Measurements and Simulations of Charge Collection Efficiency of p+/n Junction SiC Detectors

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Outline

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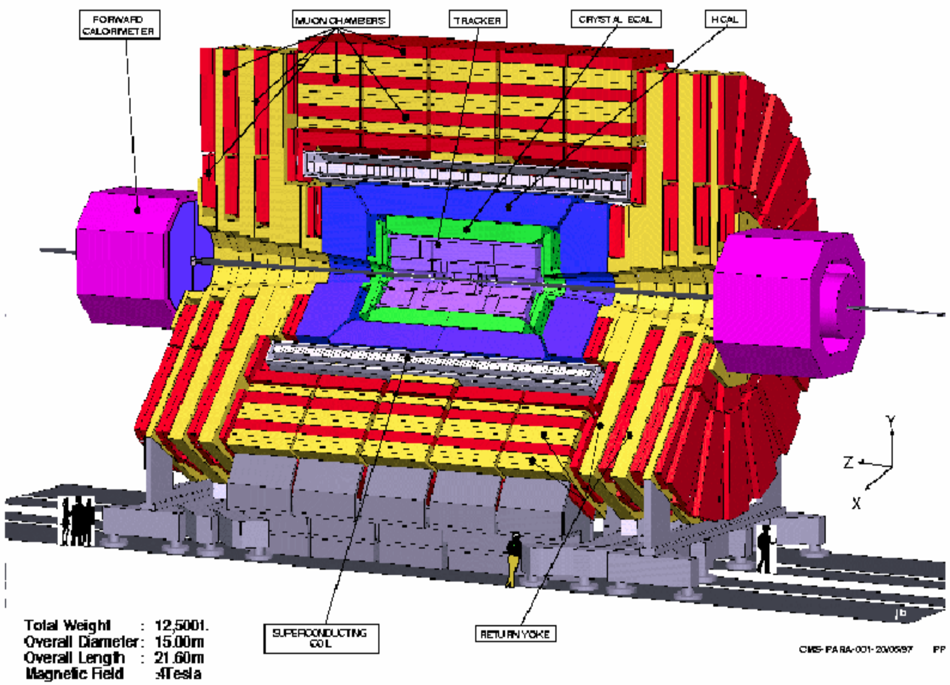
- Technological processes and I/V - C/V measurements on p^+/n diodes
- CCE setup and measurements
- Modeling of SiC detectors
  – Motivations and simulation tool
  – Results
- Conclusions

Introduction



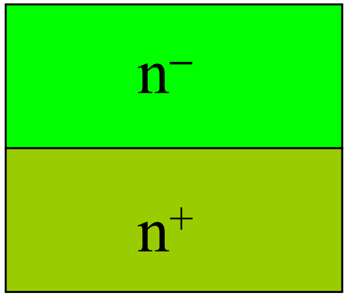
- Large Hadron Collider (LHC) experiment (upgrade)
- Fast hadron fluences above 10^{16} cm^{-2} (after 10 years)
- Current <u>silicon technology</u> is unable to cope with such an environment
  - Unreachable full depletion voltage
  - Very high leakage current
  - Poor charge collection efficiency

Silicon Carbide

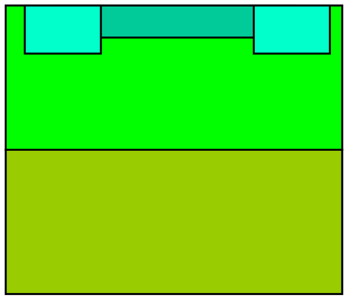
- large E_g (3-3.3 eV) → very low leakage current
- MIP (Minimum Ionizing Particle) generates 55 e/h pairs per μm
- radiation hardness (?) (high atomic binding within the material)
- high quality crystals now available
- Schottky barrier detectors have been studied as α-particle detectors (100% of charge collection efficiency (CCE))*
- complex radiation detectors → an integrated electronic readout on board of the detector chip. p/n junctions are needed

* F. Nava, et al. , IEEE Transactions on Nuclear Science, Vol. 51, No. 1 (February, 2004).

