# Planar SiC Diodes for Material and Radiation Hardness Studies

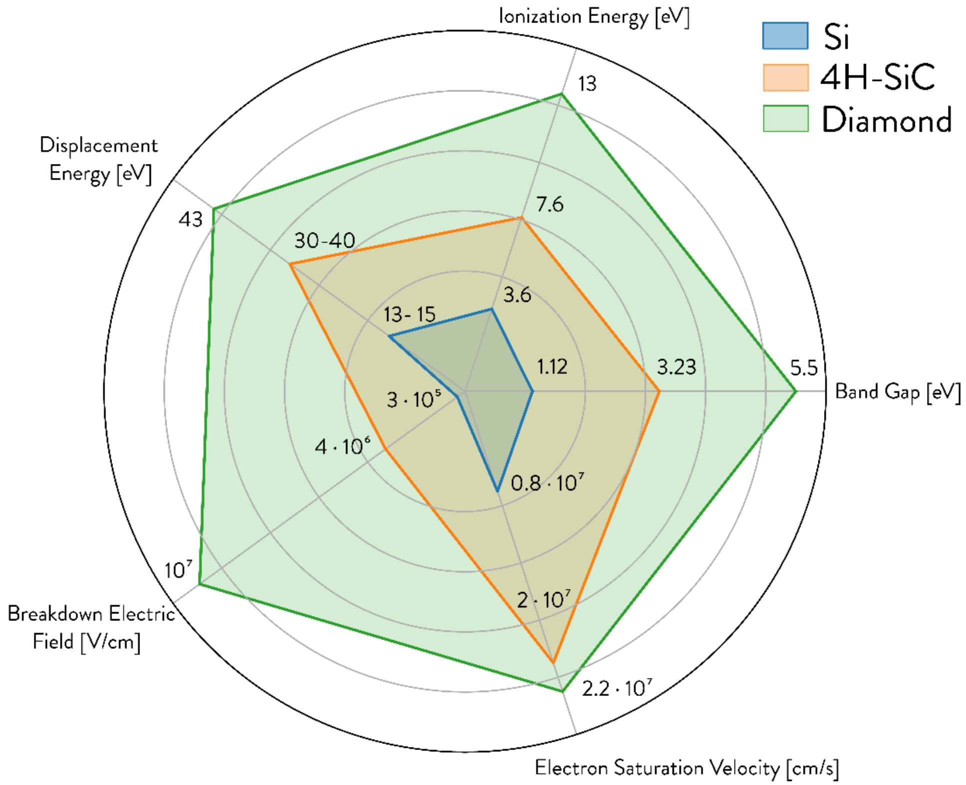
DRD3 WG6 Project Proposal

Sebastian Onder (HEPHY) on behalf of Thomas Bergauer and others

DRD3 Workshop, 5.12.2024

# Silicon Carbide for Particle Detectors

- Wide bandgap material
  - Bandgap between silicon and diamond
  - Low leakage current (pA)
- Features high…
  - Breakdown field & saturation velocity → faster signals → timing
  - Displacement energy → potentially less radiation induced defects
  - Ionization energy → particles deposit less charge
- Insensitive to visible light
- Polytype 4H commonly used
- Received much attention in industrial sector → better accessibility



# 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
  - 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**
  - **Planar Schottky and pn-junction diodes of own design on the mid- to long-term**
  - **Collaborating institutes with DRD3 share lab resources and samples coordinatively**
- **Note: project focus on material study not on design of specific devices**

# Plan/Deliverables: Measurements

- Selection of appropriate samples:
  - Multiple device models, e.g. differing substrate doping, IV/CV characteristics
  - If possible, different manufacturers
  - Many identical samples per combination

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

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

# Plan/Deliverables: Simulation

- Need TCAD design of used devices
- For commercial diodes: TCAD reverse engineering i.e. reconstruction of IV, CV and CCE characteristics
- Additional information available through:
  - SEM, TEM and SIMS measurements for device structuring
  - SPICE models
  - Details or TCAD models maybe offered by manufacturer

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

# Possible Contributions

- **HEPHY Vienna**: irradiation, characterization, test beam @ Medaustron, TCAD
- **INFN Perugia**: TCAD, characterization
- **INFN Torino**: characterization
- **INFIM Romania**: defect investigations, FTIR and Hall measurements
- **FBK**: production of Schottky and pn-junction 4H-SiC diodes

- **We are open for anyone who is interested and wants to participate in any kinds of measurements, simulations or wants to contribute samples to the study!**

