Planar SiC Schottky Diodes

Studying Material properties, traps, irradiation effects, annealing
Towards a Radiation Damage Model

DRD3 WG6 Project Proposal

Thomas Bergauer (HEPHY) and others

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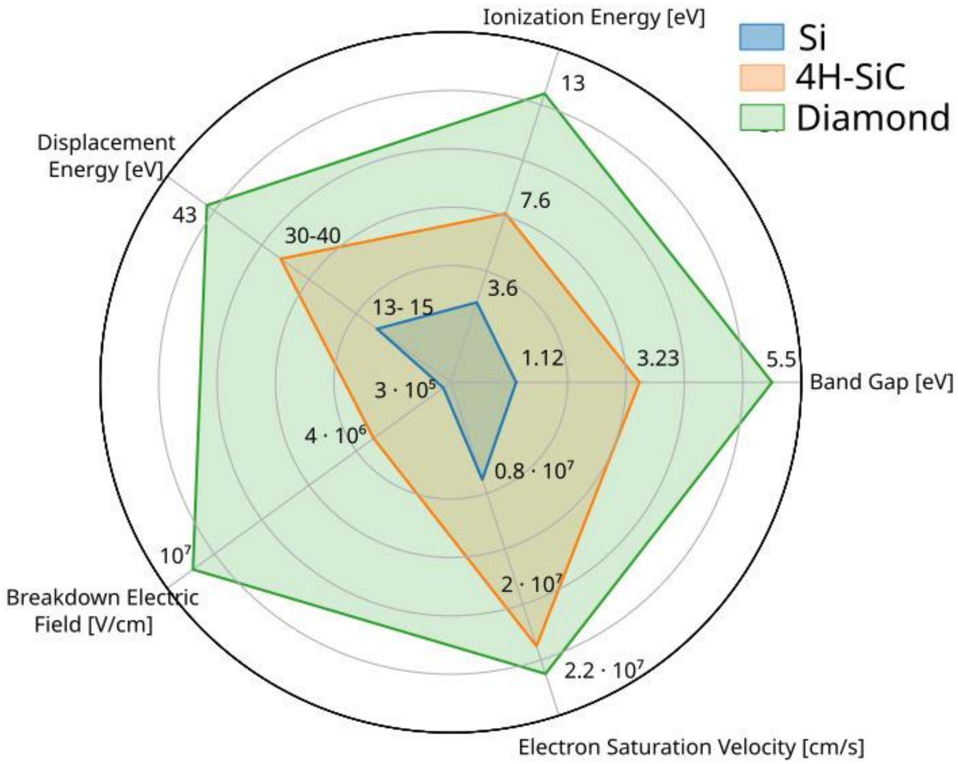
Silicon Carbide

- Wide bandgap material
  - One of first investigated semiconductors
  - Used in power electronics
  - Polytype 4H commonly used
- Features high
  - Charge carrier mobilities
  - Breakdown field
  - Thermal conductance
- Utilization @ HEPHY
  - Low noise particle detector
  - Medical and HEP applications



Radiation Damage in SiC: Open Challenges

- Open challenges in radiation damage modelling for SiC:
  - Trap information deviate in literature
  - Existing models are based on small sample sizes and specific fluences
  - Integration of a dedicated model in TCAD
- Demand for large-scale irradiation study:
  - Statistically significant sample size (>? devices)
  - Large spectrum of fluences 10^{13} n_{eq}/cm^2 - 10^{18} n_{eq}/cm^2
- However: not enough sensor samples available

- **Proposal:**
  - **irradiation study with commercially available SiC-Schottky diodes on the short term**
  - **Production of planar Schottky and pn-junction diodes**

Available SiC Producers

- CNM Barcelona
  - Had a couple of runs already
  - Currently too many other projects
  - Delays
- FBK Trento
  - Plan to start SiC processing
  - First run with Schottky, second run with pn-junction diodes
- Fraunhofer IISB
  - CMOS SiC process with 2μm

Commercial SiC Schottky Diodes

- Increasing availability due to demand in power electronics (BV of up to 3kV, I_f up to 40A)
- Can be obtained online & off the shelf in large numbers
- Cheap: a few cents per diode
- Come with validated characteristics, datasheets and SPICE models