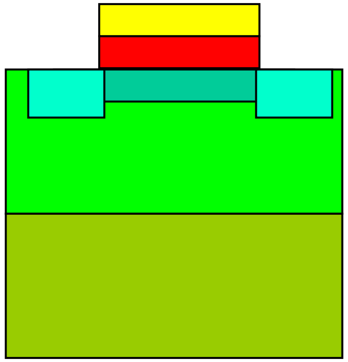
SiC Process: p^+/n



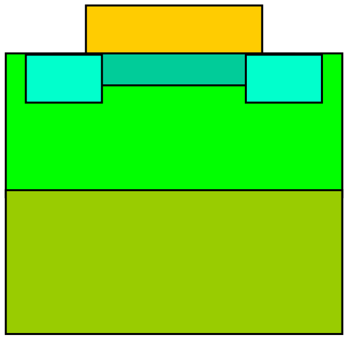
Epi (40 μm) doping:
1×10^{15} cm^{-3}



Ion implantation
Al^+ @ 300°C
Annealing 1650°C 30 min
p^+ doping (0.4 μm)
= 4×10^{19} cm^{-3}
p^- doping (0.6 μm)
= 5×10^{17} cm^{-3}



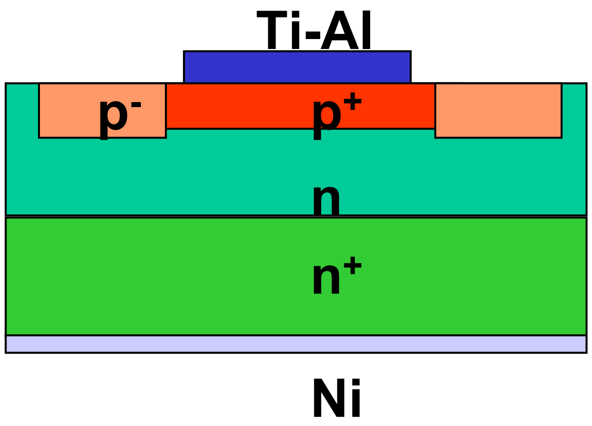
Al (350 nm) /
Ti (80 nm)
deposition

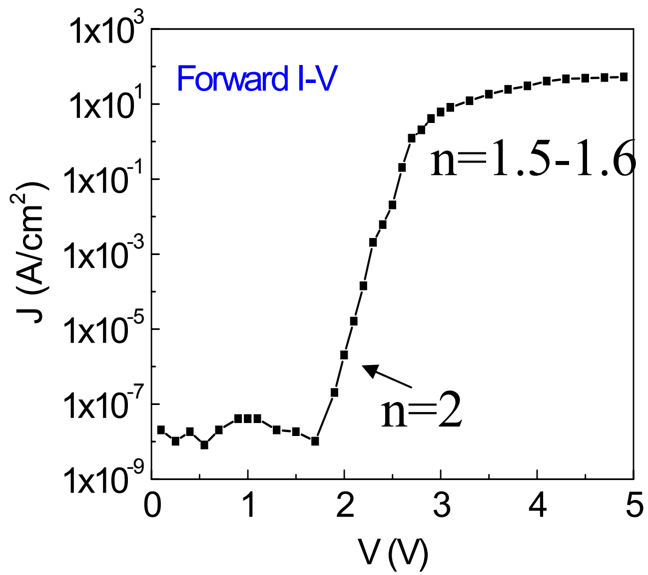


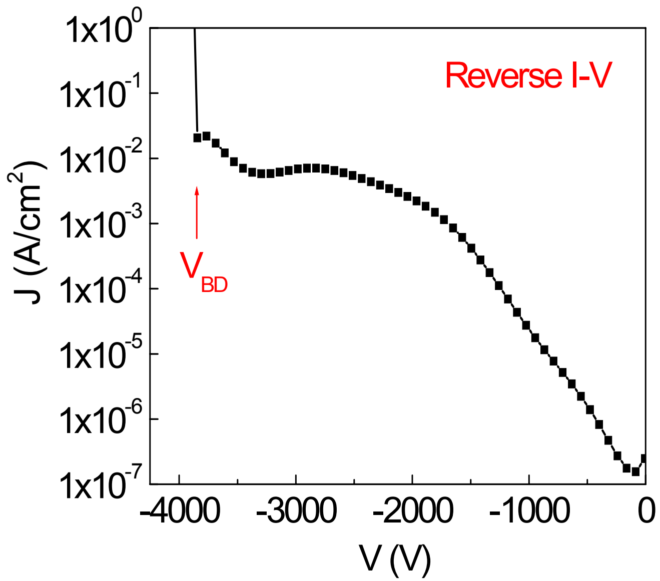
Annealing 1000°C
in vacuum 2 min

I-V measurements on p^+/n diodes

In collaboration with INSA-CEGELY, Lyon France







- 75% of diodes have good I-V curves
- V_{BD} is about 4 kV
- Theoretical limit for this device: 5 kV

