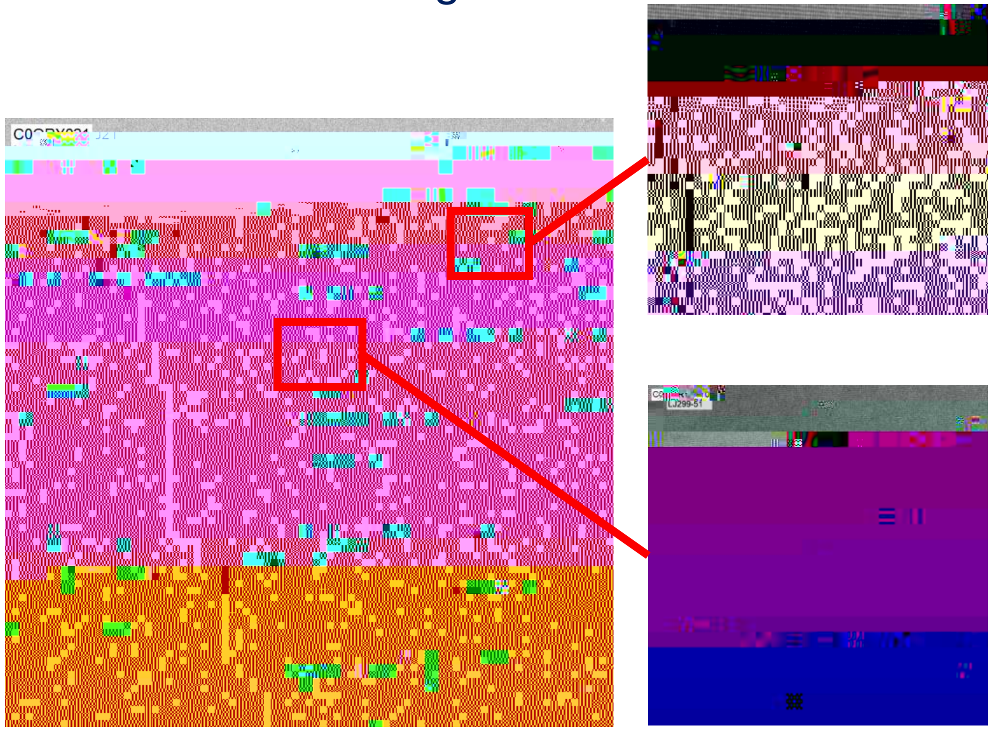




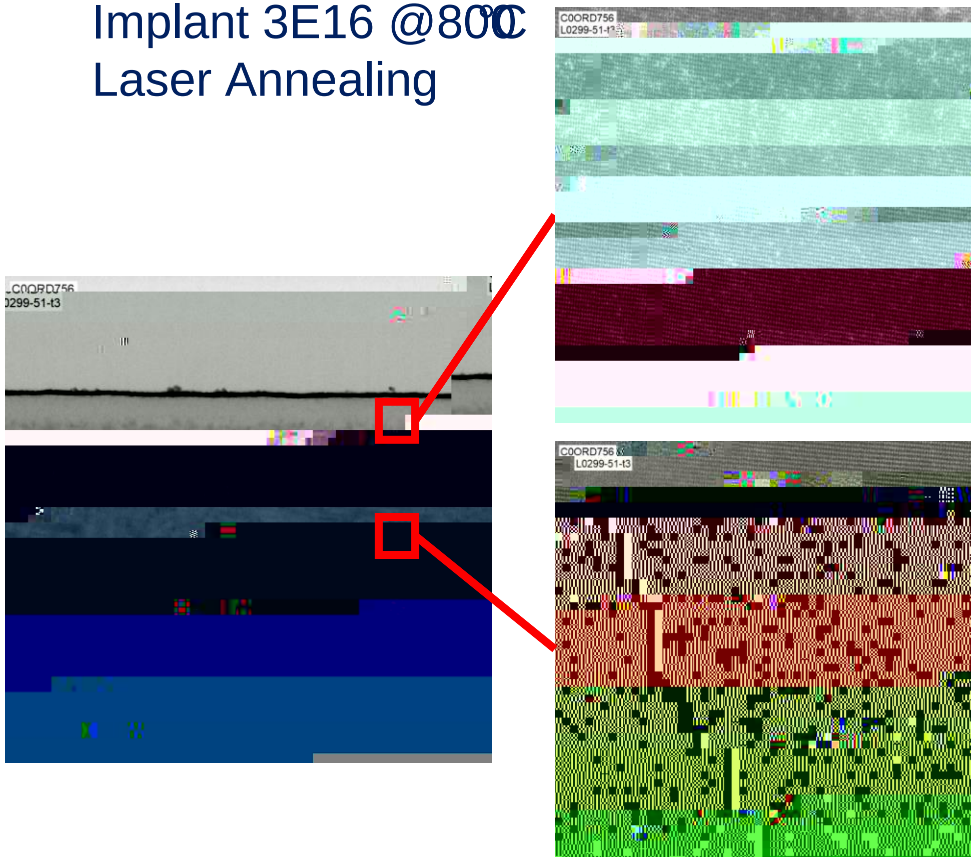
Raman shows that 800°C implantation can preserve crystal quality at the same level of EP

