Centro Nacional de Microelectrónica CSIC

Development of SiC sensors for harsh environment applications

S. Otero Ugobono, P. Godignon, G. Pellegrini, J.M. Rafí Tatje, G. Rius Suñé

Centro Nacional de Microelectrónica, IMB-CNM-CSIC, Barcelona, Spain

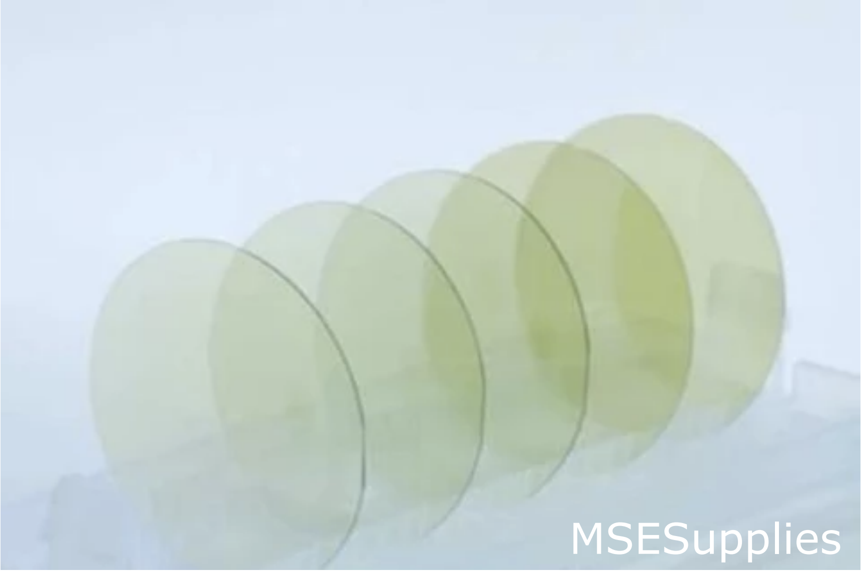
Silicon Carbide (SiC)

Material properties and benefits

- Wide band gap material
- Low leakage current even after irradiation
- High breakdown voltage
- Possibility to work at room temperature after irradiation
- High saturation velocity
    - Potential for timing applications

Properties	Si	4H-SiC
Crystal Structure	Diamond	Hexagonal
Energy Gap : E_G (eV)	1.12	3.26
Electron Mobility : μ_n (cm^2/Vs)	1400	900
Hole Mobility : μ_p (cm^2/Vs)	600	100
Breakdown Field : E_B (V/cm) $X10^6$	0.3	3
Thermal Conductivity (W/cm°C)	1.5	4.9
Saturation Drift Velocity : v_s (cm/s) $X10^7$	1	2.7
Relative Dielectric Constamt : ε_S	11.8	9.7

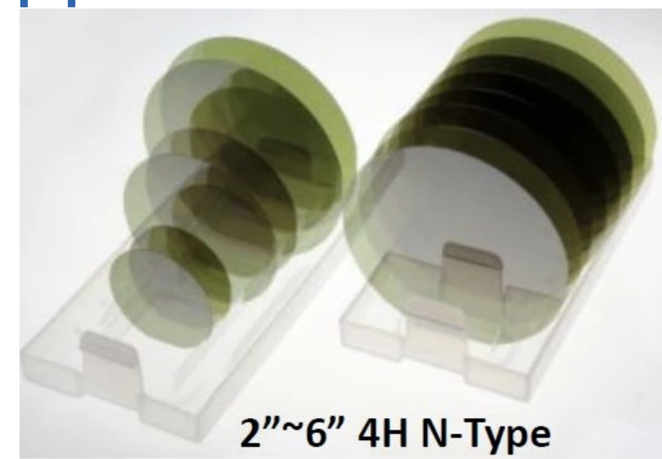
ROHM, *SiC Power Devices White Paper*



Potential for fabrication of 3D detectors and other MEMS structures.

Current status of SiC technology

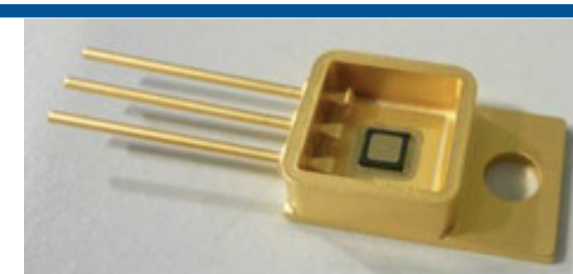
- SiC technology is fully developed for commercial applications
  - High quality 4- and 6-inch SiC wafers available
  - Sought after for power electronics
  - Diodes have been successfully developed