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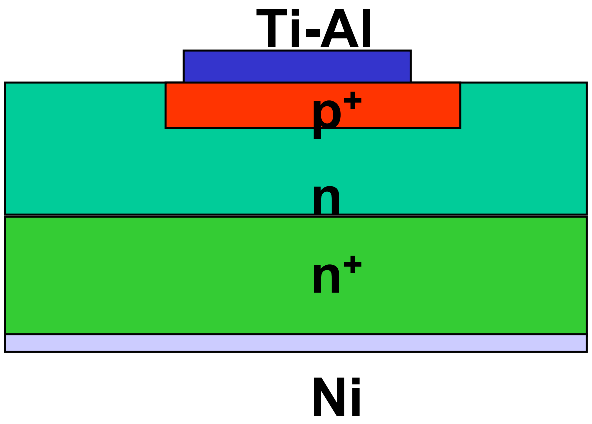
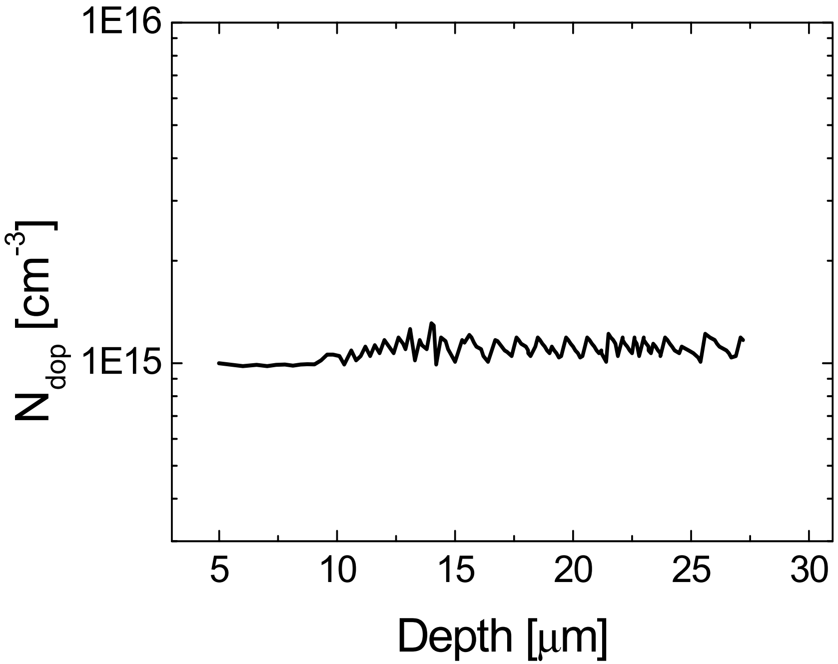
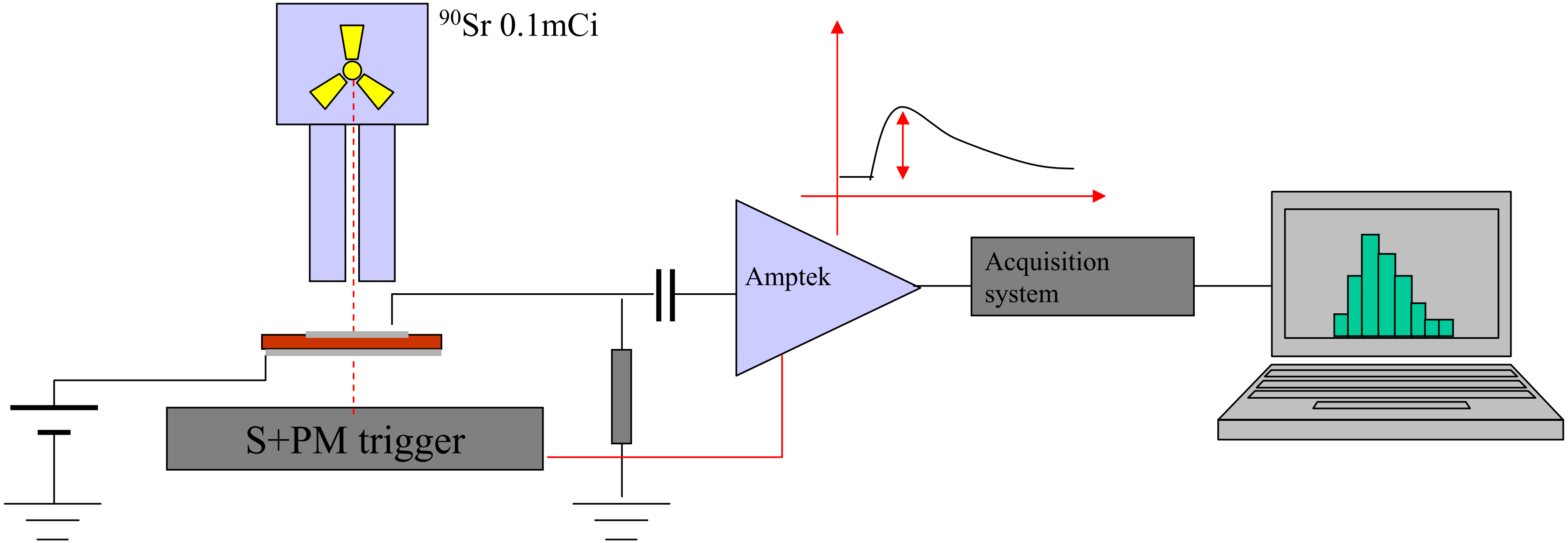
CV measurements





