Silicon Strip Sensor Simulations for the CMS Phase II Tracker Upgrade

Thomas Eichhorn, CMS Upgrade Week at DESY, 3rd – 7th June 2013

The CMS Phase II Tracker Upgrade

Plans exist to upgrade the Large Hadron Collider (LHC) to a high luminosity stage in 2020. This is expected to significantly increase the number of particles traversing the detector. The CMS tracker is a high-precision tracker system providing momentum information for each particle. The tracker is composed of silicon strip sensors arranged in a barrel and an endcap configuration. The position of the tracker within the CMS detector is shown below.

In order to identify the technological baseline for the CMS Phase II tracker upgrade, a large-scale campaign has been started to study radiation damage effects, a field-effect transistor and simulation studies performed at the FRIB lab. The simulation platform is divided into the following steps:

1. **Preparation phase:** The physical models and conditions for simulating the radiation damage process were selected and the simulation settings were configured.
2. **Simulation phase:** Three basic simulation modes can be selected: transient, steady-state, and transient boundaries. The desired physical properties, such as electric fields, current fluxes, and charge distributions, are solved.
3. **Post-processing phase:** The simulation results are analyzed and compared with experimental data. The simulation parameters, various sensor properties which are yet to be determined, are characterized by mesh points.

The HPK Campaign

Sensor Properties in Simulation and Measurement

The picture below depicts a simulation of a 5x5 mm² sensor. The first run involves a bare silicon wafer and the second run includes a gold/gold-plated bar, resulting in an inter-strip capacitance of 1000 pF/cm². The simulation is capable of calculating the number of occupied traps, resulting in the following parameters:

- **Effective mobility**
- **Capture cross sections**

Examples of cluster defects are the E30K, H116K, H140K and H152K defects. The simulation platform is used to simulate the movement of charge carriers within the sensor, resulting in an inter-strip capacitance of 1000 pF/cm². The simulation is capable of calculating the number of occupied traps, resulting in the following parameters:

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Charge Collection in a Silicon Strip Sensor

The charge collected at a silicon strip sensor is a result of the charge generated by the particle, the separation, drift and collection of the charge at the strips can be seen in the following time-resolved images.

Modeling Radiation Damage

Understanding radiation damage and correctly implementing it in simulations is a major issue. Experimental data shows that damage affects a silicon sensor on the nanometer scale, in the form of lattice vibrations and micro-defects. The electric field in the sensor must be calculated correctly to ensure accurate results. The type and concentration of defects are determined using a variety of techniques, such as luminescence measurements.

Point defects can be included in simulations by the means of traps – energy levels in the silicon band gap. Important parameters are:

- **Particle fluence**
- **Impact ionization rate**
- **Capture cross sections**
- **Electronic temperature**
- **Charge density and potential**

The simulation then calculates the number of occupied traps, resulting in a change in the charge density and finally computes the capture and annihilation rates. The electric field between conduction band, holes, and Fermi level is given by the following equation:

\[ E_{\text{eff}} = \frac{q}{\varepsilon_0} \left( \frac{\partial N_{\text{tr}}}{\partial x} - \frac{\partial N_{\text{tr}}}{\partial y} \right) \]

Where:

- \( q \): Charge carrier density
- \( \varepsilon_0 \): Dielectric constant
- \( N_{\text{tr}} \): Number of occupied traps

The electric field shows linear behaviour for fluences of 10^{12} cm^-2, where leakage current and changes in the electric field are negligible. The electric field shows linear behaviour for fluences of 10^{12} cm^-2, where leakage current and changes in the electric field are negligible.

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Ongoing and Future Work

TCAD simulations can provide an important insight into the future development of silicon sensors for particle physics experiments.

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