Extend Doping Capability - Ultra-Low Resistivity
Defect Evolution vs. Thermal Budget

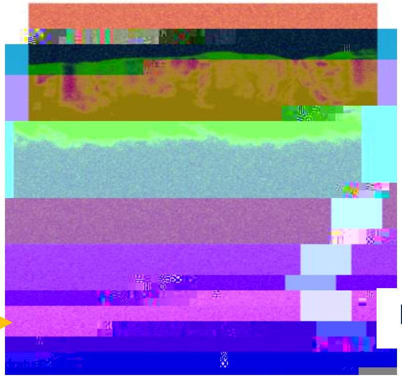
Implant 3E16 @800°C
Furnace Annealing 1700°C 30 minutes



Implant 3E16 @800°C
Laser Annealing



Extend Doping Capability - Ultra-Low Resistivity
Defect Evolution vs. Thermal Budget



lower p-type

Extend Doping Capability - Ultra-Low Resistivity Implant Laser Annealing Key Requirement

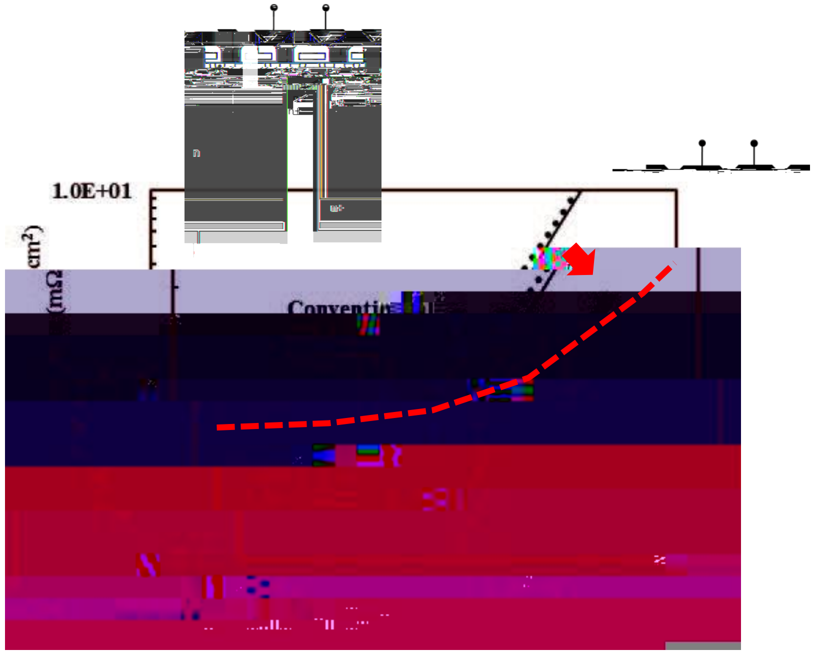
Hallén, A., & Linnarsson, M. (2016).
Surface and Coatings Technology, 306, 190-193.