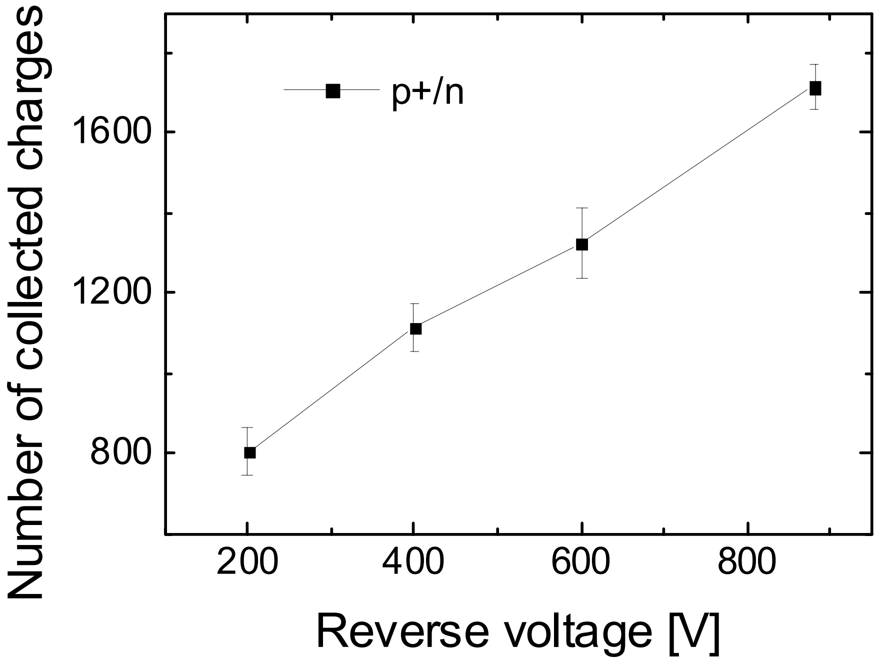
- Epi doping (1.1×10^{15} cm^{-3}) confirmed

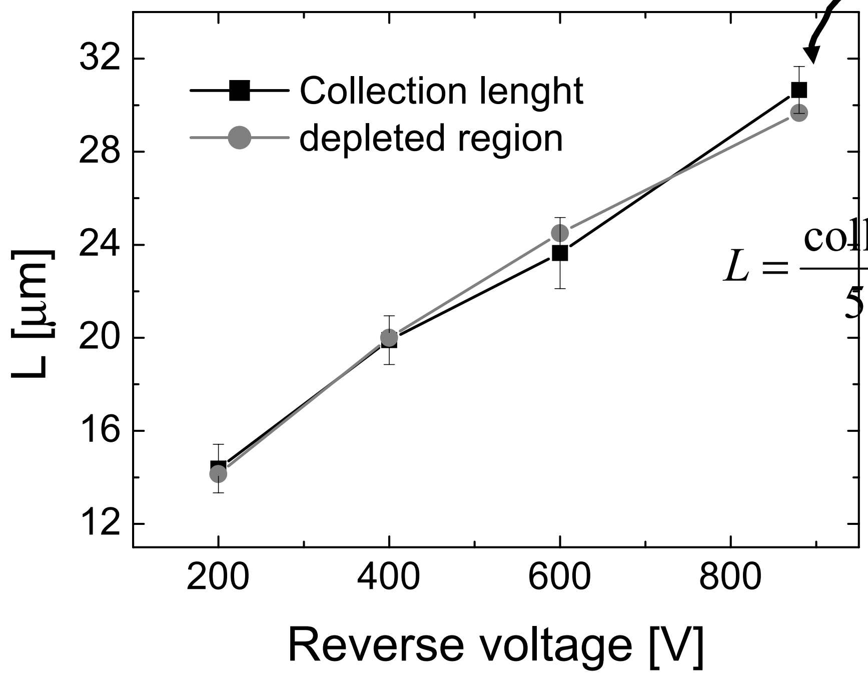
CCE measurements setup



CCE measurements

- Measurements on p+/n diodes: epi 1.1.10^{15} cm^{-3} 40 μm,
- Max. applied voltage: 900V (30 μm depleted). V_{dep} (from theory) =1600V





$$L = \frac{\text{collected charge}}{55\ \text{pairs}/\mu\text{m}}$$

- 100% collection efficiency in the 30 μm deep depleted region using measured lengths of depleted region