- A project proposal document on CDS has not yet been set up

# 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

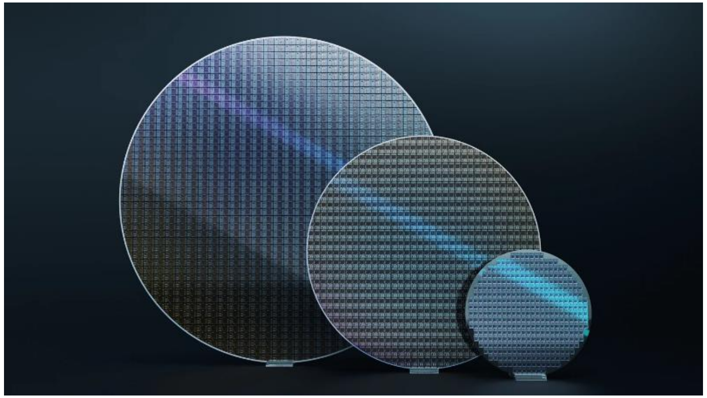
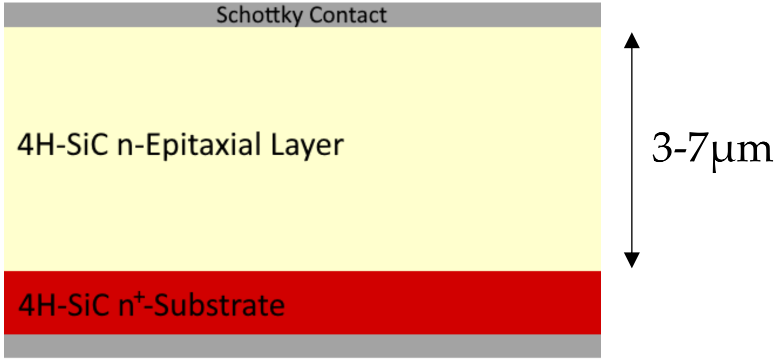


Image from: https://questsemi.com/products/copy-of-copy-of-qs-hcs-6510-650v-10a

- Expected depletion region thickness of 3-7μm

  → 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



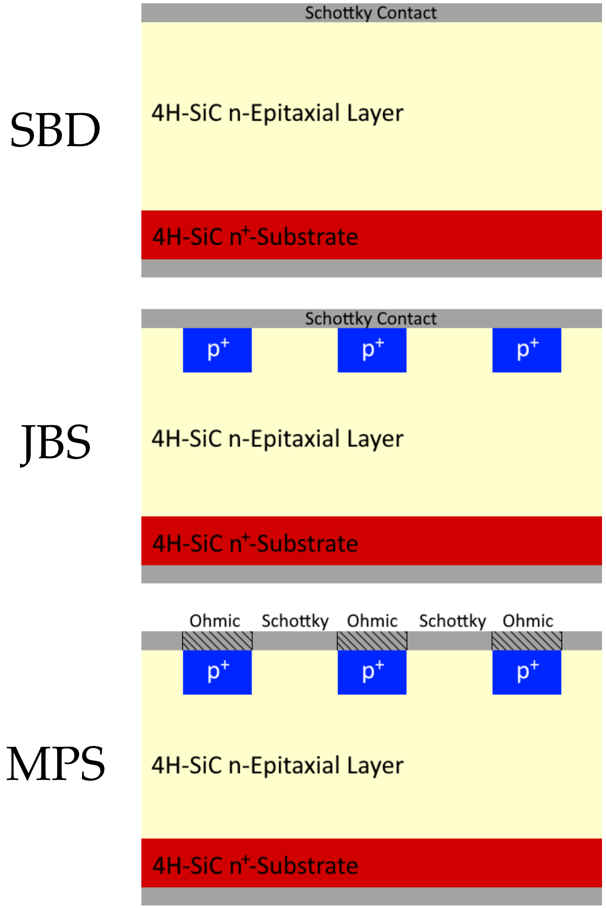
# Types of SiC Schottky Diodes

- 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

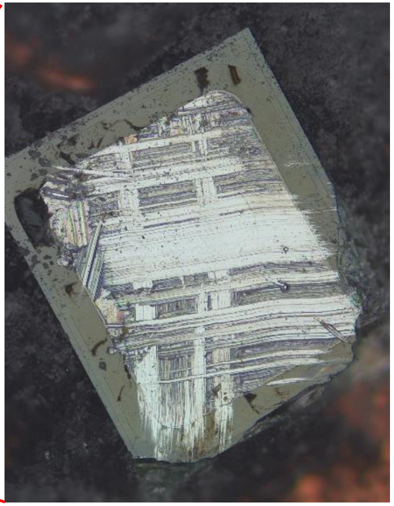


# Availability of Bare Dies

- **For radiation sensing: need for bare dies**
- Several vendors offer bare dies: Central Semiconductor, WolfSpeed, SemiQ, QuestSemi…
- First contact approaches for samples only answered by one company (in progress)

