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Nuclear Instruments and Methods in Physics Research A 518 (2004) 328–330

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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Beam-loss-induced electrical stress test on CMS Silicon Strip Modules

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Abstract

Based on simulated LHC beam loss scenarios, fully depleted CMS silicon tracker modules and sensors were exposed to 42 ns-long beam spills of approximately 10^{11} protons per spill at the PS at CERN. The ionisation dose was sufficient to short circuit the silicon sensors. The dynamic behaviour of bias voltage, leakage currents and voltages over coupling capacitors were monitored during the impact. Results of pre- and post-qualification as well as the dynamic behaviour are shown.

PACS: 29.27.Ac; 29.27.Eg; 29.40.Gx; 29.40.Wk

Keywords: Beam loss; Beam abort; Silicon sensor; Silicon strip sensor; Silicon strip module; Tracker; CMS; LHC

1. Motivation

At the LHC, it is assumed that beam loss caused by kicker magnet pre-fire or unsynchronised beam abort will occur at least once in a year. Simulations predict 10^{12} protons to be lost in CMS within 260 ns corresponding to 10^9 protons per cm^2 [1]. To insure the robustness of the CMS Silicon Strip Tracker Modules against such a beam loss scenario, several modules were exposed to a similar beam environment, and operational module parameters were monitored. No integral radiation effects were expected with this fluence other than electrical stresses on the module.

2. Setup

The testbeam was performed at CERN PS using 24 GeV protons on the East Hall T7 beam line. Two possible beam setups, a fast extraction spill (42 ns), and a double shot structure of 42–526–42 ns (spill–gap–spill) were used to approximate conditions in the Tracker Endcap from an unsynchronised beam abort. The beam profile had dimensions of $10 \times 3\ \mathrm{cm}^2$, with 7×10^{10} protons deposited per spill. The large beam spot was used to cover the full module placed in a small angle to the beam line. Dosimetry was done with ^{11}C.

Preamplifier electronics on top of the module carrier were used to drive 12 signals over a distance of 30 m from the beam area to the counting room.

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doi:10.1016/j.nima.2003.11.011

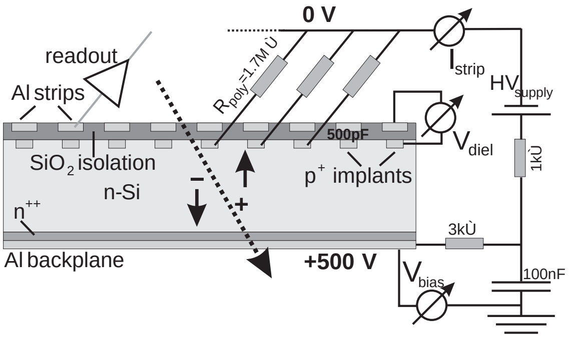

Fig. 1. Sensor schematics with electrical setup.

Several sensor parameters were monitored (Fig. 1): bias voltage (V_{bias}), global leakage current, voltage over dielectric layer (V_{diel}), strip leakage current (I_{strip}), front end hybrid (FEH) supply voltages and currents. Scopes were triggered on leakage current. Three runs with six devices in total were realised (three sensors, two modules and one FEH). Two runs were done with multiple shots at different bias voltages. In the last run, six consecutive shots were applied at a bias voltage of 500 V.

