Discussion
Defect Characterization

Defect and Material Characterization

- **Collaboration on "acceptor removal"** in p-type Si: Bucharest, CERN, Minsk, Hamburg, CiS formed (TSC, DLTS, HRTEM, PL)
- **project**: *Schottky diodes on Epitaxial Silicon for Radiation Damage Characterization of CMOS MAPS* : (RAL, Giulio Villani)

Defect and Material Characterization

- ## Main activities

  - Detection and microscopic characterization of standard and material engineered silicon via dedicated techniques (DLTS, TSC, TDRC, SIMS, ICP-MS, PITS, FTIR, TCT, EPR, HRTEM, PL, fluorescent centers ?)
  - Identification of electrically active defects induced by irradiation responsible for trapping, leakage current, change of Neff , change of E-Field
  - Studying possible application for radiation hardening
  - Deliver input for device simulations (e.g. TCAD) to predict detector performance under various conditions

- ## Milestones [2018-2022]

  - WP 1.1 Electrically active defects in p-type silicon [7 MS]

  - WP 1.2 Microstructural Investigations on extended and clustered defects [4 MS]

  - WP 1.3 Theory of defects and defect kinetics modeling [5 MS]

WP 1.1. Electrically active defects in p-type silicon

M2: Determine defect annealing behaviour in STFZ and engineered silicon. Correlation with device performances (**Q4/2019**)

M3: Determine defect transformations and kinetics in STFZ and engineered silicon after treatments at high temperatures (between 150 °C and 350 °C). Correlation with the device performance (**Q3/2020**)

M4: Identify the role of impurities in the formation of defects impacting on device performance **(Q1/2021)**

M5: Detection/characterization of radiation induced defects in LGAD and HV-CMOS (test structures fabricated through the RD50-2021-04 common project) via sensors based on STFZ and defect engineered p-type silicon, establish the annealing behavior (annealing at 80°C), correlation with electrical performance of the devices **(Q3/2021)**

M6: Validity tests on optimized material engineered sensors (pads, LGADs and HV CMOSs). Comparison between prediction and experiments (Q1/2022)

M7: Validity tests on finally optimized material engineered sensors (pads, LGADs and HV CMOSs) (Q3/2023)

WP 1.1. Electrically active defects in p-type silicon

Status: **As irradiated – several type of diodes (FZ, CZ, EPI), several type of irradiations (e, n, p)**

- High fluences (CV, IV, TSC and HRTEM):
    - STFZ, EPI and CZ PiN diodes, different resistivities, CERN, Hamburg and Bucharest
    - HRTEM on highly neutron irradiated samples (10^{17}cm^{-2} and 10^{19}) (done in Bucharest)
    - LGADs – by TSC (still ongoing)
- Low fluences (CV/IV and DLTS):
    - electron irradiated EPI PiN diodes (Minsk, CERN and Hamburg) (ongoing)
    - neutron and proton irradiated EPI, CZ and FZ PiN diodes (CERN, Hamburg and Bucharest)
    - DLTS on LGADs not work – PiN samples mimicking the gain layer might be a good solution for characterizing the gain layer

Annealing studies (DLTS, TSC, HRTEM)

- at 60 / 80^0 C – TSC, partly done for hadron irradiation (EPI 50 ohmcm at Hamburg), DLTS (Bucharest and CERN); at T > 150 C – done on electron irradiated samples (DLTS, Minsk), on proton and neutron irradiated PiN samples in Bucharest (DLTS) and at Hamburg and CERN (TSC) , still ongoing.

- HRTEM on highly neutron irradiated PiN samples (in Bucharest)

WP 1.2. **Microstructural Investigations on extended and clustered defects**

M1: Microstructural characterization of the radiation induced clustered defects (fluences between 10^{15} and 10^{17} n_{eq} cm^{-2}) and monitoring of the evolution of clusters at 80 °C **(Q3/2019)**

M2: In situ- annealing studies at 5 temperatures (between 150 °C and 350 °C) in order to determine the structural transformations of the extended and clustered defects (Q3/2020)

M3: Microstructural characterization of the oxide semiconductor interface in irradiated LGADs and HV CMOS devices, time evolution at 80 °C **(Q3/2021)**

M4: Microstructural characterization of the oxide semiconductor interface in irradiated optimized LGADs and HV CMOS devices **(Q3/2022)**

Status:

- HRTEM on STFZ PiN diodes and LGADs (CNM), fluence 10^{15} n/cm^2, and annealing up to 240 C, in Bucharest (2019)
- HRTEM on LGADs (fluence ~10^{19}cm^{-2}) in Bucharest

WP 1.3 Theory of defects and defect kinetics modelling

M1: Modelling of the detected defect generation/kinetics and of the impact on the device performance corresponding to annealing treatments at 80 °C (Q3/2020)

M2 : Modelling of the detected defect generation/kinetics and of the impact on the device performance corresponding to annealing at temperatures between 150 °C and 350 °C and final assessment of the role of the intentional added impurities **(Q1/2021)**

M3 : Identification of the optimal impurity concentrations for pads, LGADs and HV CMOSs as input for production. **(Q3/2021)**

M4 : Improvements of the developed models according to validity test foreseen at WP.1.1 - M6 and provide new optimization solutions for WP.1.1-M7 **(Q3/2022)**

M5 : Validity test for the developed theoretical models based on the results obtained on WP.1.1 - M7 optimized sensors **(Q3/2023)**

Status:

– ongoing with the BiOi generation rate "puzzle", A&B configurations, B, P and C content

Thoughts

- **Acceptor removal**
  - Need to clarify and parametrize, if possible, the multiple reasons for the strong variations of gBiOi. Combine the "macroscopic" acceptor removal models (i.e. parameterization of the c parameter) with the formation of defects (i.e. BiOi introduction rates)
    - $g_{Bi} = 2g^A_{BiOi} + g^B_{BiOi,}$ where g^B_{BiOi} is unkown yet!
  - Need to have all the information about the samples (producer, process, size, macroscopic behaviour –when sent for DLTS/TSC investigations)
  - Need to clarify the impurity content by SIMS (especially C) in the samples
  - Need DLTS/TSC on CMOS sensors and DLTS for characterizing the gain layer in LGADs
  - Need to link observations (acceptor removal) on LGADs, CMOS and p-type pad sensors with the defect formation (TSC, DLTS,..) measurements
  - Try to measure []
  - Find effective capture parameters of BiOi for different electric fields to be used in TCAD simulations
  - Determine the actual [B] in the samples (how much of B doping is compensated by P in the different samples)by LA-ICPMS (B and P), cross check with SIMS on highly doped samples, and determine how much B can go in other than BiOi defect (e.g. BiBs)