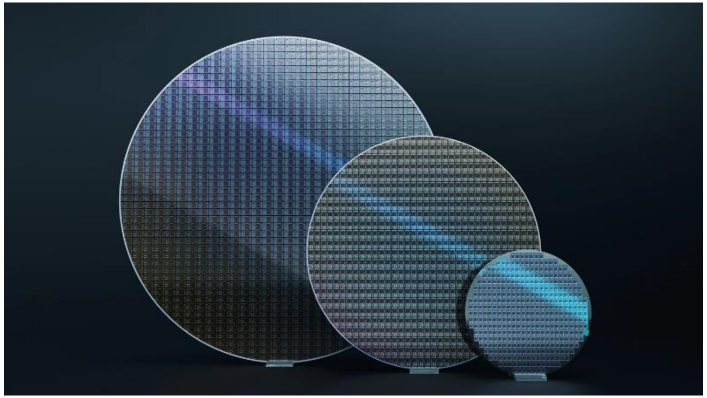


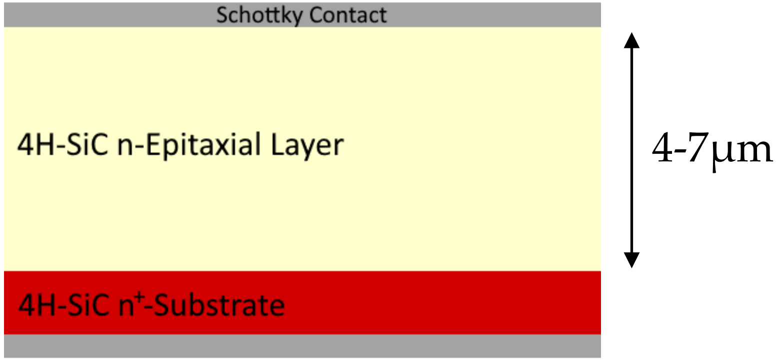
Image from: https://questsemi.com/products/copy-of-copy-of-qs-hcs-6510-650v-10a

- Expected depletion region thickness of 4-7μm

  → challenge for MIP detection

  → laser and alpha particle measurements preferred for radiation sensing

- Have metal contact on top → metallization needs to be removed for laser tests



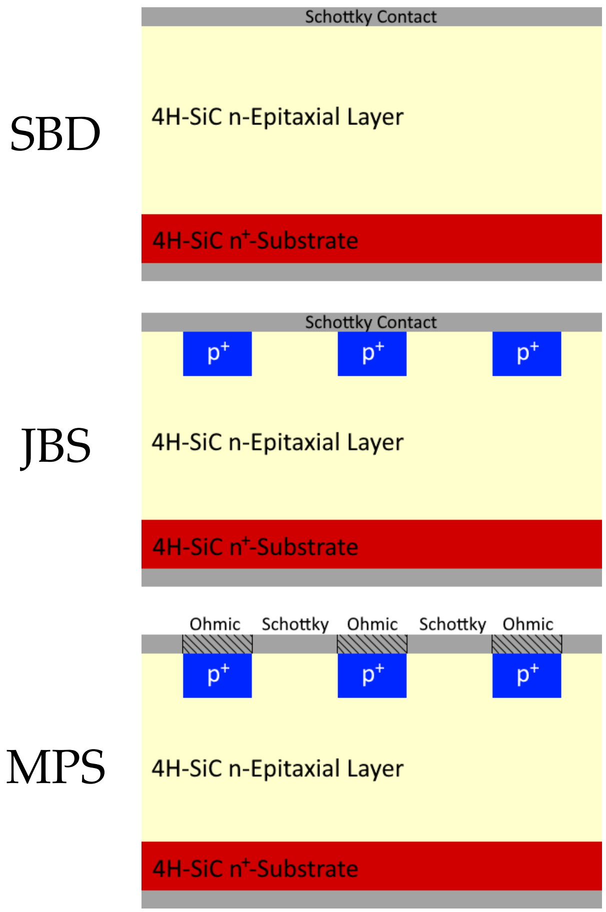
Types of SiC Schottky Diodes

- Schottky Barrier Diode (SBD)
- Junction Barrier Schottky (JBS) Diode
  - p-implants with Schottky contact to metal
  - Reduction of leakage current in reverse bias
- Merged PIN Schottky (MPS) Diode
  - P-implants with ohmic contact to metal
  - Reduction of leakage current in reverse bias
  - PN-junction dominates forward current at high forward voltages → better thermal stability