3. Results and interpretation

When the beam is incident on the silicon, the bulk material is highly ionised by 10^{11} protons, producing at least 10^{15} electron–hole pairs. Free charges move to the backplane and p^+-implants, and discharge the sensor and bias voltage buffer capacitances. This short circuit of the bulk leads to a nearly complete breakdown of the sensor bias voltage (Fig. 2). A residual voltage is seen as a voltage over the coupling capacitance (Fig. 3). The highest peak of about 13 V is far below the critical limit of 120 V, which would cause a pinhole by breaking the dielectric layer between p^+-implants and readout strips. The corresponding single strip leakage current peaking at 13 μA does not damage the poly silicon resistors. The bias voltage recovers after a few ms. Such recovery occurs faster at higher bias voltages, as the current supplied by the power supply is larger and does not react on a timescale of below one ms, so permitting the excess free charges to be removed faster. The transient

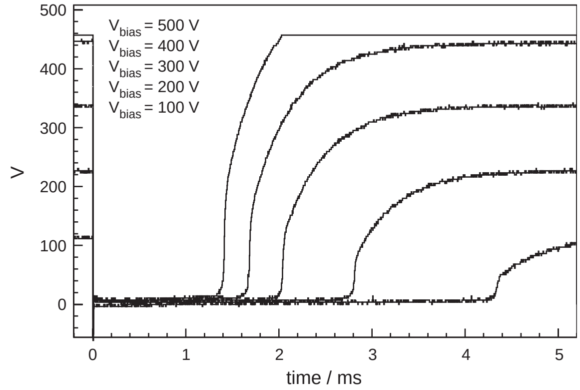

Fig. 2. Time behaviour of bias voltage.

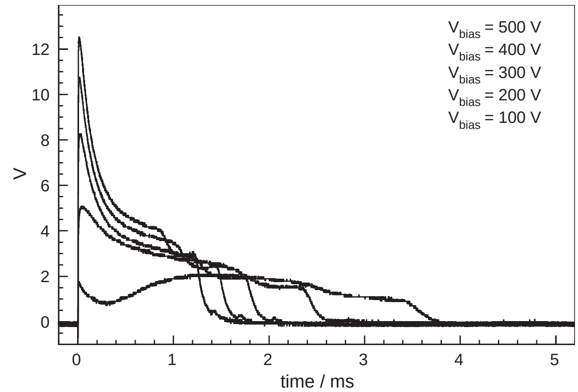

Fig. 3. Time behaviour of voltage over dielectric layer.

time of about 900 μs corresponds well with strip bias resistor (1.7 MΩ) and coupling capacitance (500 pF).

The readout was still operational after the test. The modules showed tickmarks, which are produced continuously, and frame headers, which are generated for each event.

Another study with respect to effects of beam losses on silicon detectors has been published in 2000 [2]. A strong laser signal was sufficient to short circuit the bulk material even though the number of produced electron–hole pairs was much less than in our experiment. Similar shapes for implant voltage and breakdown and recovery of bias voltage are shown there. Time constants depended on bias resistors and capacitances are comparable with ours as ATLAS silicon detecors were used in a similar electrical setup.

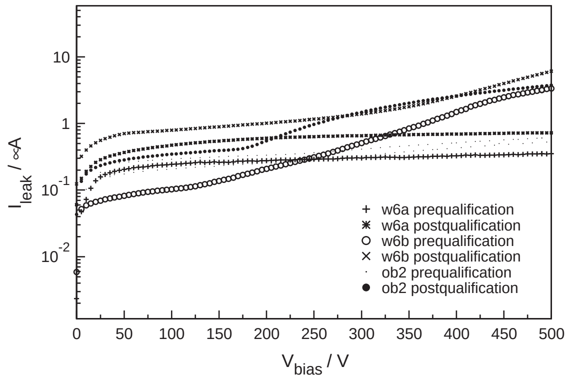

Fig. 4. Leakage current over bias voltage for three sensors before and after the test beam.

4. Characterisation before and after the test beam

All sensors show a slightly increased leakage current (Fig. 4) probably coming from mechanical stress. Depletion voltages did not change. Other parameters show no additional defects. The modules are fully operational after the test beam, and no problems in rms noise and readout calibration pulse heights have been observed.

5. Conclusion

There is strong evidence that CMS silicon strip modules will survive a beam loss, because the fast breakdown of bias voltage protects electronics and sensors, especially the dielectric layer and the poly silicon resistors.

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