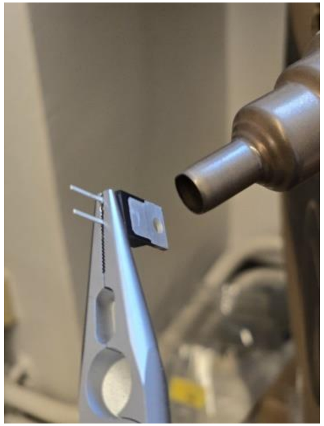
…

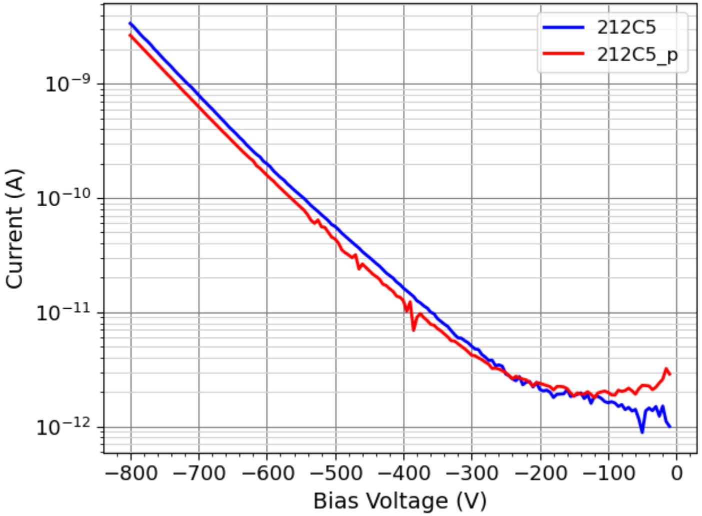
- Workaround 1: open packaged diodes
  – Opening packages is tedious for many samples
  – Destruction-free opening still an open question
- Workaround 2: commercial production run
  – Advantages:
    – Custom structure → easier reverse engineering of TCAD models
    – Diodes tailored for radiation sensing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



# First Efforts with Packaged Diodes

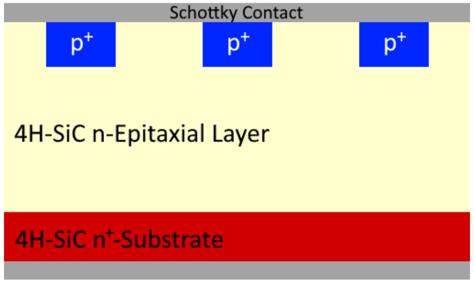
- Packaged Infineon MPS diodes
- Packaged diode opening:
  - Heat package at 650°C for 20-30s
  - Mecanically remove package and filling
  - Yield ~70% at the moment
  - Diodes become slightly more leaky
- Particle detection with alphas planned next

