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 instantaneous luminosity of 10⁻²⁹ cm⁻²s⁻¹. This significant upgrade is necessary to accommodate the currently installed CMS silicon tracker, which consists of 1144 detector modules arranged in a barrel and an end-cap 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, the CMS upgrade group has been studying radiation damage effects, using both experimental and various different simulation methods.

To ensure overall compatibility, a single producer was chosen and a common management procedure between participating institutes has been agreed upon.

The picture below shows the structural layout of a produced wafer containing various regions. Each of these dedicated wafer sections contains a temperature specific parameter set and a radiation simulation.

Charge Collection in a Silicon Strip Sensor

The picture below depicts a simulation of a 5×5 mm² sensor. The first input relates to the material and the second input relates to the geometrical parameters. The next step needs the wafer bulk material and the finally, the backplane with the simulated electric field for various fluences. The electric field shows linear behaviour for fluences of 10¹⁶ n/cm² and non-linear behaviour for higher fluences.

Sensor Properties in Simulation and Measurement

Charge collection is obtained in the simulation with the point charge energy deposit. The simulation parameters, various sensor properties which are yet to be determined, and the numerical data are compared with experimental characteristics.

Modeling Radiation Damage

Understanding radiation damage and correctly implementing it in simulations is a major issue. Experimental data shows that damage effects on a silicon sensor can be categorized and the formation of point and cluster defects. Vacancies, combinations with oxygen, the silicon dangling bond and carbon complexes and though in post-defects with a separation of a few Angstroms are created.

Point defects can be included in simulations by the means of traps – i.e. position in the band gap – and a characteristic radiation damage rate. Important parameters are the electric field and the carrier continuity equations.

Radiation Damage in Sensor Simulations

The above two plots show that simulations (in green) can reproduce measurements (in red). The radiation damage model implemented in Sentaurus adds the correct bias voltage for different materials and geometries. Both simulators are in good agreement with measurements.

Simulation Software: Synopsys Sentaurus

How does the simulation work?

Simulation is carried out in Sentaurus for radiation damage, specifying for example material, time and electronic doping of the sensor. A defect model is then generated, so that the structure is characterized by mesh points.

- Radiation damage – The physical models and conditions to be applied during the simulation procedure are then selected and can be further parameterized. These can include temperature, electric field generation, charge carrier recombination, mapping and carrier diffusion.
- External effects – A variety of external effects can be added to the simulation. Examples are an electrical circuit via a SPICE network (useful for comparison with experimental measurements), laser irradiation or transport parameters.
- Simulation type selection – There are three basic modes: SPICE, electro-thermal and time transient simulation.
- Simulation run – With all parameters specified, the actual full-sensor simulation is done.
- Postprocessing – The results are then evaluated and examined in a separate program.

The performed simulations aim to reproduce measurements obtained in selected silicon sensors and materials.

The Sensor Simulation Working Group in CMS

To streamline and coordinate tasks, a simulation group has been formed, with members coming from various other institutes besides DESY.

- Technical University of Munich
- University of Freiburg
- University of Fribourg
- University of Helsinki

Aims of the group:

- To coordinate the CMSSP10 simulation efforts for the CMS Phase II Upgrade.
- The following topics are under investigation:
  - Comparison of simulation tools: There are various simulation packages available on the market. An understanding of how different programs work, knowing their benefits and also their short-comings is important.
  - Device design – Silicon sensor concepts, verify leading techniques for p-type silicon devices.
  - Radiation damage – Create a list of known defects and their properties. Once this model is established, how does it change the sensor properties.
  - Charge collection and analysis – Research optical layer, how does radiation damage effect charge collection efficiency?

Contact: thomas.eichhorn@desy.de

Sensor Geometry

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