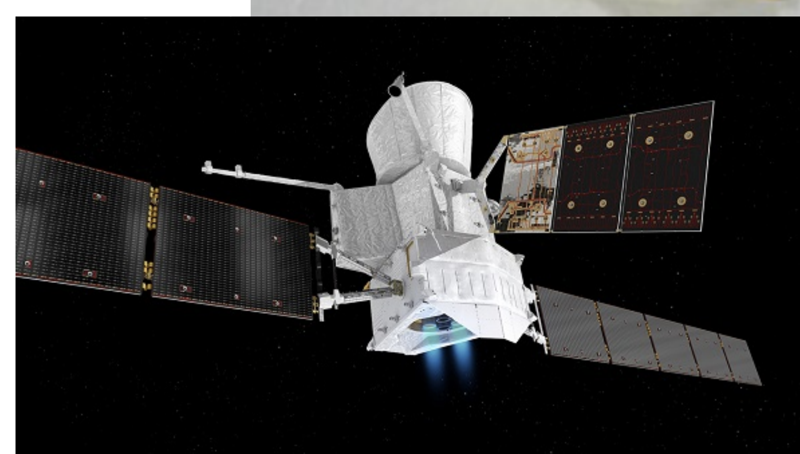


CNM, ALTER, Universitat de València

BepiColombo space mission

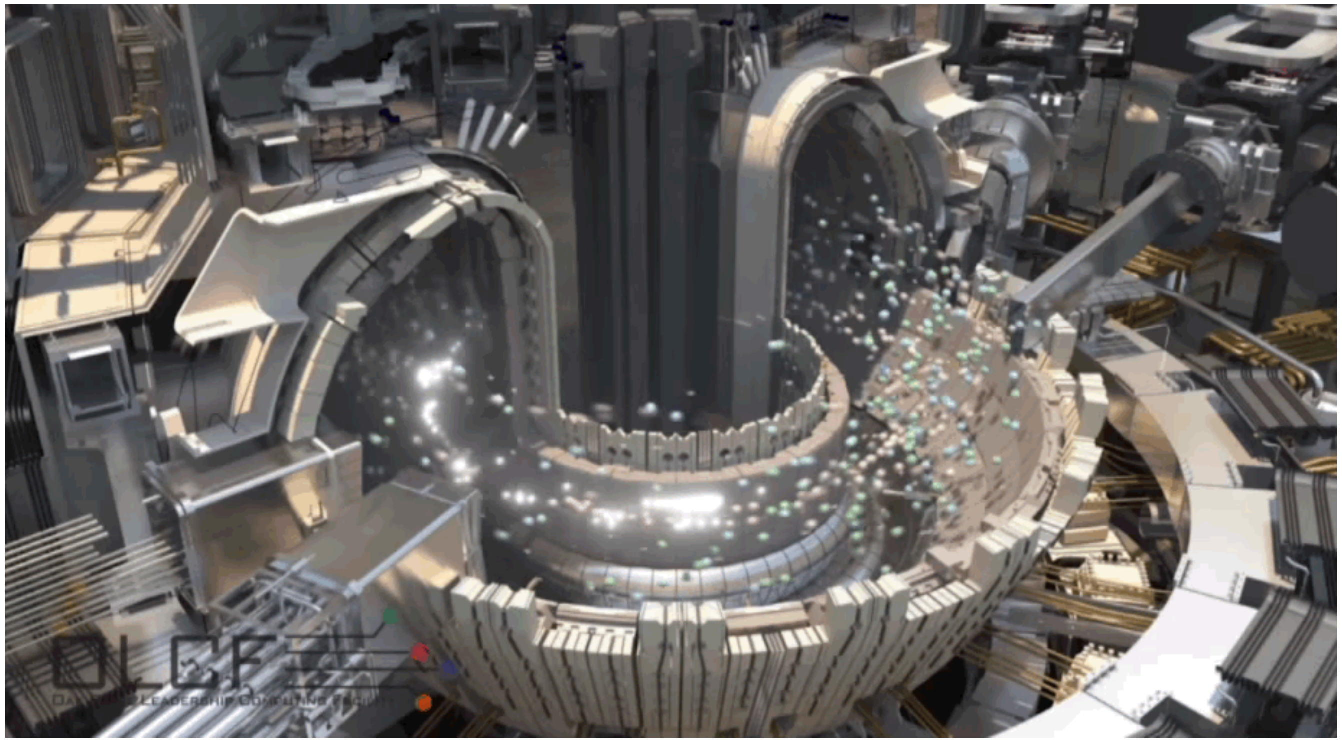
- Protection diodes for solar arrays
- Working temperature range -170ºC to 300ºC
  - Stable with thermal cycling
- High reliability and radiation hard