- MPS diodes offer best performance for power applications

  → mostly MPS diodes available online

  → TCAD modelling becomes more complex

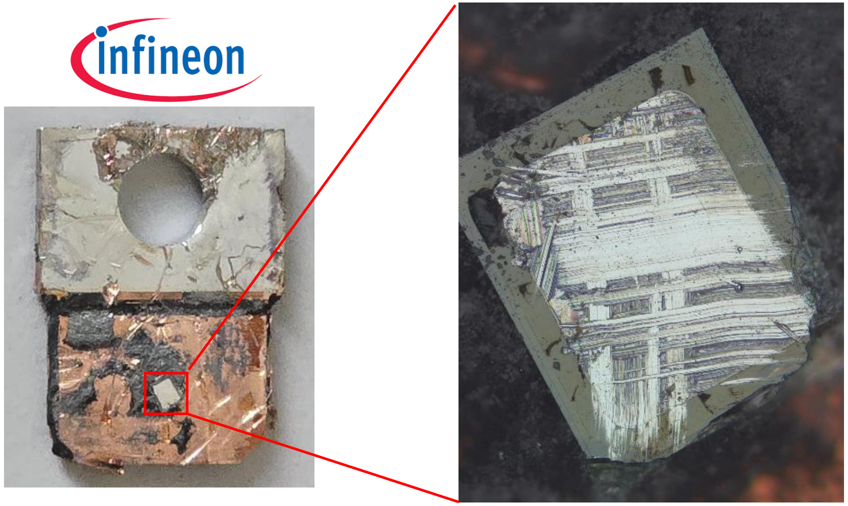


Availability of Bare Dies

- **For radiation sensing: need for bare dies**
- Several vendors offer bare dies: Central Semiconductor, WolfSpeed, SemiQ, LeapSiC…
- However: first contact approaches for small number of samples were left unanswered

…

- Workaround 1: open packaged diodes
  - Opening packages is tedious for >? samples
  - Destruction-free opening still an open question
- Workaround 2: commercial production run
  - Advantages:
    - Custom structure → easier reverse engineering of TCAD models
    - Diodes tailored for radiation sensing → thick epi-layer, simple architecture, metallization opening for laser tests
  - Disadvantages: possibly higher costs and lead times



Plan/Deliverables: Measurements

- Selection and commissioning of samples:
  - Multiple devices, e.g. differing substrate doping, IV/CV characteristics
  - If possible, different manufacturers
  - >? samples per combination

- Irradiation campaign
  - Fluences of 10^{13} n_{eq}/cm^2 - 10^{18} n_{eq}/cm^2 (EURO-LABS)
  - Irradiation with different particles (neutron, proton, electron, γ)
  - ≥ 3 devices per fluence and particle

- Pre/post irradiation measurements
  - IV, CV, CCE, DLTS, MCTS, . . .
  - unchanged measurement setups
  - with(out) thermal annealing