Agenda

Innov1244 08.17 90.009 412.87 c h C q 0.000014305 0 960 5

- Path for ultra-low resistivity by implant and laser annealing optimization
- Device innovation with SJ with Channeling implant

Device Innovation
Super Junction with High Energy - Channeling Implant



Masuda, T., et al. IEDM IEEE, 2018.

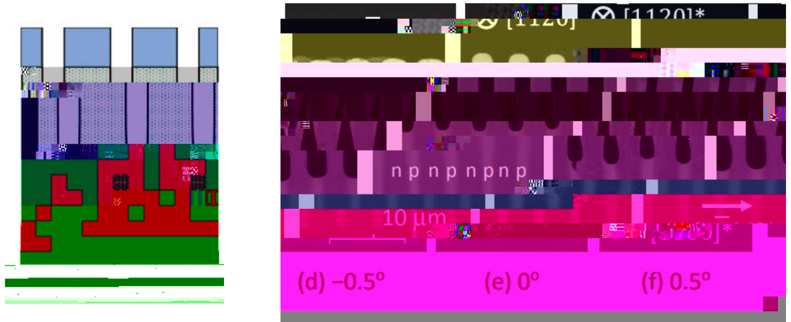
Multi-Step EPI/Mask/Implant

Kobayashi, Y. et al. (2019). (ISPSD) (pp. 31-34). IEEE.

Pro
- Achievable with current technologies

Cons
- High costs
- Alignment and uniformity between layers

Trench filling by EPI

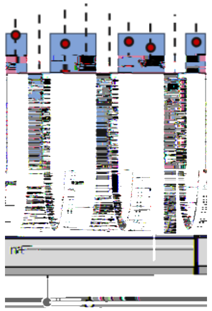


Ryoji Kosugi et al 2017 Jpn J. Appl. Phys. 56 04CR05

Pro
- Higher process flexibility

Cons
- Require complex EPI step. (doping variability, sensitive to } Œ] v š š] } v Y •