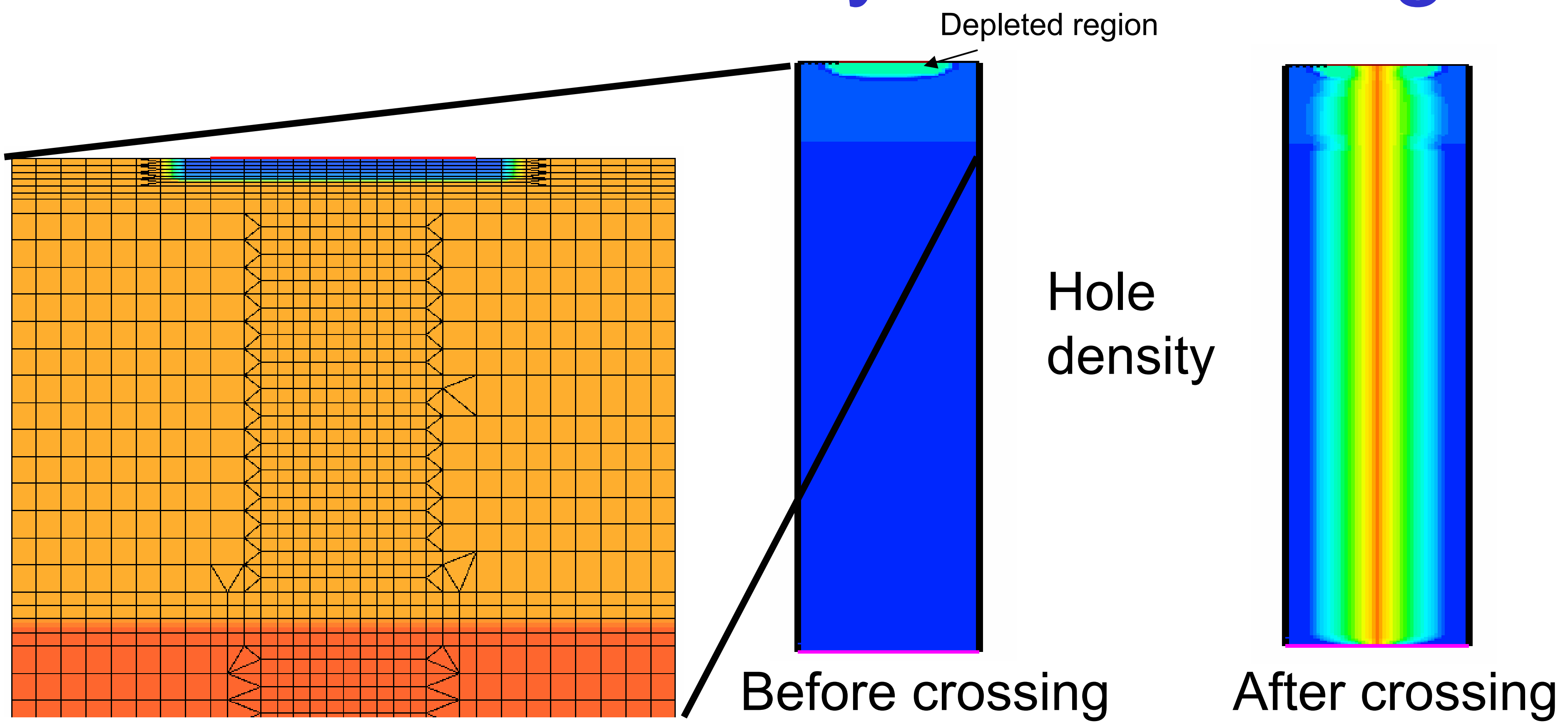
Motivations for simulation

- Very high cost of SiC wafers
- Trade off between SiC wafer quality and available budget
- Suitability of device simulation for design optimization
- Introducing traps, we will be able to analyze which defects are important to decrease the CCE

Simulation Tool

- DESSIS ISE-TCAD
  - Discrete time and spatial solution to the fundamental semiconductor equations
  - **6H-SiC model available**