P. Godignon et al., ISPSD Hiroshima, 2010, pp. 351-354

Main potential applications



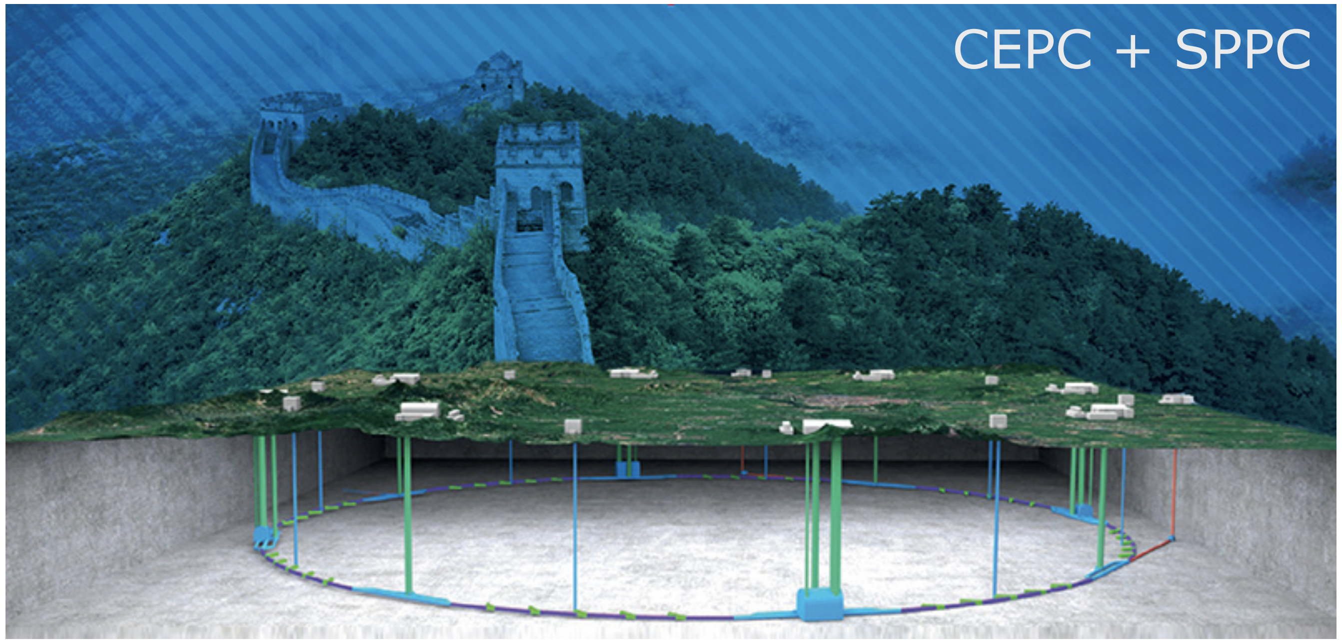
Nuclear fusion reactors

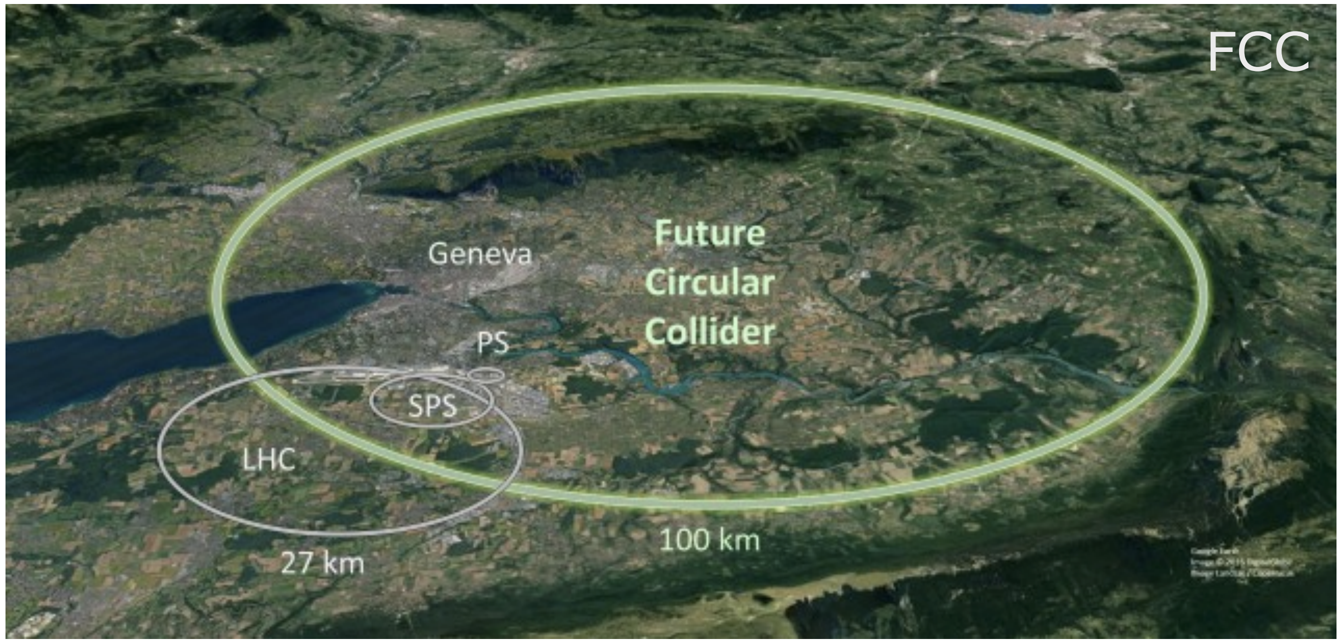
- Neutron diagnostics.

Aerospace

- Sensors and electronics.

Main potential applications





High energy physics

- Sensors for large colliders

Planar Devices

GRACE Project

Graphene-enhanced Radiation detector on Silicon Carbide for harsh Environments

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Unión Europea
Fondo Europeo de Desarrollo Regional
"Una manera de hacer Europa"
Project funding reference: RTC-2017-6369-3