High Energy Channeling Implan

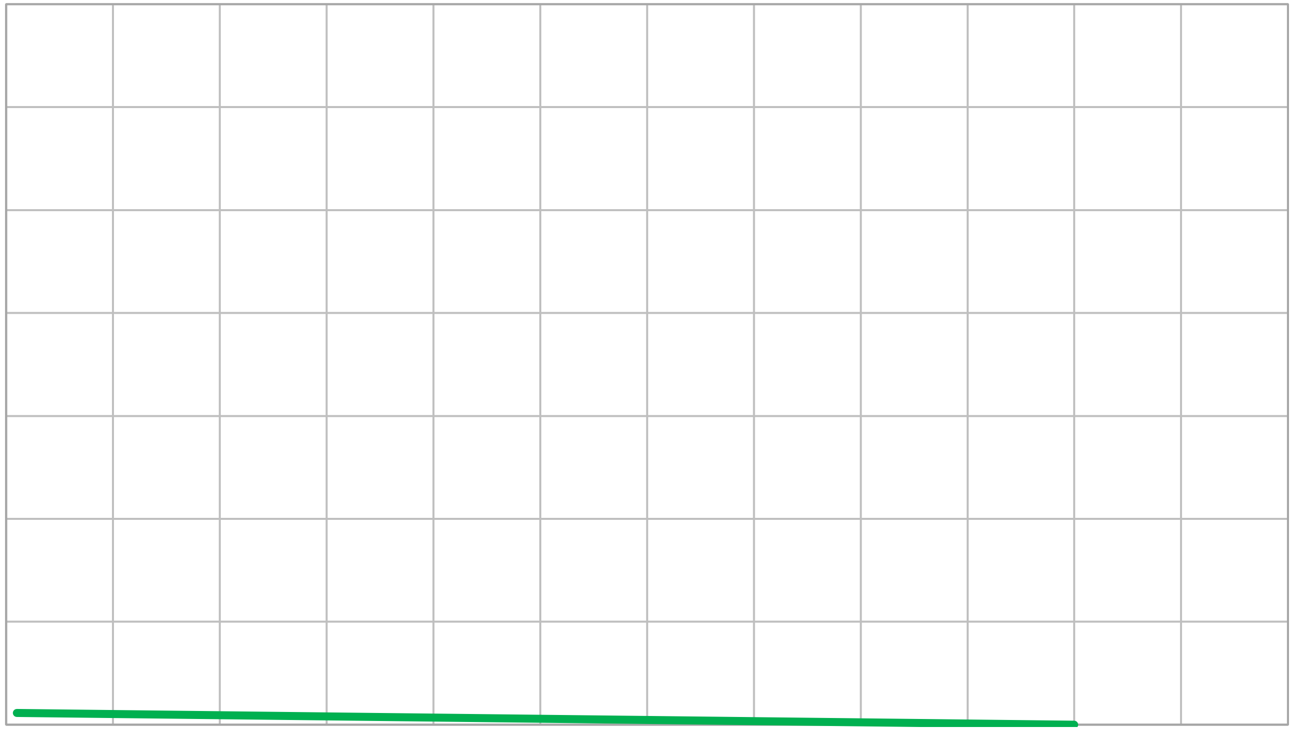


Pro
- A more cost-effective approach

Cons
- Require industrial implanter capable of >5um projected ranges
- Masking capability with high stopping power

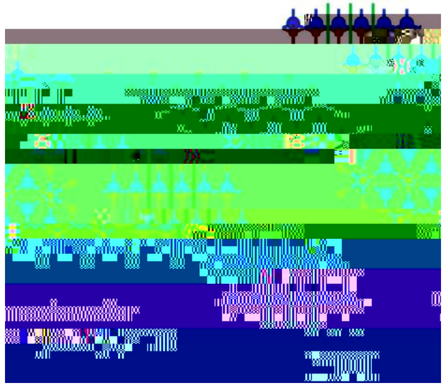
Super Junction MOSFET is the best-known path for extending SiC unipolar limit
High energy Implant the promising solutio

Super Junction with High Energy Channeling Implant Projected Range ±Current Capability



Path for Extending Implant Depth
High Energy Channeling Implant Key Requirements

Beam-Channel alignment



Theoretical critical angle for Aluminum channeling

1MeV	Æ	0.37°
3MeV	Æ	0.21°
12MeV	Æ	0.11°
15MeV	Æ	0.09°

M. Belanche al. Mater. Sci. Semicond. Process. 179 (2024): 108461.
Ziegler, James F., ed. Ion implantation science and technology. Elsevier, 2012.

Energy Range

- g Up to 10MeV with channeling to reach 7-6µm depth profiles identified as best trade off:
  - ‡ Most effective solution for majority of SiC devices class below 2kV
  - ‡ Achievable process window (Critical angle > 0.1£)
  - ‡ Achievable ion acceleration (for production purpose)

Agenda

Innovation t Extend Doping capability

- Path for ultra-low resistivity by implant and laser annealing optimization
- Enabling Device innovation with SJ Channeling implant

Reliability- SiC Material modification

- Proton implant for mitigation of stacking fault expansion
- Amorphization implant for selective oxidation