Grid and Heavy Ion crossing



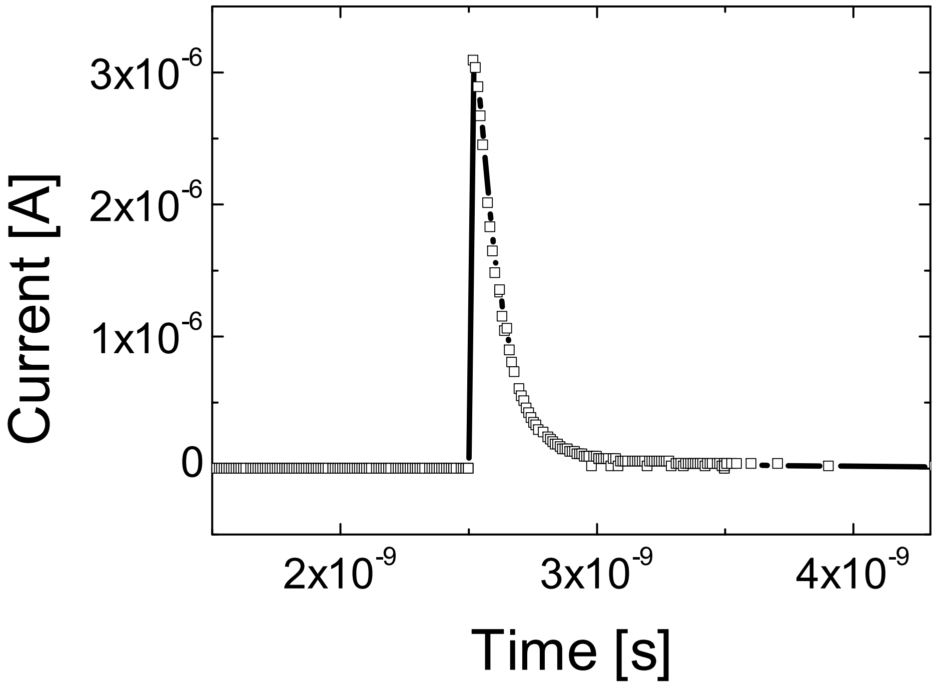
Heavy Ion crossing modeling available within DESSIS ISE-TCAD