Institutes and people involved

ALTER

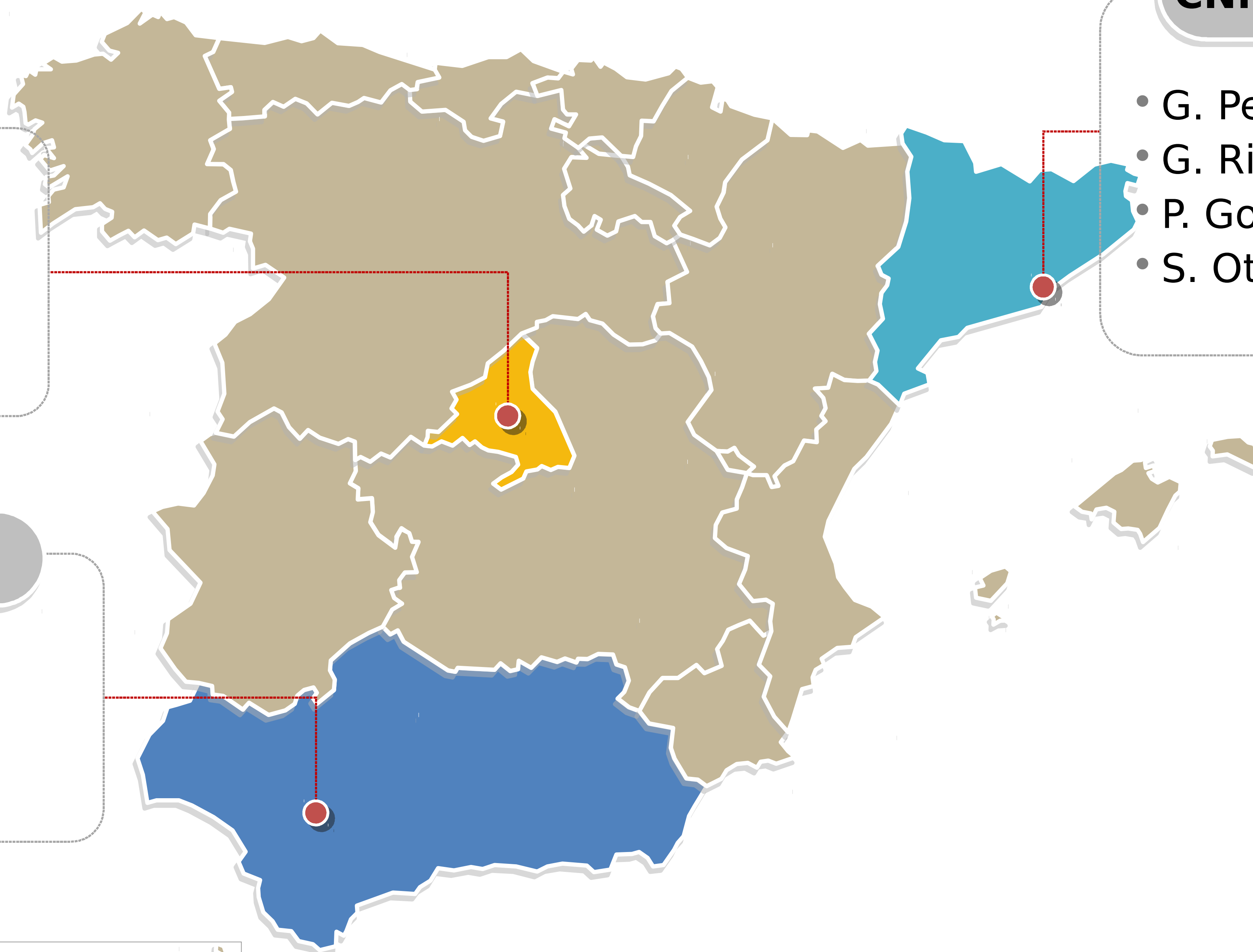
- J. Moreno
- D. López
- E. Cordero

CNA-CSIC

- M. C. Jiménez Ramos
- J. García López

CNM-IMB-CSIC

- G. Pellegrini
- G. Rius Suñé
- P. Godignon
- S. Otero Ugobono



GRACE Project

Graphene-enhanced Radiation detector on Silicon Carbide for harsh Environments

Main target applications:

- Plasma diagnosis in fusion reactors (e.g. ITER)
- Monitoring and control of high-temperature-operation components in spacecrafts

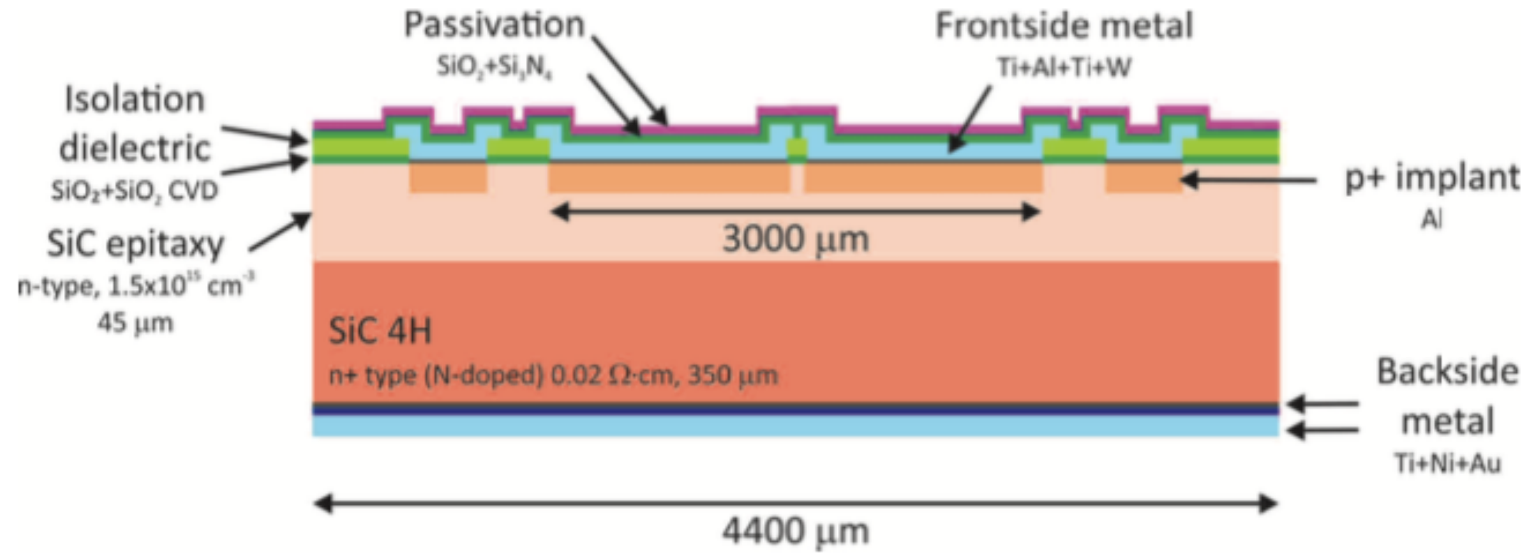
GRACE Project

Graphene-enhanced Radiation detector on Silicon Carbide for harsh Environments

Devices tolerant to

- **High radiation levels:** neutrons, protons, heavy ions, α-, and β-particles.
- **High temperatures:** at least [200ºC, 500ºC].

Cross section of a *conventional* 4-quadrant SiC sensor



J.M. Rafí et al., 2018 JINST 13 C01045

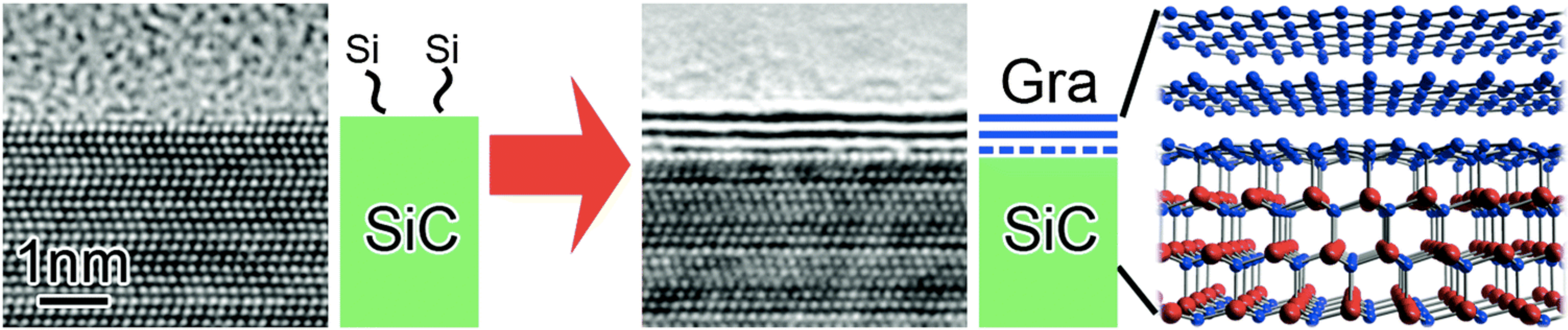
Graphene-enhancement

- Graphene layer between SiC surface and metallisation
- The metallisation may be removed altogether
  - Useful for heavy-ion detection
- Graphene could potentially improve
  - SiC-metal electrical contact
  - Thermal management