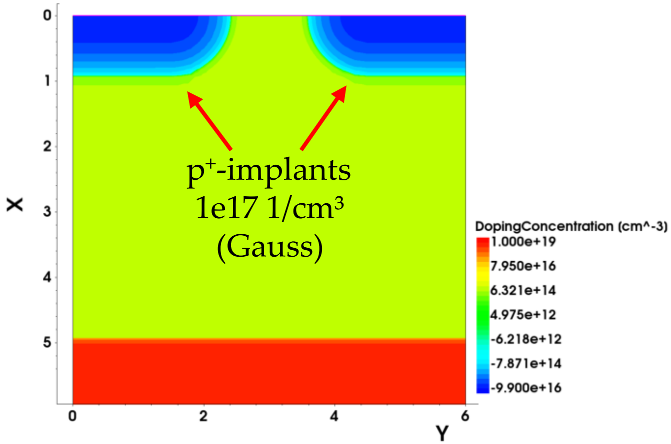


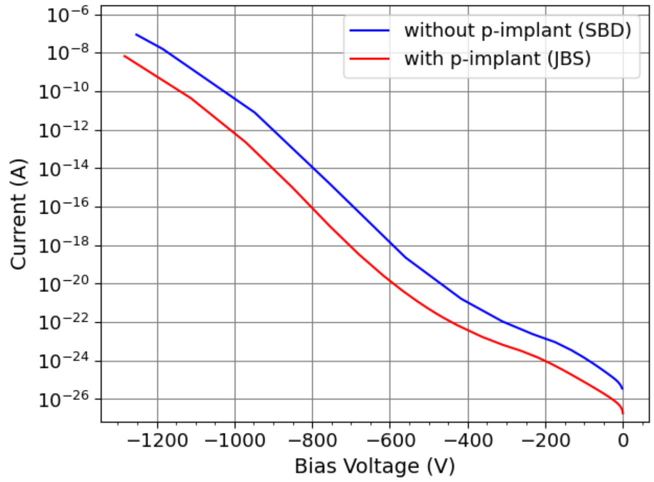


# First Simulation Efforts for JBS Diode

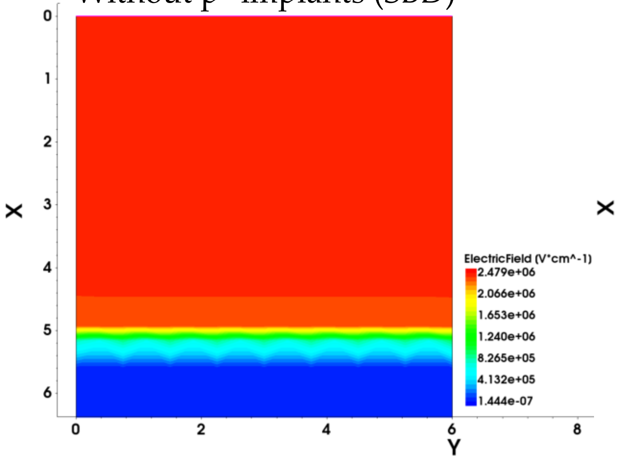
- From SiC Schottky template in Sentaurus TCAD:
  - Oxide and edge termination removed
  - p⁺-implants added
- Electric field lowered at metal-semiconductor interface
- Reduced leakage current



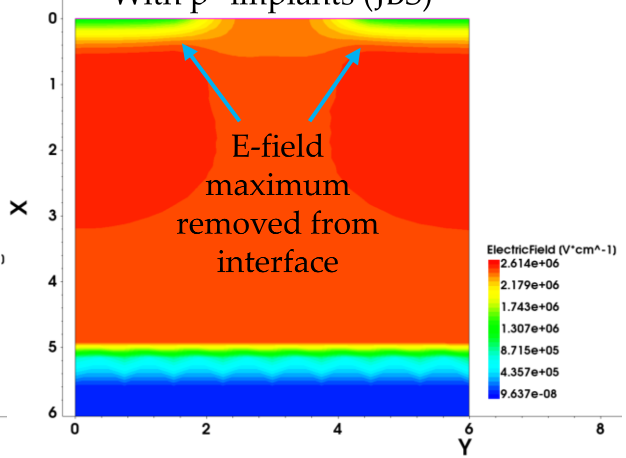




Without p⁺-implants (SBD)




With p⁺-implants (JBS)



# Summary

- Proposal for large-scale irradiation study
  - Large sample size: several identical devices per fluence, particle and device model (100s-1000s in total)
  - Coordinated across several interested institutes in the DRD3 collaboration
  - Project complementary to SiC LGAD development
- Commercial SiC Schottky diodes as short-term solution:
  - Easily accessible in large numbers
  - Thin epi-layers (3-7μm)
  - Getting bare dies not quite as easy as initially thought
- Initial efforts:
  - Opened packaged diodes almost ready for particle detection with alphas
  - TCAD simulations of JBS and MPS diodes ongoing