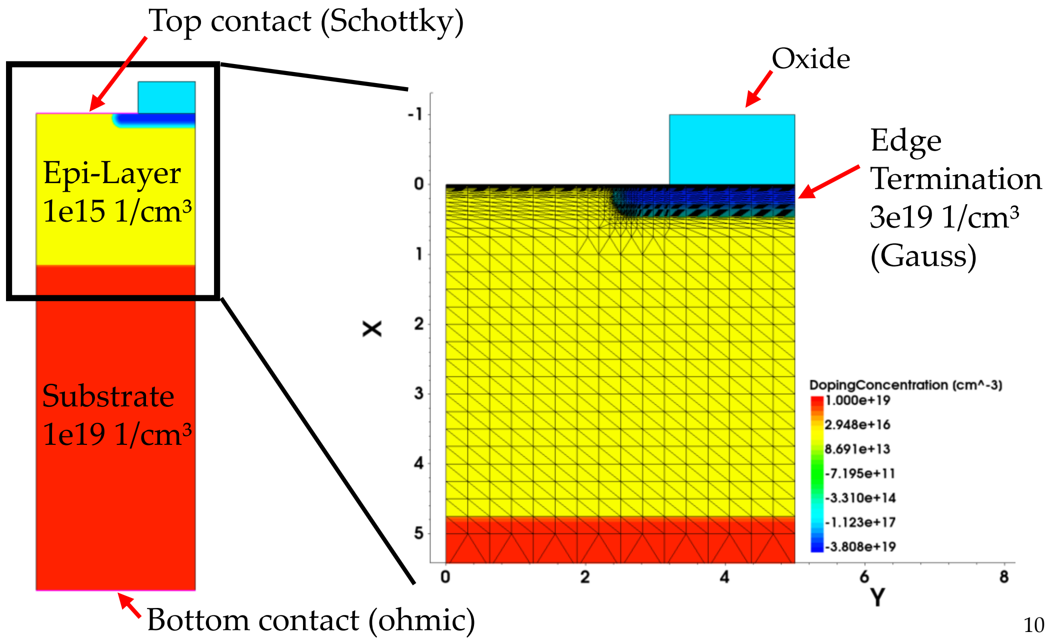
Plan/Deliverables: Simulation

- TCAD reverse engineering: reconstruction of IV, CV and CCE characteristics
- Additional information available through:
  - SEM, TEM and SIMS measurements for device structuring
  - SPICE models
  - If devices from production run: TCAD models maybe offered by manufacturer

- Model fitting based on measurements from irradiated samples:
  - traps
  - type (donor/acceptor)
  - ionization energy
  - introduction rate
  - electron/hole capture cross sections

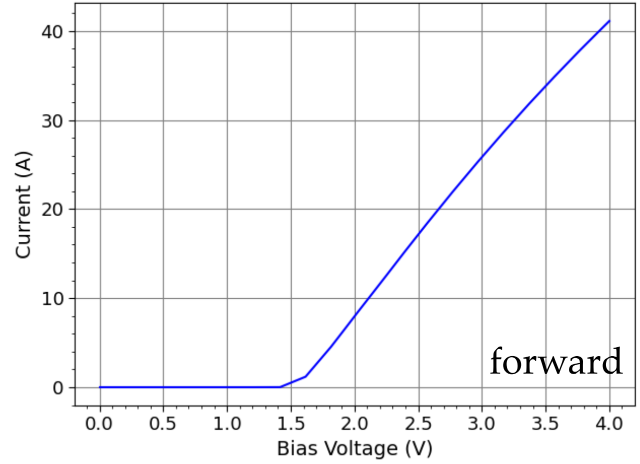
TCAD Challenge

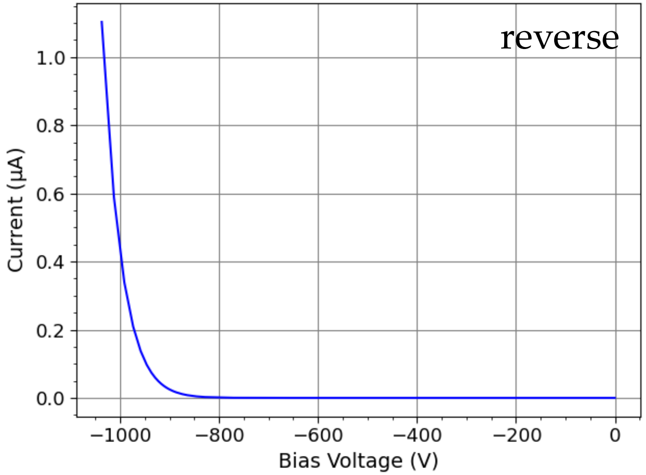
- Main challenge: reverse engineering of unirradiated devices
- Large parameter space:
  - Work function energy (depends on metallization)
  - Substrate doping (higher doping = higher tunneling current)
  - Schottky barrier tunneling parameters
  - Diode architecture (SBD, JBS, MPS)
  - Recombination, impact ionization, …
- Starting point: SiC Schottky diode template in Sentaurus TCAD [1]
  - Schottky contact with 5.1eV work function energy
  - Area Factor: 2e5 -> device area of $1mm^2$
  - Non-local barrier tunneling model (NLM)



Sentaurus SiC Schottky Template

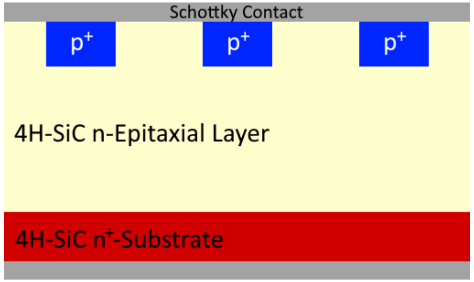
- Forward IV:
  - $V_{on} \approx 1.4V$
  - Forward current in the same ballpark as commercially available diodes
- Reverse IV:
  - breakdown starts at ~900V
  - Commercial devices have breakdown at 650V up to ~3000V (1200V most popular)