Epitaxial graphene technology

Graphenisation: epitaxial growth of graphene layers

- Thermal decomposition of SiC surfaces
  - Selective sublimation of atomic silicon
  - C atoms rearrange into a honeycomb structure



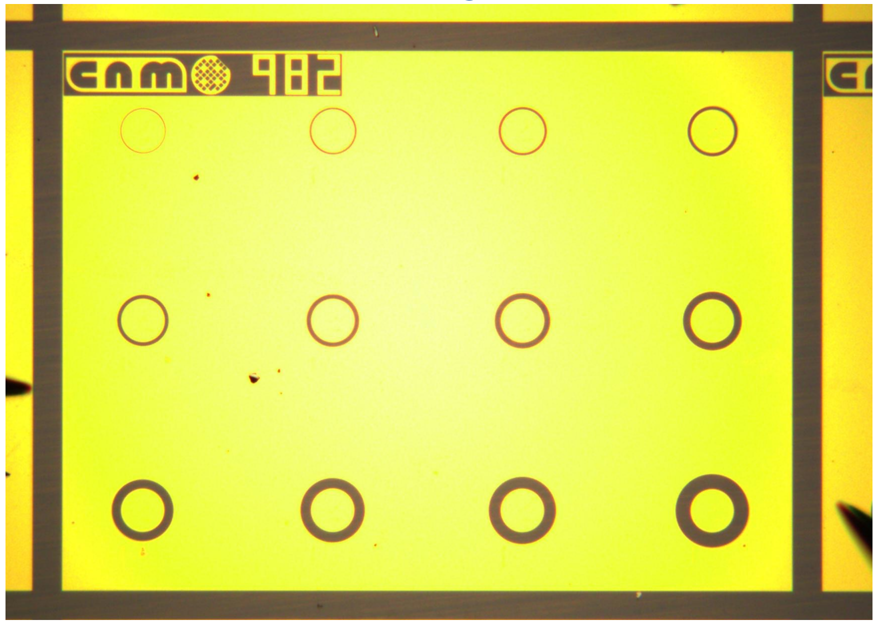
W. Norimatsu et al., Phys. Chem. Chem. Phys. 2014,16, 3501-3511
G. Rius, P. Godignon, Epitaxial Graphene on Silicon Carbide: Modelling, Devices, and Applications, Pan Stanford Pte. Ltd. (2018)