p^+/n diode output signal

- Collected Charge

$$CC = \int_0^t I \cdot dt$$

- Particle crossing at 2.5 ns



epi doping (40 μm) = 10^{15} cm^{-3}
p^+ doping (0.45 μm) = 4×10^{19} cm^{-3}

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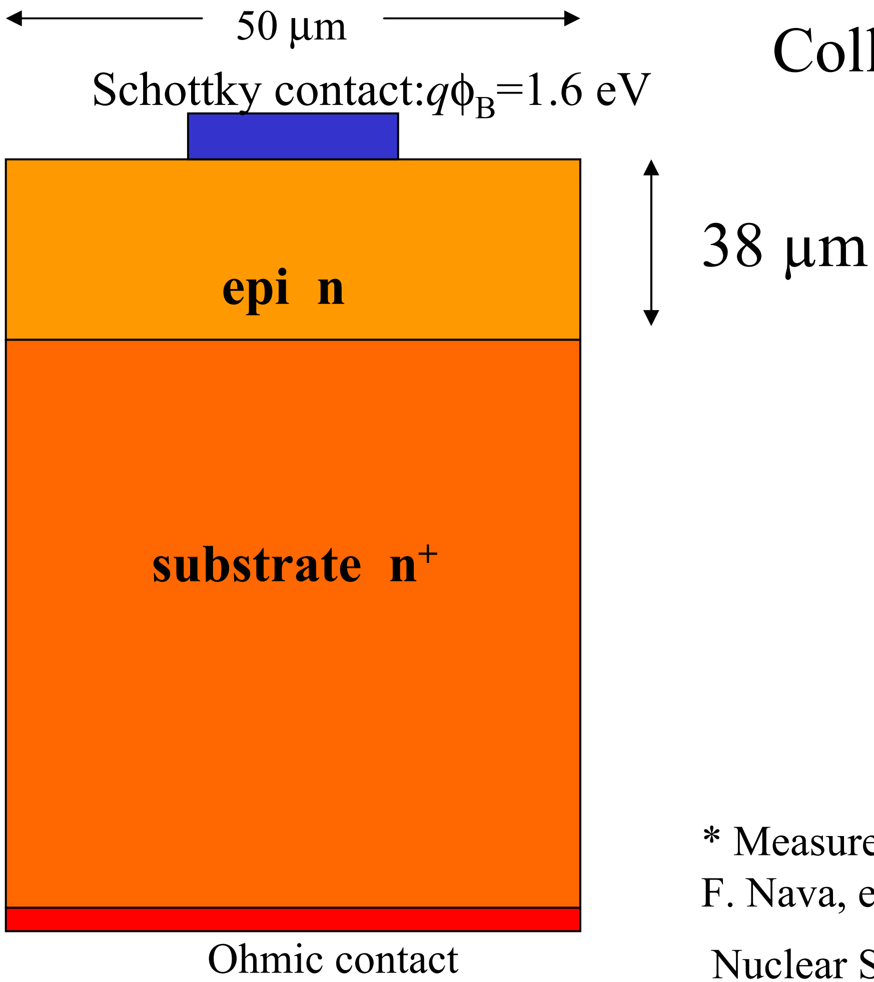
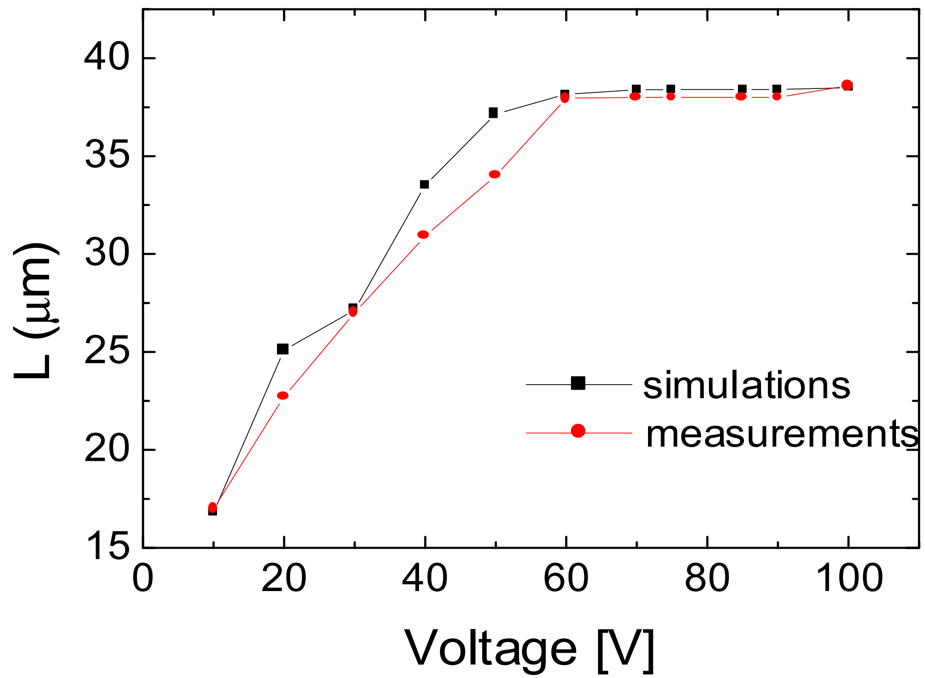
Simulations of CC of Schottky diodes

