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Development of Silicon Sensor Characterization System for Future High Energy Physics Experiments

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Abstract: The Compact Muon Solenoid (CMS) is one of the general purpose experiments at the Large Hadron Collider (LHC), CERN and has its Tracker built of all silicon strip and pixel sensors. Si sensors are expected to play extremely important role in the upgrades of the existing Tracker for future high luminosity environment and will also be used in future lepton colliders. However, properties of the silicon sensors have to be carefully understood before they can be put in the extremely high luminosity condition. At Delhi University (DU), we have been working on the development of Si sensor characterization system, as part of the collaboration with the CMS Experiment and RD50 collaboration. This works reports the installation of current-voltage (I-V) and capacitance-voltage (C-V) systems at DU.

Keywords: silicon, radiation, characterization, high energy physics, detectors

1. INTRODUCTION

Silicon sensor is one of the most important candidates for present as well as future high energy collider experiments. Some of its important characteristics which leads to the success of the experiments like ATLAS, CMS at CERN are its high spatial resolution, compactness in size, high speed (their signal collection time is of the order of 10ns), linearity in response, tolerance to high radiation dose upto 10MGy and and efficient operation in strong magnetic fields. The requirement to study rarest reaction channels will impose a large increment in the flux during the high luminosity grade. Higher fluence will deteriorate the electrical properties of Si sensors. Radiation damage causes both bulk and surface damage. Bulk damage results in formation of donor and acceptor traps in deep energy levels of the energy band gap of silicon, which

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further results in a) increase of its leakage current as defects act as centers for increasing the generation-regeneration bulk current b) increase in depletion voltage and c) deterioration in charge collection efficiency as lot of charges get trapped in the trapping centers before reaching the electrodes. Surface damage due to ionizing radiation contributes to the formation of oxide charge layer and interface traps around the $Si\text{-}SiO_2$ interface. The major consequence from surface damage is the reduction in the inter-strip isolation due to accumulation of charge carriers, which provide a conduction channel and result in an increase in inter-strip capacitance. Hence, charge generated by the ionizing radiation grows over many strips resulting in degradation of position resolution. In order to achieve high collection charge efficiency, sensor should be operated in over depleted mode to have electric field over the entire sensor.

Silicon sensors are operated in reverse bias mode. A charged particle moving through a silicon sensor generates many electron-hole pair along its path. The number of the charge carriers produced is proportional to the particle energy loss. An average of 3.6eV energy is required to produce an electron-hole pair. Under application of bias electron will drift towards the n^+ side and hole towards p^+ side. Migrated charge will drift and get collected at electrodes to produce signal.

Particle detection efficiency and spatial resolution strongly depends on the electrical properties of sensor. It's important to accurately measure the electrical properties of silicon sensors before the final assembly to be put in future experiments. Therefore, there is a need of extensive study of both simulations and measurements. The leakage current (I) behavior as a function of voltage (V) and the voltage needed to fully deplete the sensor are two important parameters to study the static characteristics. The voltage needed to fully deplete the sensor can be measured by determining the capacitance (C) of the sensor. Both capacitance and the leakage current will affect the performance of the readout electronics. We have to measure different sensors in the laboratory to find the good sensors that can be built into the experiments. Guard ring is incorporated to reduce the effects occurring from the surface current.

2. CHARACTERIZATION FACILITY

Figure 1 shows the characterization setup at DU. Characterization setup has 10% accuracy for current ranging from O(100pA) to O(10mA), resistances of O(GΩ) to O(TΩ) and capacitances down to O(pF).Measurements are performed in clean room with purity of class 100 with monitored temperature. Work table consists of main filters of efficiency better than 99.97% down to 0.3μm air filtration, HEPA filters made with HNV filtering media and pre

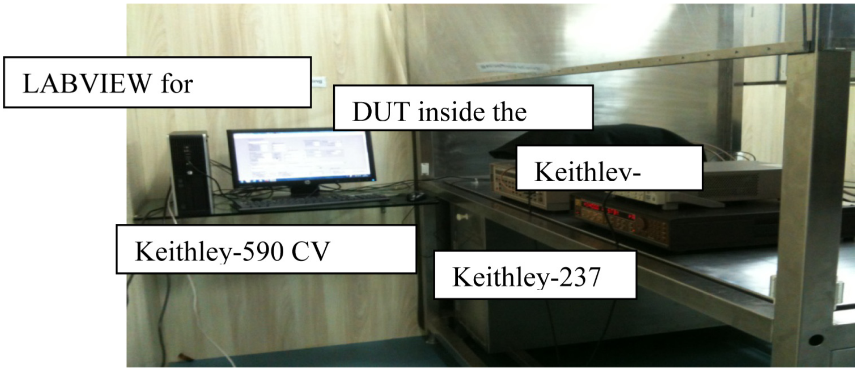
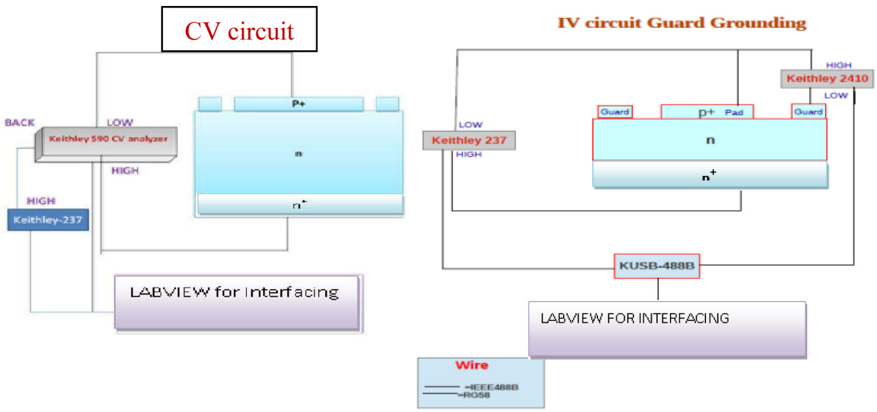


Figure 1: Characterization set up at University of Delhi.