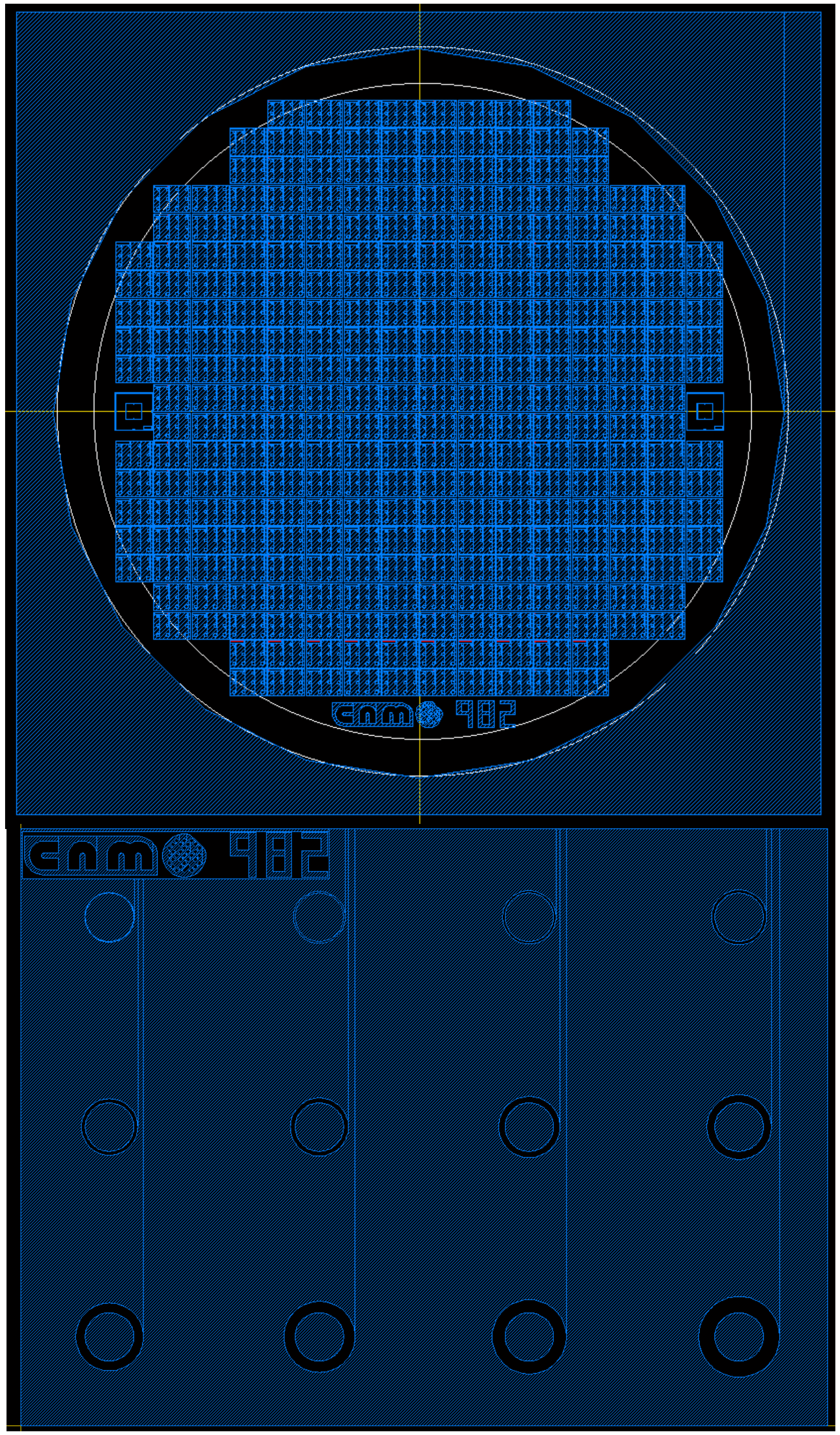
Graphenisation a.k.a. graphitisation

Current work plan at CNM

Optimisation of various contact configurations

- Contact, and sheet resistivity study
- Testing of different metal combinations
- Effect of graphene in overall conductivity
- Radiation hardness
- Tolerance to high temperatures
- Wire-bond reliability

