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Silicon microstrip detector irradiation using a 26 MeV proton beam

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Abstract

This paper describes the proton irradiation campaign, performed at the INFN "Laboratori Nazionali del Sud" (LNS), on a silicon microstrip detector. The irradiated module is identical to the ones which are used to assemble the tracker inner barrel of the CMS experiment at the CERN Large Hadron Collider (LHC). The aim of the test was to verify the radiation resistance of the detector module to the LHC environment by checking its behavior with increasing fluence.

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Keywords: Radiation damage; CMS; Silicon; Microstrip; LHC

1. Introduction

Silicon microstrip sensors have been commonly used in high energy physics experiments as charged particle position sensitive detectors for many years. The Atlas [1] and CMS [2] experiments at the 14 TeV proton–proton collider Large Hadron Collider (LHC), will extensively use silicon microstrip detectors to track charged particles; the CMS experiment will cover a surface of about 200 m^2 with this kind of detectors in its inner tracking volume [3]. The innermost silicon microstrip detector layers, surrounding the LHC interaction points, will be exposed to a flux of particles which, during the foreseen 10 years of detector lifetime,[1] will reach a total fluence of 1.6×10^{14} 1 MeV equivalent neutrons/cm^2 (n_{eq}/cm^2). The CMS silicon microstrip sensors have been designed taking into account the extensive studies carried out in the past years to verify their radiation hardness at LHC level [4,5]. Furthermore the front-end electronics has been produced using deep sub-micron technologies: the thin gate oxide together with special layout techniques ensure their radiation tolerance [6].

The aim of the test described in this paper was to expose a fully assembled CMS silicon microstrip module to a 26 MeV proton fluence which reproduces the expected LHC damage and to verify its functionality at different stages of the detector lifetime.

2. The silicon microstrip module

A total of 15 148 detector modules will be installed in the CMS tracker around the LHC interaction point from 20 to 110 cm radial distance from the beam axis [7]. There are two families of detector modules consisting of 1 (resp. 2) silicon crystals, 320 μm (resp. 500 μm) thick, glued on a carbon fiber support frame, and wire bonded to the front-end readout chips mounted on a kapton hybrid circuit. The sensors are single sided *n*-type low resistivity bulk silicon, ⟨1 0 0⟩ crystal orientation, with 512 (or 768) p+ implant strips [8].

The irradiated module was chosen among the double-sided detectors which have been installed in the first two innermost barrel layers of the CMS silicon strip tracker. This type of detectors are realized simply gluing back to

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[1]Equivalent to an integrated luminosity of 500 fb^{-1}.

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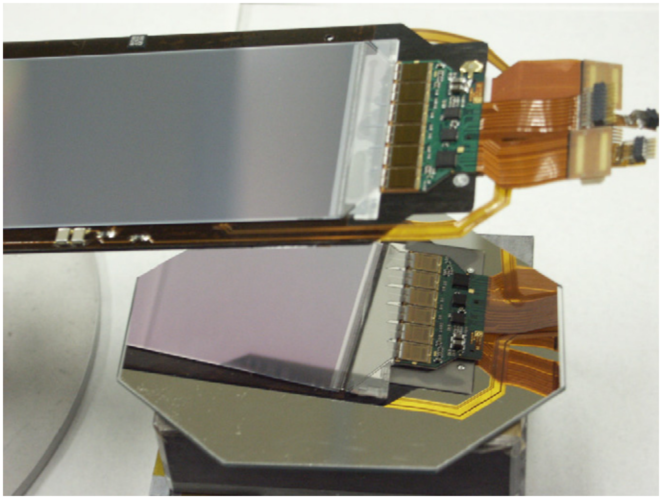

Fig. 1. A CMS inner barrel double-sided module; the Stereo module is visible reflected by a mirror.

back, at an angle of 100 mrad, two independent modules, called "R-Phi" and "Stereo", each made of one single-sided 320 μm thick sensor. The initial depletion voltages of the two sensors were 184 V for the "R-Phi" and 210 V for the "Stereo", both having a bias current measured at 400 V and room temperature of 200 nA. Their strip pitch is 80 μm, with implant strip width of 20 μm and aluminum readout strips designed with a metal overhang of 4 μm per side to improve the breakdown resistance of the sensor. The module outer dimensions, which include the $6.33 \times 11.9\,\text{cm}^2$ sensor, were $8 \times 17\,\text{cm}^2$ (Fig. 1).