(a) (b)

Figure 2: A schematic showing a) CV set up b) IV set up.

filters efficiency 90% down to 10μm air filtration media. Fresh air-cum-lab air booster is installed for 0.3μm final air delivery. Automation and speeding up the measurements are performed using LABVIEW program for interfacing with devices. Reproducibility of results is immediately interpretable.

3. CHARACTERIZATION SET UP

A schematic view of set up for current-voltage and capacitance-voltage measurement is shown below in figure 2. IV measurement of total leakage current consists of Keithley-237, which is used as a source meter (voltage source and current measure) to reverse bias the sensor from 0 to 400V, keithley-2410 is used

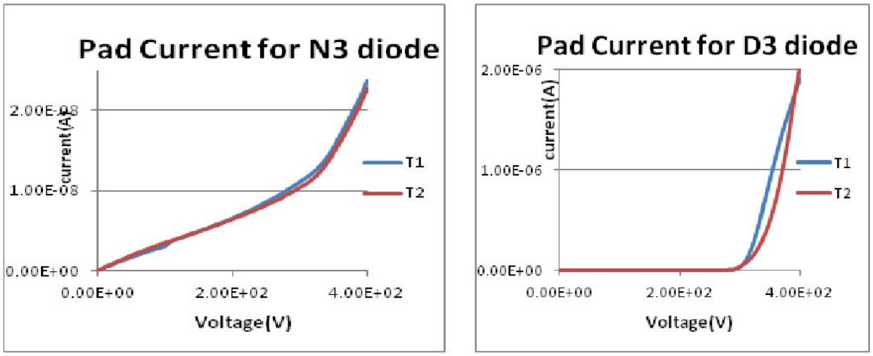


Figure 3: IV results of diodes N3 and D3 with guard floating.

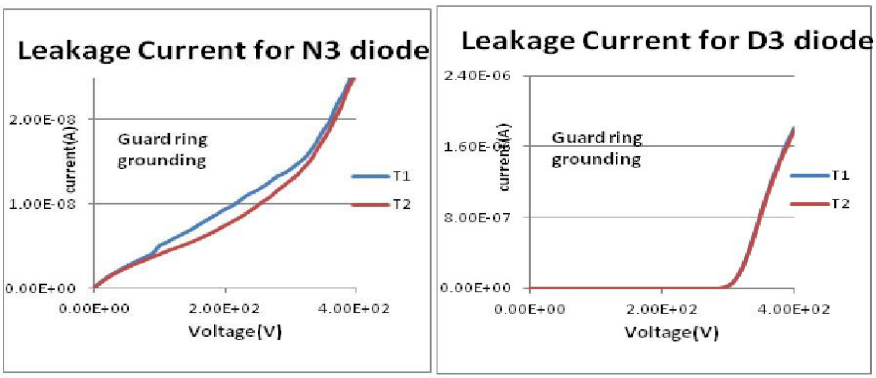


Figure 4: IV results of N3 diode and D3 with guard grounded.

as an ammeter to measure the pad (sensor) current and LABVIEW (installed in computer) program for interfacing with the devices. The current is measured between the backplane and bias line, keeping the guard floating as well as guard grounding, in steps of 10V. CV measurement of total capacitance of the sensor from 0 to 200V consists of keithley-590 CV analyzer and keithley237, which is used as an external voltage source for biasing sensor from 0 to 200V. The capacitance is measured between the backplane and bias line, keeping the guard floating, in steps of 10V, at a frequency of 100 KHz. From this measurement it is possible to extract depletion voltage of the sensor and to check its thickness.

Figure 3 and Figure 4 show the IV measurement of two different diodes, referred to as N3 and D3, with guard rings floating and grounded respectively. Two curves superimposed on each other shows the reproducibility of the same results, when measured at different times. Leakage currents of the diodes are

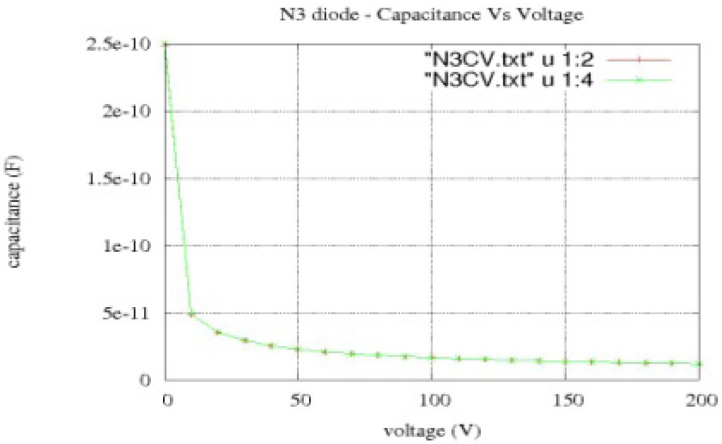


Figure 5: CV characteristics of N3 diode.

less when guard rings are grounded as guard rings absorb the edge leakage currents. Both the diodes show breakdown of the sensor from around 300-400 V under all configurations. Figure 5 shows the CV measurements.

4. SUMMARY AND FUTURE OUTLOOK

A clean room is developed with clean bench of class 100 specifications at DU to measure IV and CV characteristics of the silicon diodes. IV & CV measurements were performed on pad sensors and its reproducibility is checked. Characterization is automated using Labview software. The capabilities of the setups will be extended to characterize multi-strip sensors.

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