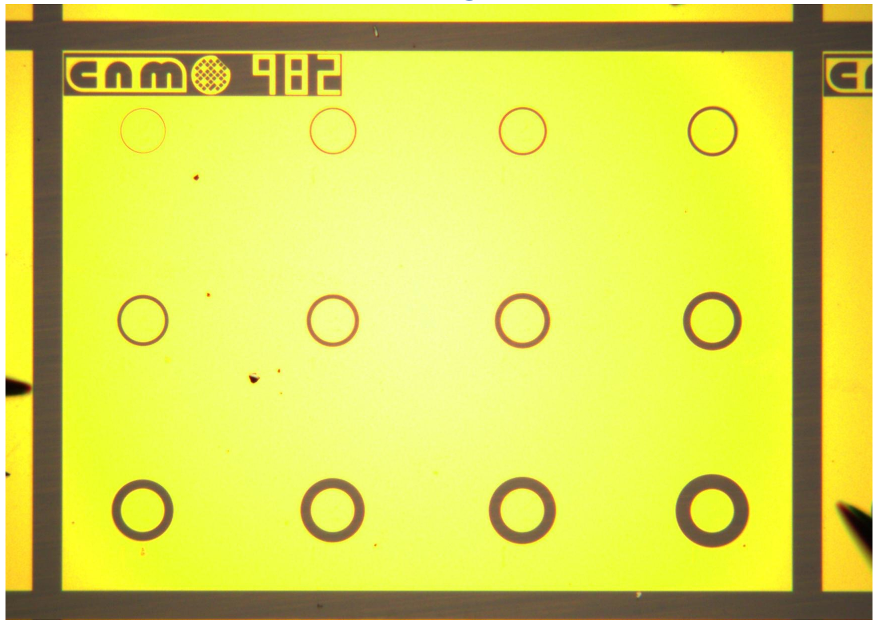


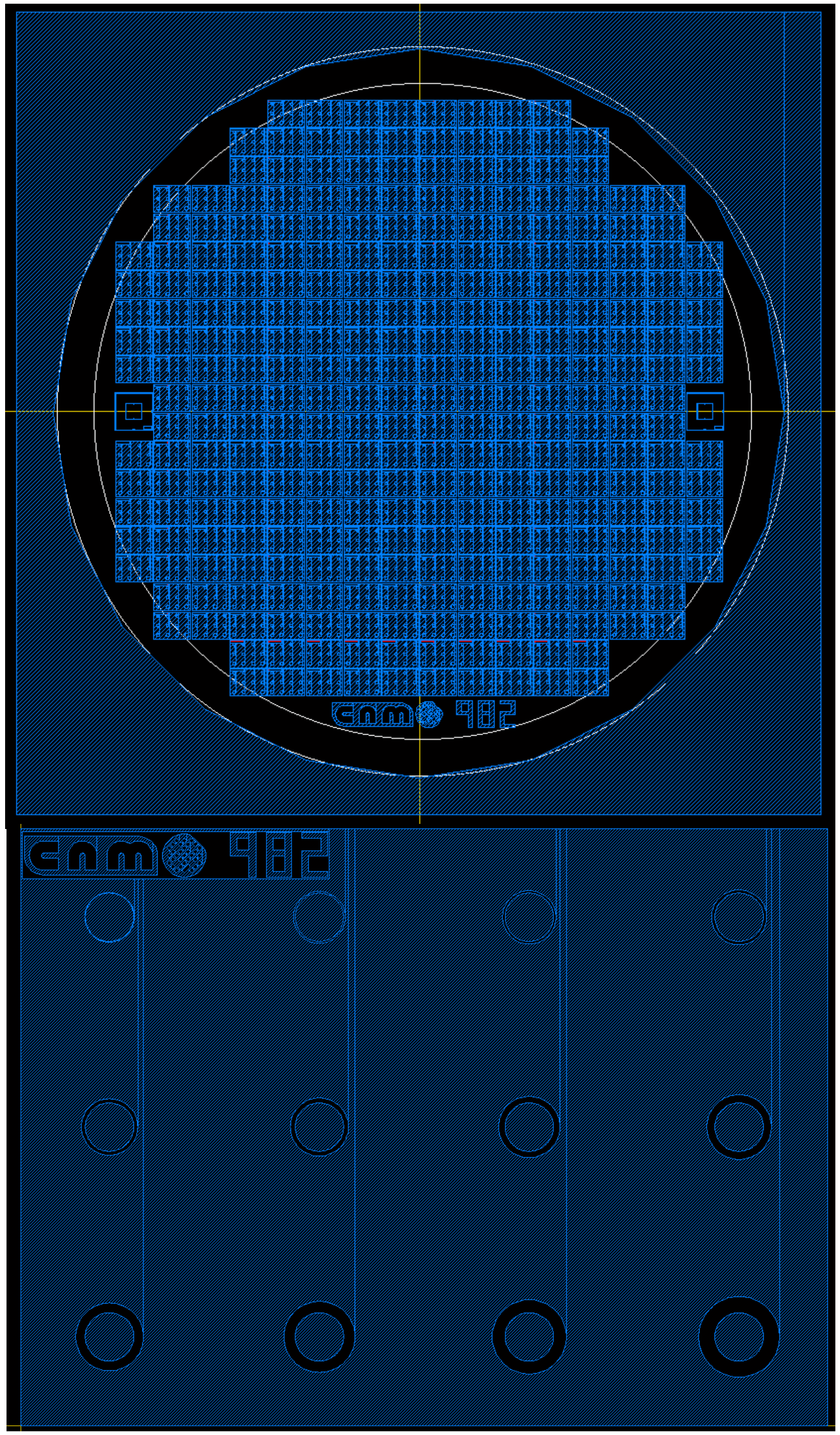


Current work plan at CNM

Optimisation of various contact configurations

- Contact, and sheet resistivity study
- Testing of different metal combinations
- Effect of graphene in overall conductivity
- Radiation hardness
- Tolerance to high temperatures
- Wire-bond reliability





Future work

- **Design and development of sensor prototypes**
- **Full characterisation to determine sensor viability:**
  - electrical properties
  - charge collection efficiency
  - tolerance to high temperatures
  - tolerance to temperature fluctuations (thermal cycle tests)
  - endurance limit (mechanical stress)
- **Irradiation campaigns**
- **Package design and development**
- **Device simulation**

3D Devices

RD50 Project on SiC

Proof of concept of 3D detectors fabricated in Silicon Carbide (SiC) semiconductor layers

- **Explore an innovative method to produce 3D SiC sensors:**
  - Doping-selective electrochemical etching.

RD50 Project funding reference: RD50-2019-02

Institutes and people involved

JSI
- G. Kramberger

PSI
- M. Camarda
- M. Carulla Areste

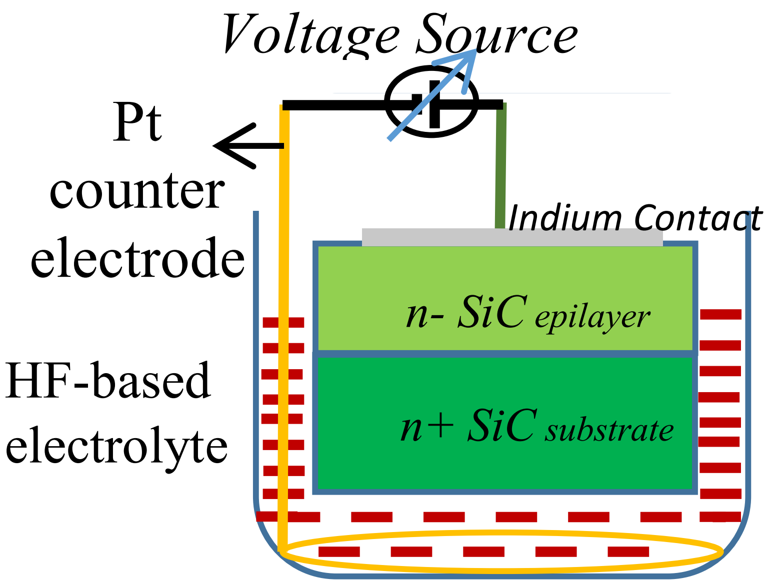
CNM
- G. Pellegrini
- G. Rius Suñé
- P. Godignon
- J.M. Rafí Tatjer
- S. Otero Ugobono

IFAE
- S. Grinstein

IFCA
- I. Vila Álvarez

Doping-selective electrochemical etching

Basic etching mechanism:



- Carried out in an electrochemical cell
- The SiC is dipped in a solution of HF
- An electrical current is applied to the SiC
- Two-step process:
  - Oxidation of the SiC (current + electrolyte solution)

$$SiC + 2H_2O + 4h^+ \Rightarrow SiO + CO\uparrow + 4H^+ \quad (1)$$

$$SiC + 4H_2O + 8h^+ \Rightarrow SiO_2 + CO_2\uparrow + 8H^+ \quad (2)$$

  - Oxide is removed by HF (electrolyte solution)

$$SiO_2 + 6HF \Rightarrow 2H^+ + SiF_6^{2-} + 2H_2O \quad (3)$$

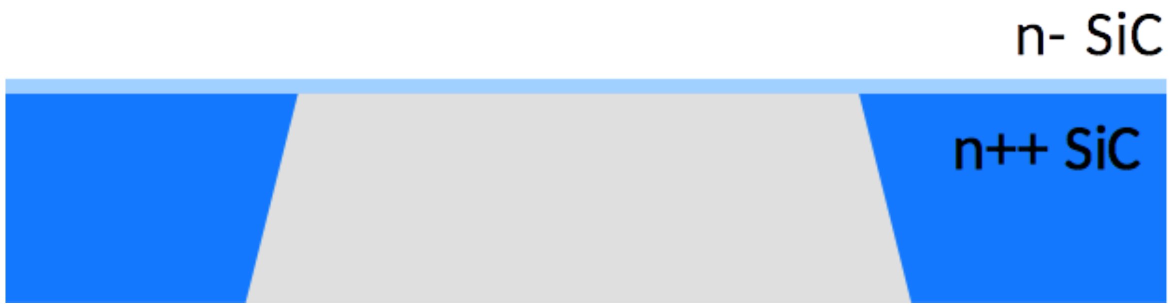
HF: hydrogen fluoride

S. Nidaet al., J. Synchrotron Rad. (2019) 26, 28-35
S. Rysy et al., J Solid State Electrochem (1999) 3: 437-445
R. Dahal et al., Materials Science Forum (2017), 897, 379–382