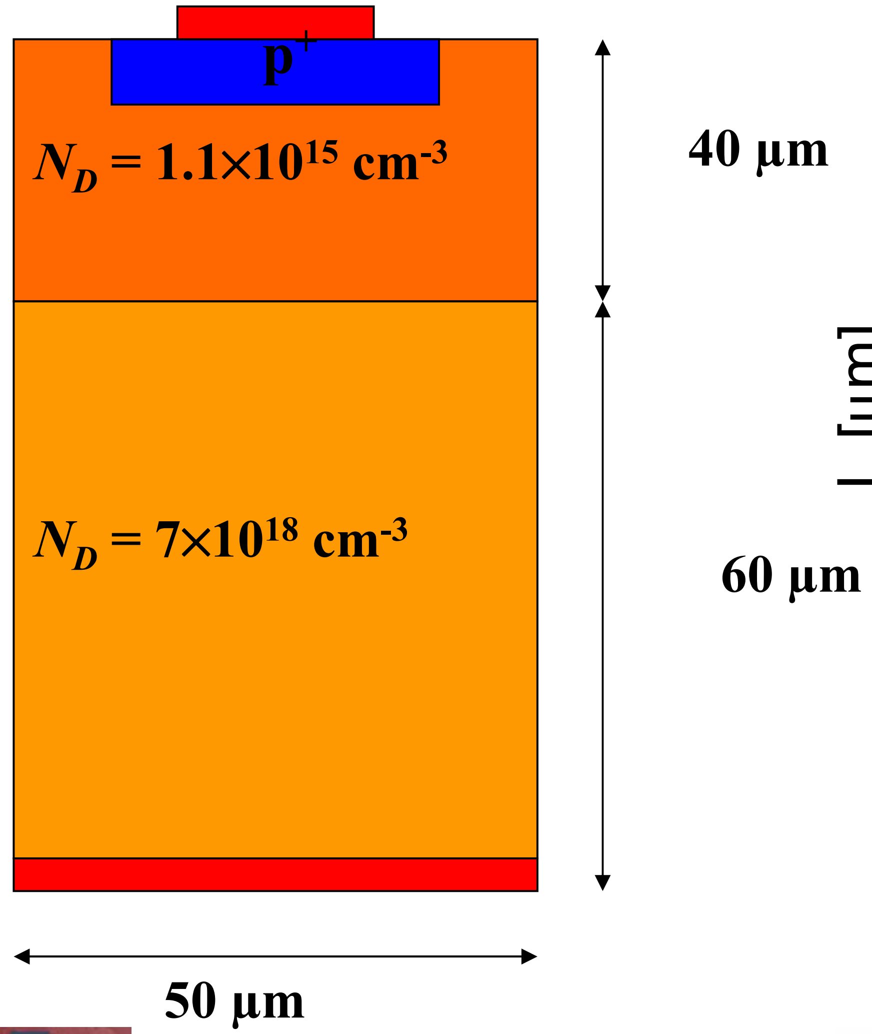


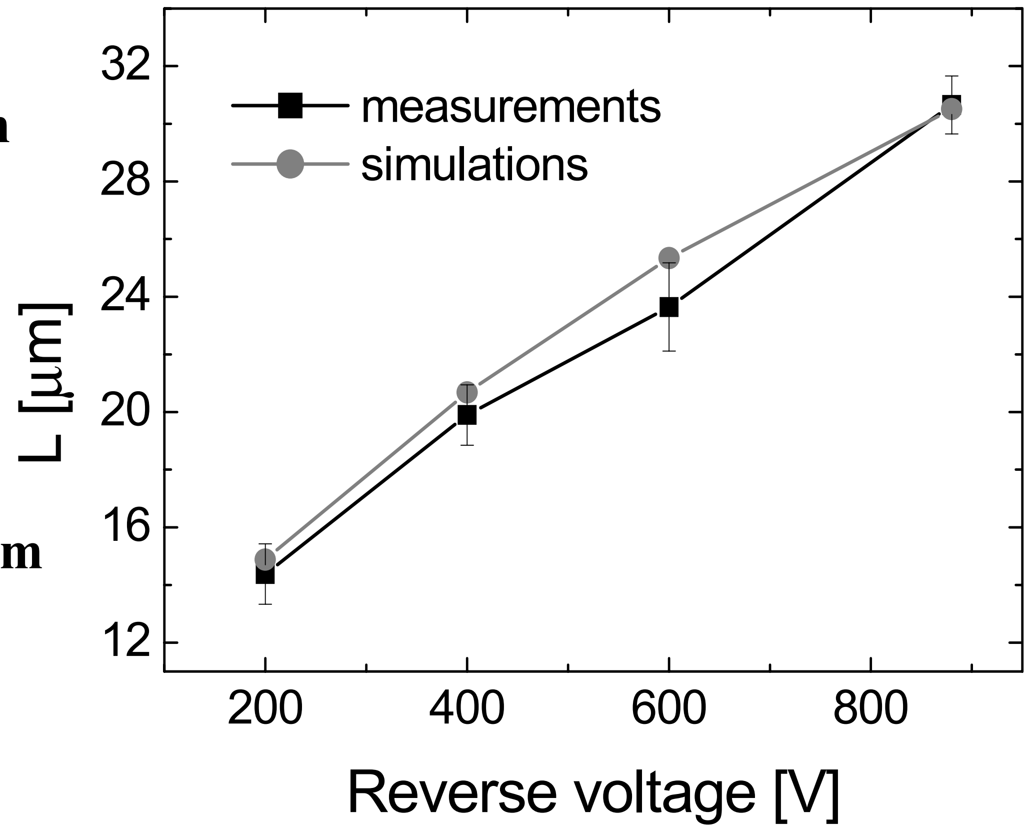
Collection length (^{90}Sr source, β particles)



* Measurements from:
F. Nava, et al. , IEEE Transactions on
Nuclear Science, Vol. 51, No. 1 (February, 2004).

Simulations of CC of p^+/n diodes





CCE experimental results are well reproduced

Conclusions

- p^+/n junctions have been realized and electrically characterized. Good forward and reverse characteristics have been obtained
- First CCE experimental results on SiC pn junctions: 100% collection efficiency in 30 μm using measured lengths of depleted region
- Development of a simulation model for SiC to obtain good agreement with CC measurements on Schottky and p+/n SiC diodes

Future developments

- Radiation hardness will be verified.
- New SiC detectors will be realized taking into account the simulation results.
- Using DLTS measurements and simulations, we will be able to analyze which defects are important to decrease the CCE