Device Characterization and Device Simulation

- Milestones [2018-2022]
  - WP 2.1. Silicon materials [5 MS]
  - WP 2.2. Extreme fluences [5 MS]
  - WP 2.3. Experimental techniques [3 MS]
  - WP 2.4. Surface damage [1 MS]
  - WP 2.5. TCAD simulations [7 MS]

Device Characterization and Device Simulation

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- WP 2.1. Silicon Materials

FZ p-type silicon will be used for ATLAS and CMS upgrades. In running pixel systems oxygen enriched (DOFZ) n-type with n-side readout is used. For radiation hardening different impurity engineered material like MCz, oxygen enriched epitaxial (DOEPI) or nitrogen enriched FZ or EPI will be tested. Also the optimal thickness of the sensor material has to be studied in more detail.

Upcoming milestones

- M1: Development of impurity engineered p-type silicon with possible vendors (Topsil for N enriched FZ, …) (Q3/2019)
- M2: Search for possible production of nitrogen enriched epitaxial silicon (e.g. ITME) (Q3/2019)
- M3: Production of diodes, strip and pixel sensors with engineered materials by different vendors (CiS, CNM, FBK, ….) and field tests (Q3/2019)
- M4: Several irradiation campaigns with different particles up to fluences exceeding 10^{17} n_{eq}/cm^2 on standard and engineered materials (Q4/2020)
- M5: Macroscopic studies on all irradiated devices including Edge-TCT, TPA-TCT and investigations with radioactive sources/test-beams, including annealing studies (Q3/2023).

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• WP 2.2. Extreme Fluences

Device properties (I-V, C-V-f, CCE) on different p-type silicon materials to fluences ranging from 10^{16} to 5×10^{17} n_{eq} cm^{-2} with neutrons and protons of different energies.

Upcoming milestones

- M1: Precise mobility parametrization for electrons and holes (Q4/2019)
- M2: Development of method for extraction of trapping times/distances from the measured data (Q3/2020)
- M3: Establishing leakage current behavior at extreme fluences (Q3/2020)
- M4: Measurement of recombination lifetimes in silicon bulk (Q3/2021)
- M5: Modeling/parameterization of CCE(fluence, voltage, annealing time) (Q3/2023)

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Upcoming milestones

• WP 2.3. Experimental techniques

Beside standard device characterization tools (I-V, C-V, TCT), more complex systems like "Edge-TCT" and "Two Photon Absorption (TPA)" technique became available.

- M1: Full specification of a TPA-TCT method for the characterization of irradiated devices (Q4/2018)
- M2: Commissioning of the top-bench fiber-based femto second laser TPA-TCT setup at the SSD/CERN (Q4/2019).
- M3: Phenomenological parametrization of the radiation effects on diodes using the TPA-TCT method (Q3/2020)

• WP 2.4. Surface Damage

The build-up of oxide charges in the passivation layers and traps in the SiO_2-Si interface by ionizing radiation influences the electric field at the structured implants and the surface generation current. This affects the performance of irradiated sensors and it can be of increasing importance with thin and more complex devices (e.g. HV-CMOS). RD50 has a dedicated research effort.

- M1:Investigation of surface damage on test structures with oxide and oxide-nitride passivation layers irradiated with protons up to 1MGy (Q3/2020).

Device Characterization and Device Simulation

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Upcoming milestones

- WP 2.5. TCAD simulations and custom device simulators
  - M1: Comparison of commercial TCAD tools; preparation of a recommendation for parameters and physics models (Q4/2019)
  - M2: Development of a reliable radiation damage model (I-V, C-V, CCE and the E-field) covering the HL-LHC fluences for protons and neutrons for a given operation temperature (Q4/2020)
  - M3: Model M1 extended to cover temperature dependence of the bulk-damage related effects from room temperature down to -30 °C. (Q3/2021):
  - M4: Model from M2 extended to cover annealing effects (Q3/2022):
  - M5: Model of the donor and acceptor removal (SiPMs, LGAD, CMOS,..) (Q3/2020):
  - M6: Surface damage model with implementation of surface damage in p-type segmented sensors (Q1/2021)
  - M7: Evaluation of possible implementation of cluster defects in commercial TCAD device simulators using a charge carrier occupation dependent energy level distribution (Q2/2021)

Full Detector Systems

Extensive studies of segmented detectors are being performed within RD50 with strip and pixel readout systems especially developed by Alibava and PSI. RD50 is an ideal testing environment for the development of detection systems. RD50 methods are complementary to the ones of the large experiments and are based on mini-strip detectors and pixels. Beyond the measurements on the segmented sensors, RD50 contributes to the analyses and understanding of data taken on the operating experiments.

- Milestones [2018-2022]
    - WP 4.1 LHC [7 MS]
    - WP 4.2 HL-LHC [3 MS]
    - WP 4.3 FCC [2 MS]

Full Detector Systems

- WP 4.1. LHC: Radiation Damage in operating tracking detectors

RD50 has a unique role in creating tools and dialogue for the modelling and monitoring of in-situ detector systems and actively collaborates with ATLAS, CMS, and LHCb.

- M1: Hold a follow-up radiation damage workshop at the end of Run 2. Produce CERN Yellow Report documenting the status and experience gathered (Q1/2019).
- M2: Develop common software that can be used for making comparisons to irradiated sensors at test beams (Q3/2019).
- M3: Complete a program of irradiation and test beam campaigns with accurate thermal control to carefully study the impact of annealing with Run 2-like levels of irradiation (Q3/2019).
- M4: Using the full Run 2 dataset and digitization models that incorporate radiation damage, tune TCAD radiation damage parameters to data and establish systematic uncertainties on these parameters. RD50 will maintain a database of models and parameters (Q4/2019).
- M5: Using the full Run 2 dataset, lab and test beam data to develop a model that incorporates a non-uniform E-field and annealing effects (Hamburg + TCAD). The fine-tuning of this model will require further work (Q4/2020).
- M 2021-2023: Repeat and extend the in-situ studies for Run 3.
- M6: During LS3 we intent to perform a post-operation characterization of de-installed LHC sensors.

Full Detector Systems

WP 4.2. HL-LHC

- M1: Understanding dependence of CCE/CM in segmented detectors on long-term bias at different annealing stages (Q4/2020).
- M2: Understanding the noise performance in CM operation mode at high voltages and modelling it for fast electronics readout (Q4/2020).
- M3: Comparative studies of mini-strip detectors from two main producers (Infineon, HPK) in terms of CCE/CM differences (Q4/2020).

WP 4.3. FCC

- M1: Punch Through Protection (PTP) structure at high fluences, beyond that of strip sensors (Q2/2021)
- M2: CCE studies of different geometry sensors after extreme fluences of up to 5-6×1017 cm-2 (3D samples of different columns widths, mini-strips, pads). The most challenging action will be the readout of segmented devices (Q3/2022).