CHARACTERISATION OF SI DETECTORS FOR THE USE AT 2 K*

V. Eremin, E Verbitskaya, IOFFE, St Petersburg, Russian Federation

Abstract
It is expected that the luminosity of the Large Hadron Collider (LHC) will be bounded in the future by the beam loss limits of the superconducting magnets. To protect the superconducting magnets of the high luminosity insertions an optimal detection of the energy deposition by the shower of beam particles is necessary. Therefore beam Loss Monitors (BLM) need to be placed close to the particle impact location in the cold mass of the magnets where they should operate in superfluid helium at 1.9 Kelvin. To choose optimal detectors n-type silicon wafers have been examined at superfluid helium temperature whilst under irradiation from a high intensity proton beam. The radiation hardness and leakage current of these detectors were found to be significantly improved at 1.9 Kelvin when compared to their operation at room temperature.

INTRODUCTION
The magnets close to the Interaction Points (IP) are exposed to high irradiation from the collision debris.

EXPERIMENTAL SETUP
The principle of the experiment is to irradiate the detectors being immersed inside superfluid helium during the measurements to observe the detector’s degradation.

Detector Modules
Three different detector modules were used in the experiment: holders for direct current (DC) measurements (see Fig. 3), holders for current pulse response measurements using Transient Current Technique (TCT) with a pulsed laser measurements [3] (see Fig. 4), and modules with 4 silicon detectors each, as beam position monitors (see Fig. 5).

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#marcin.bartosik@cern.ch

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The irradiation lasted 4 weeks and temperature of the detectors was, most of the time, 1.9 Kelvin. At the end of the test the temperature was increased up to 80 Kelvin to simulate the temperature of the detectors during a long stop of the LHC, like e. g. the Christmas break.

RESULTS

At the end of the irradiation a total integrated fluence of \(1.22 \times 10^{16}\) protons/cm\(^2\) was reached, corresponding to an integrated dose of about 3.26 MGy for silicon. Detectors are p–n–n\(^+\) silicon structure with a thickness of 300 \(\mu\)m, an active squared area of 23 mm\(^2\), aluminium as metallisation material and of different intrinsic resistivity. The voltage was switched from -400 V to +400 V for all detectors. This means that along with a standard reverse bias forward bias was applied that corresponds to Current Injected Detectors (CID) [4].

DC Measurement Results

The figures 7 and 8 show the decrease of collected charge for the silicon devices. The curve for 10 k\(\Omega\)cm silicon with 100 V reverse bias has been plotted in all graphics as reference curve [5].

Figure 7: Dependence of the charge collected in Si detectors with a resistivity 500 \(\Omega\)cm on fluence.

Figure 8: Dependence of the charge collected in Si detectors with a resistivity 4.5 \(\Omega\)cm on fluence.

Signal Readout and Beam Properties

Figure 6 depicts the shape of a signal from a spill for different stages of irradiation, the signal is recorded by the LeCroy Oscilloscope (WaveRunner 204MX-A).

The irradiation conditions are:
- Particle momentum of 24 GeV/c.
- Beam profile of FWHM 1.2 cm at the cryostat.
- Beam intensity per spill of \(1.3 \times 10^{13}\) protons/cm\(^2\), corresponding to an average of about \(1 \times 10^{10}\) protons/s on detectors.
At the beginning of the irradiation and for non-irradiated or low-irradiated silicon detectors in superfluid helium bath, the forward current is about 100 μA at 100 V. With increased radiation damage, the forward current goes down. Further observations are that the forward bias for low resistivity silicon is less stable than for high resistivity silicon. This can especially be seen for the 4.5 Ωcm sample, which had a very stable but low charge collection at the beginning and increased leakage current instabilities towards the end of the irradiation.

Voltage Scan

The voltage scans of the collected charge for the different detectors at different fluencies are depicted in the figures 9 and 10. In the voltage scans positive voltage denotes a forward bias.

There is no full charge collection for silicon detectors above full depletion voltage, as it would be expected for non-irradiated silicon detectors at room temperature.

Going to voltages beyond 400 V, a saturation of the charge collection is expected (as seen for room temperature irradiation), but for the considered voltage range until 400 V in cryogenic conditions, a linear fit is adequate and has been used to fit the measurements.

![Figure 9: Voltage scan for 500 Ωcm silicon.](image)

![Figure 10: Voltage scan for 4.5 Ωcm silicon.](image)

**SUMMARY**

Different Si detectors at cryogenic temperatures were tested for their radiation hardness. A total integrated fluence of $1.22 \times 10^{16}$ protons/cm$^2$ was reached, corresponding to an integrated dose of about 3.26 MGy for silicon.

An irradiation effect on the silicon detectors sensitivity could be observed. The forward bias modus leads to high signals at the beginning of the irradiation, but unfortunately the decrease in signal at higher fluence is faster compared to reverse bias modus. Further observations are that the forward bias for low resistivity silicon is less stable than for high resistivity silicon.

The data require more treatment to allow further relevant conclusions and physical results.

More experiments with current pulse response measurements using TCT with a pulse laser at cryogenic temperatures during irradiation are foreseen.

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