AUSTRIAN ACADEMY OF SCIENCES

HEPHY INSTITUTE OF HIGH ENERGY PHYSICS

# Thank you

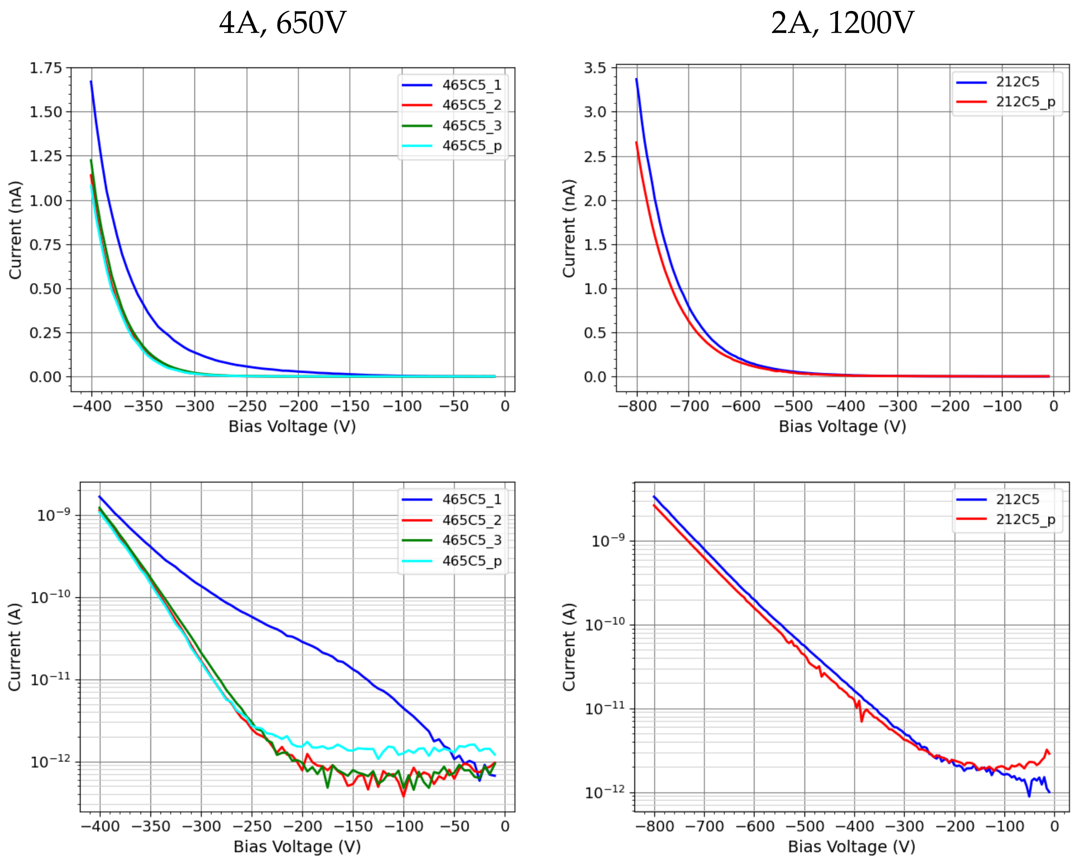
# Back Up

# Opened Diode IV

- Reverse-IV of opened Infineon diodes
  - 3x 4A, 650V aka 465C5
  - 1x 2A, 1200V aka 212C5

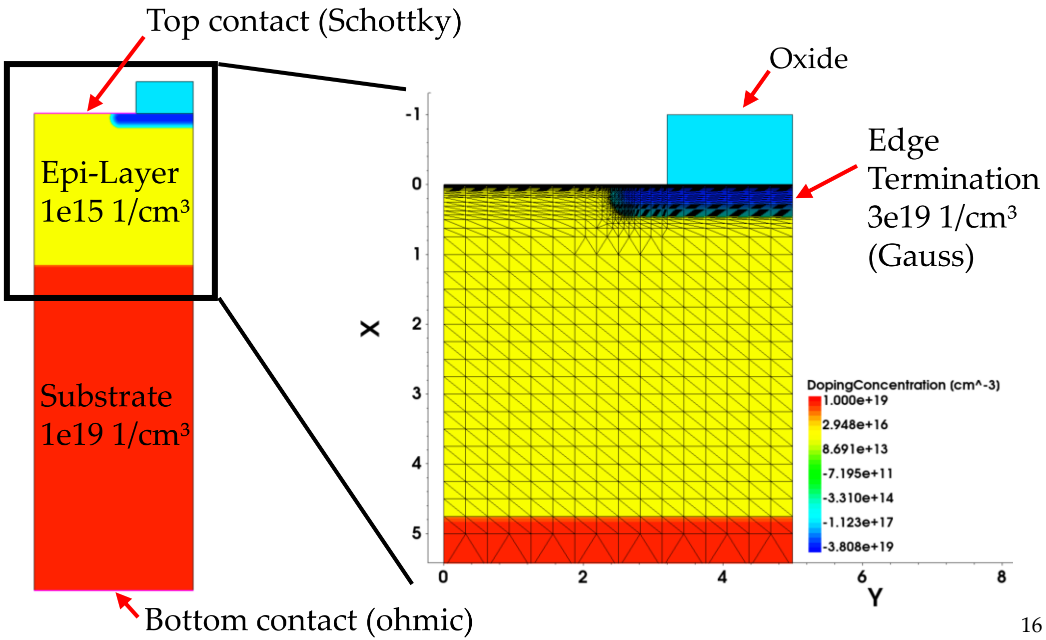
- 465C5_1 is leaky

- Use 465C5_2 and 212C5 for particle detection



# 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)