Doping-selective electrochemical etching

Process already applied for thin epitaxial membrane fabrication

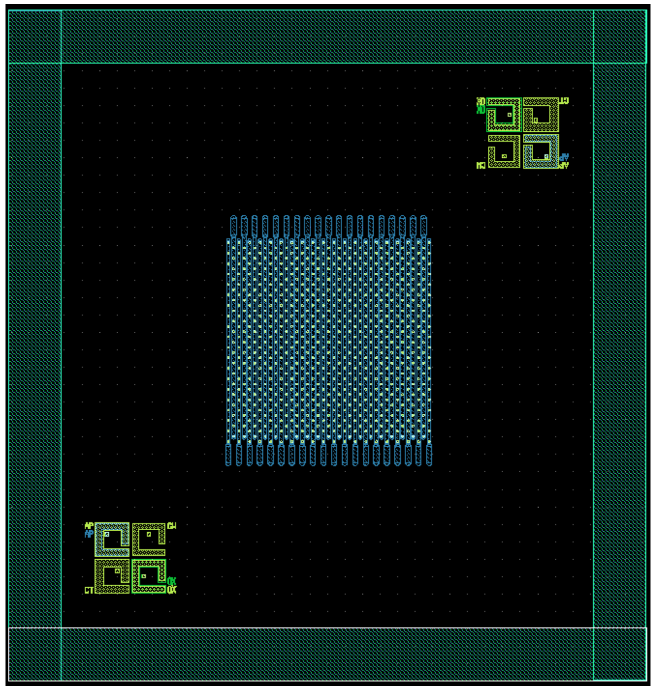
- Electrochemical etching of highly doped 4H-SiC substrate

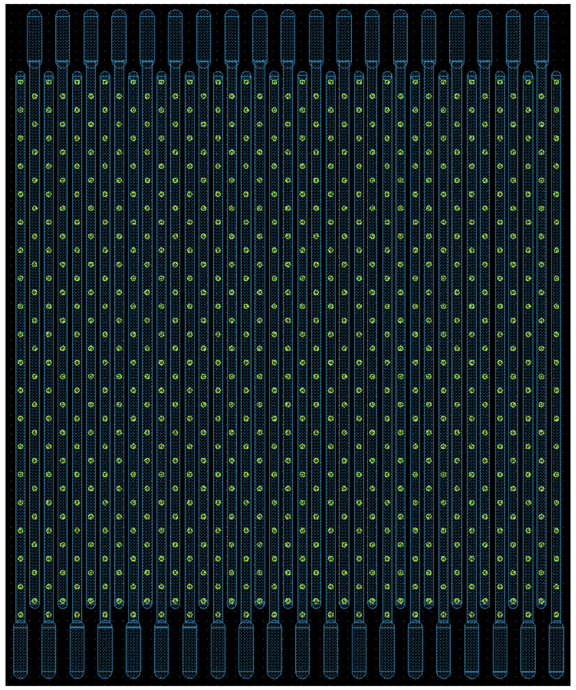


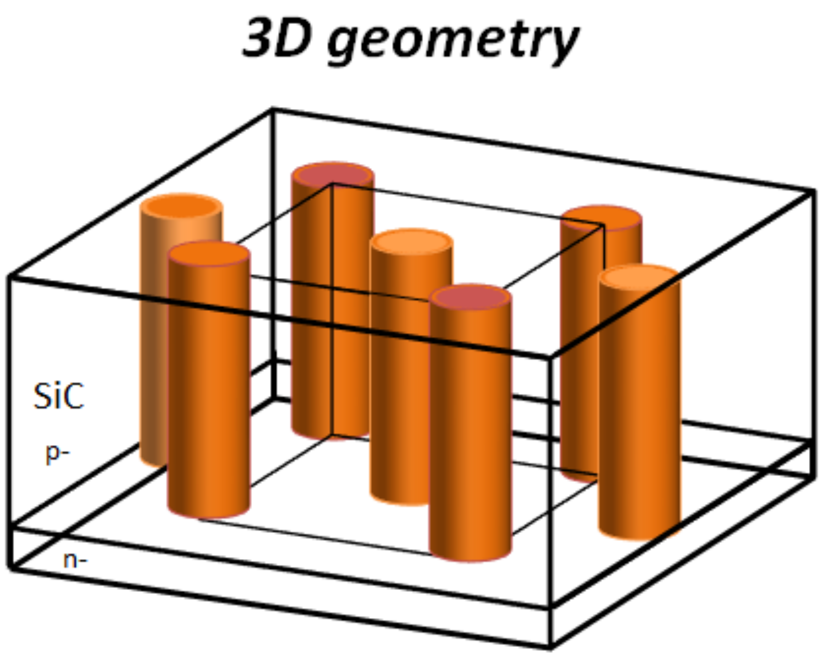
PSI, only!

up to 200um/h
doping selective

- Adaptation and optimisation of the etching process for production of columnar electrodes







Work plan

- **Explore the feasibility of the fabrication process**
- **Creation of Schottky contacts** inside the columns through metal sputtering
- **Irradiation campaigns and full characterisation:**
  - Electrical tests (CV/IV)
  - TPA and blue-laser TCT
  - Timing tests

Summary

- **SiC technology already fully developed for commercial applications**
- **CNM is developing innovative SiC sensors for harsh-environment applications**
- Architectures under study: **planar and 3D**
- Work under way on both projects

Summary

- **SiC technology already fully developed for commercial applications**
- **CNM is developing innovative SiC sensors for harsh-environment applications**
- Architectures under study: **planar and 3D**
- Work under way on both projects
- **Looking for collaborators for defect studies**

Summary

- **SiC technology already fully developed for commercial applications**
- **CNM is developing innovative SiC sensors for harsh-environment applications**
- Architectures under study: **planar and 3D**
- Work under way on both projects
- **Looking for collaborators for defect studies**

- **Interested in this technology for your experiment?**

Thank you very much for your attention