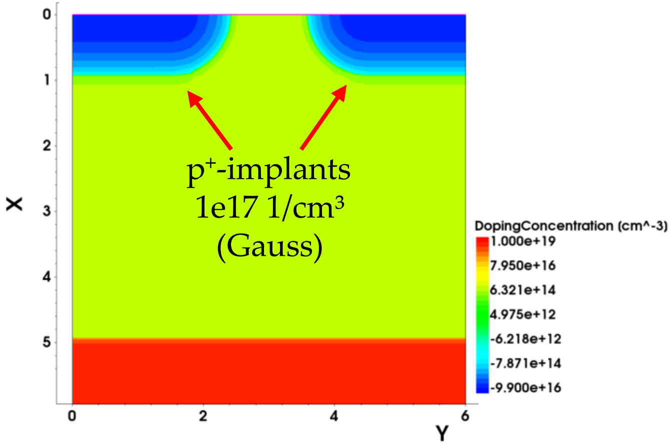


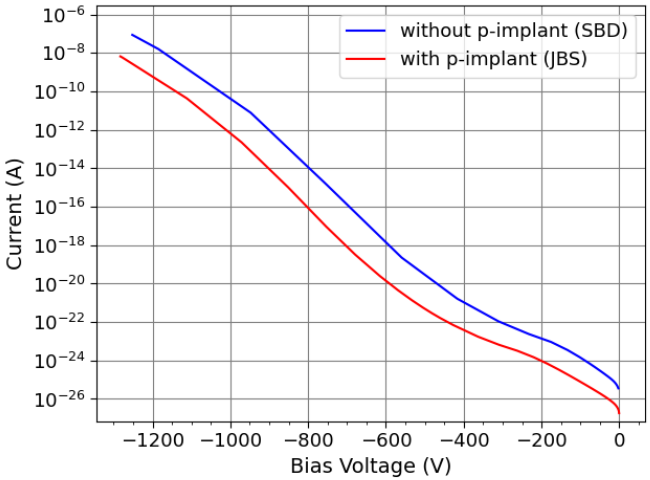


First Simulation Efforts for JBS Diode

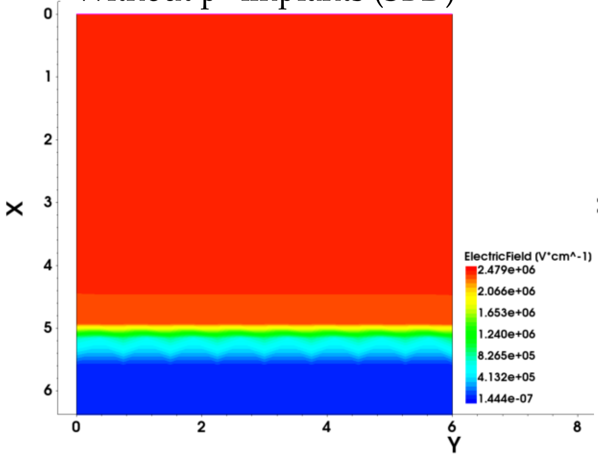
- From SiC Schottky template:
  - Oxide and edge termination removed
  - p^+-implants added
- Electric field lowered at metal-semiconductor interface
- Reduced leakage current



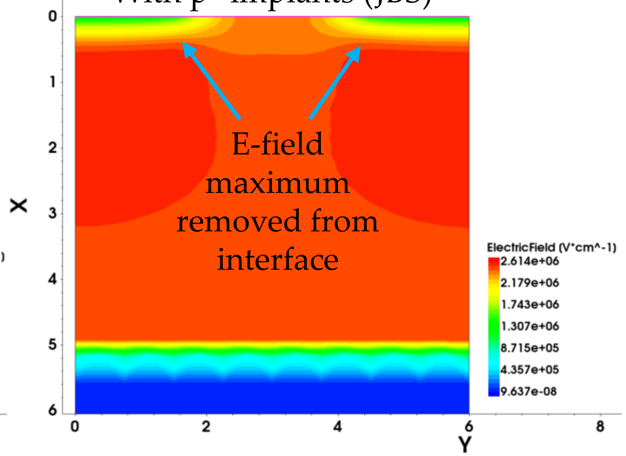




Without p^+-implants (SBD)



With p^+-implants (JBS)



Possible Contributions

- **HEPHY Vienna**: irradiation campaign, lab measurements, test beam @ Medaustron, TCAD simulations
- **INFN Perugia**: TCAD simulation, lab measurements
- **FBK**: production of Schottky and pn-junction 4H-SiC diodes
- **INFIM Romania** (Ioana Pintilie): defect investigations, FTIR and Hall measurements
- **INFN Torino**