3. The module electronics

The signals coming from each strip are processed by front-end readout chips (APV25 [9]) mounted on the module hybrid circuit. The APV25 is a 128 channel chip built in radiation hard 0.25 μm CMOS technology. Each channel consists of a preamplifier coupled to a shaping amplifier which produces a 50 ns CR–RC pulse shape. The shaper output of each channel is sampled at 40 MHz into a 192 cell deep pipeline. Each pipeline channel is read out by an analogue circuitry which can operate in one of two modes: peak or deconvolution. In peak mode only one sample per channel is read (timed to be at the peak of the analogue pulse shape). In deconvolution mode [10] three consecutive samples are used and the output is a weighted sum of all three. This operating mode is particularly important for correct bunch crossing identification during the high luminosity running phase of the LHC. A unity gain inverter is included between the preamp and shaper which can be switched in or out.

4. Experimental layout and irradiation procedures

The irradiation was performed in air using a proton beam from the SMP Tandem Van de Graaff accelerator of the INFN "Laboratori Nazionali del Sud" (LNS). The chosen energy was 26 MeV to allow a full beam cross-through of the samples and also to make a comparison with complementary investigations [11].

4.1. Beam profile and homogeneity

During the setup operation the defocused proton beam passed through a $1\,\text{cm}^2$ collimator and hit a scintillating screen located on the detector plane. The emitted light was collected by a CCD camera and analyzed on line. A central homogeneity along each dimension better than 5% over 8 mm was achieved. In order to obtain a homogeneous fluence over the entire module we moved the sample continuously by means of a remote controlled motorized *x–y* stage whose scanning velocity was proportional to the measured instantaneous beam current. This quantity was continuously monitored during the irradiation using the secondary electron emission from an isolated thin aluminum foil positioned after the collimator inside the beam pipe. The irradiation uniformity at the edge between two scan rows was controlled measuring the non-saturated radiation induced opacity on a plastic sample. To complete the calibration procedure the absolute value of the beam current was periodically measured through a Faraday cup positioned downstream from the beam collimator. Its value was used to renormalize the beam current information given by the aluminum foil.

4.2. Fluence requirements and dosimetry

Using a hardness factor for 26 MeV protons of $\kappa \simeq 1.85$ [12], to reach the 10 years LHC fluence a total of 8.6×10^{13} 26 MeV protons/cm^2 are needed. A beam current of the order of 10 nA was adequate to complete the program in a reasonable amount of time and low enough to avoid damages due to the local heating of the sample in the beam spot region. The total fluence was achieved in eight steps (see Table 1) each one followed by a set of measurements on the module.

The total and incremental fluences accumulated on the sample were calculated using the on-line monitoring of the beam current (integral of the current measured by the aluminum foil, normalized using the Faraday cup data) and also by offline measurements on reference silicon diodes. They were assembled into frames, each of them containing 4 or 5 diodes. Two frames have been exposed to the full fluence, one in front (frame A) and one behind (frame B) the module. One frame per irradiation step has also been placed in front of the module and used to measure the partial fluences. The results, calculated using the value of the reverse current measured at 20 °C, after an annealing of 80 min at 60 °C, and the conversion factor reported in Ref. [13], agree very well with the fluences measured from the beam current (see Table 1). Furthermore, the sum of the diode measured partial fluences agrees very well (at 1% level) with the total fluence measured by the frame A diodes.