Costs

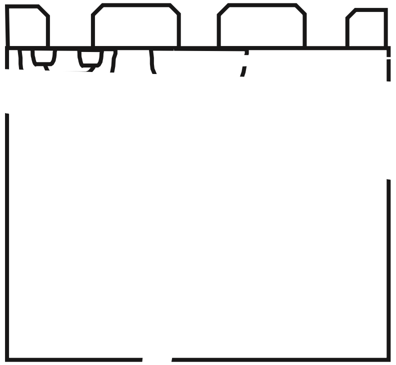
- Future implant for splitting

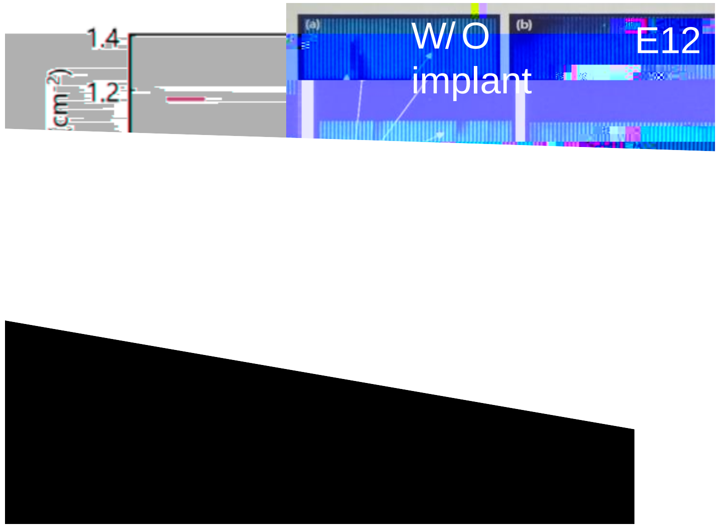
Material Modification -

Material Modification- Proton Implant for SF Expansion Mitigation Mechanism and Implantation Process

- Implant offers an effective solution for carrier lifetime control via doping and/or defect engineering. Differently from EPI-buffer, lifetime control can be masked and modulate in depth by the implant projected range.
- Proton implant solution has been demonstrated repeatedly
  - Implant effective once located in the EPI-layer up to the EPI-bulk interface. Effect vanishes if in the bulk
  - Effect increases when increasing the proton dose and tends to saturate above $1E14cm^{-2}$

Post-EPI proton I/I





Multiple demonstrations that proton-implanted layer at the Epi-Substrate interface shields the active device from bulk crystal defects expansion during operati

Agenda

Material Modification - Amorphization Implant for Selective Oxidation Challenges and Opportunities

Material Modification - Amorphization Implant for Selective Oxidation Mechanism and Implantation Process

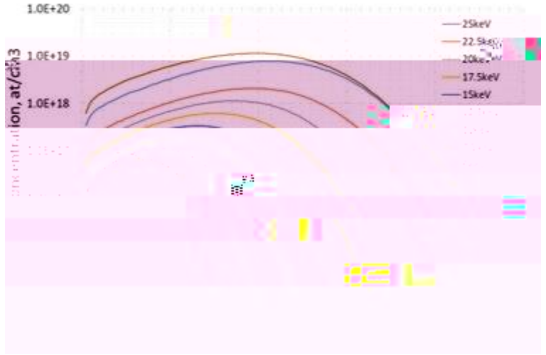
Ion implantation to solve the trade off:

- SiC

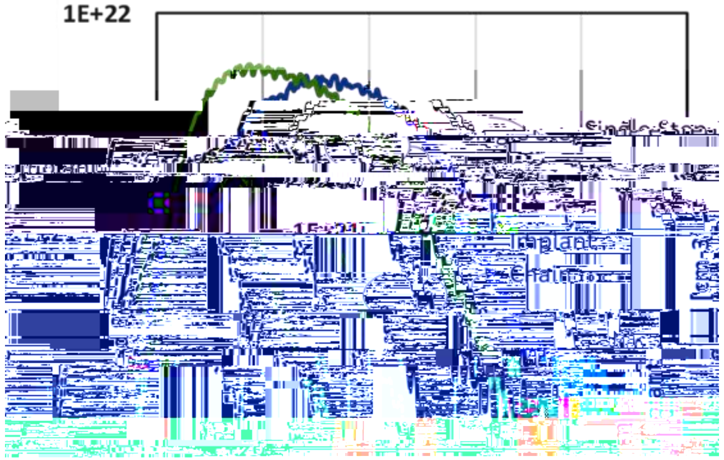
Material Modification - Amorphization Implant for Selective Oxidation Key Implant Requirements

Advance Profile Engineering

- Require the maximum capability to control 3D implanted profile and induced defects. This can be done by implanting the total dose with a sequence of subsequent implants where every step is optimized for Dose, Energy and Angle.



Example of profile engineering tuning dose, energy, angle per sub-recipe



Productivity

- Very high dose (1E16 cm^{-2} and beyond) to guarantee the amorphization and chemically enrich the layer.
  Need high productivity to be compatible with industry target costs

Agenda

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Reliability- SiC Material modification

- [redacted] selective oxidation

Future Implant for Splitting
Challenges and Opportunities

- >30% of the cost of a 1200 SiC MOSFET is the wafer cost

Summary

g Implant can play an important role to support continuous growth of

Thank You for Your Attention!