Silicon Detector Technology Development in India
for the Participation in International Experiments

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Abstract

A specific research and development program has been carried out by BARC in India to develop the technology for large area silicon strip detectors for application in nuclear & high energy physics experiments. These strip detectors will be used as the preshower detector in the CMS experiment at LHC, CERN for π^0/γ rejection. The fabrication technology to produce silicon strip detectors with very good uniformity over a large area of ~40mm^2, low leakage currents of the order of 10nA/cm^2 per strip and high breakdown voltage of > 500V has been developed by BARC. The production of detectors is already underway to deliver 1000 detector modules for the CMS and 90% production is completed. In this paper, the research & development work carried out to develop the detector fabrication technology is briefly described. The performance of the silicon strip detectors produced in India is presented. The present status of the detector technology is discussed.

1. Introduction

Silicon detectors are being used for several applications involving detection and measurement of position and energy of particles such as α particles, fission fragments, heavy ions, etc. These detectors have exceptional energy resolution, high stability and fast response time. Detectors with various geometries such as strips, microstrips & pixels are being increasingly used for detecting ionizing radiation in nuclear physics & high energy physics experiments such as LHC, CERN. BARC has carried out a specific R&D for the technology development of silicon strip detectors for applications at CMS detector, LHC, CERN. These detectors also will be used for nuclear physics experiments in India for charged particle measurements. The R&D for the development of technology has been carried out in various phases such as prototype development, preproduction and production. The silicon strip detector technology development has been targeted to produce detectors with high breakdown voltage and low leakage currents for ensuring ten years of operation in the high radiation environment of LHC. The technology development and performance of these detectors is presented in the subsequent sections of this paper.

2. Detector Design & Fabrication Process Development

The silicon strip detectors have a geometry of 63mm x 63mm and these detectors incorporate 32 P$^+$strips with width of 1.78 mm with a pitch of 1.9 mm [1]. In view of the expected radiation damage during ten years of operation in the LHC environment, the electrical specifications of the detectors are quite stringent i.e. low leakage currents and high breakdown voltage. Therefore, the strip detector mask has been specially designed to incorporate features such as strips with rounded corners and floating field P$^+$ guard-rings [2]. The floating field guard rings reduce the surface electric fields and hence increase the breakdown voltages of the strips.

The detector has been fabricated using a four layer mask process using standard silicon technology. The fabrication facility of Bharat Electronics Limited (BEL) has been utilized for the prototype development and subsequent production of detectors [2-3]. The 32-strip silicon detectors have been fabricated using 4", N-type, <111>, 300 μm thick silicon wafers having resistivity of the order of a few ohm-cm. The front P^+ strips and the back N^+ contact have been obtained by ion implantation The silicon surface of the strip detectors is passivated with a thick silicon dioxide layer. The detectors have an additional passivation layer over the metal layer.

The desired specifications of high breakdown voltage and low leakage currents have been achieved by strict contamination control, incorporating gettering, having an uniform and thick N^+ layer at the back for suppressing back injection [3-4]. Critical process parameters such as temperature, time, ambient for processes such as oxidation, implantation anneal and drive-in, etc have been optimized to meet the desired electrical specifications of the strip detectors. The fabrication process has been optimized in eight batches to tune the process parameters so as to achieve the desired specifications of leakage currents and breakdown voltages.

3. Performance of Strip Detectors

The strip detectors are subjected to several tests involving electrical and mechanical measurements for the quality control of the detector i.e. acceptance/ rejection of the detector. The breakdown voltages of strips, leakage currents and capacitance of individual strips, mechanical dimensions (thickness, length & width), dicing quality are some of the parameters which are monitored during quality control. Simultaneous measurements of leakage currents (IV) and capacitance (CV) of the 32 strips of the detectors are carried out using PC based automated measurement setups. The static characteristics of the detectors are as shown in Figure 1 and Figure 2. The characteristics show that the strip leakage currents are of the order of 5-10 nA at high voltages of the order of 500V. The CV curves are uniform for all the strips and the full depletion voltages are about 110V.
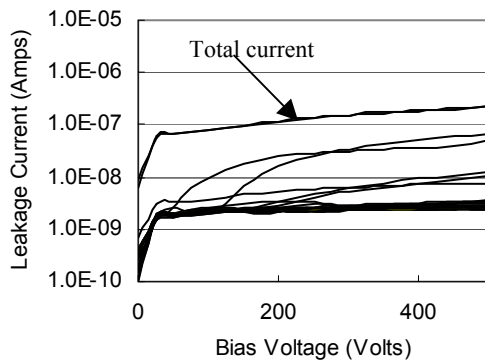
Figure 1 IV Characteristics of 32 strips of the strip detector
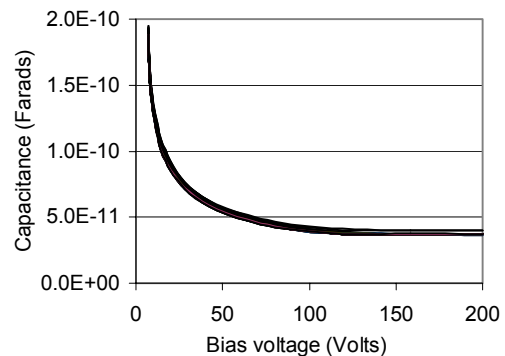
Figure 2 CV characteristics of all 32 strip of the strip detector

The radiation hardness of the detectors has been tested by irradiating them to neutrons in a reactor (at BARC and at Dubna, Russia) and using a 24 GeV proton beam at CERN. The increase of leakage current, breakdown voltage and full depletion voltage were monitored after irradiation. The detectors have been found to meet the specifications and show a stable behavior without showing early breakdown of strips after irradiation to a total neutron fluence of $1.36 \times 10^{14} \text{n/cm}^2$

4. Production of Strip Detectors and Quality Control

Detectors with very good uniformity and at a production yield of 40% are being produced at BEL to deliver 1000 Nos of detector modules to CERN and 90% of the production has been completed. During production, the quality control is being carried out as per the qualification procedures specified by the CMS Preshower Group, CERN. The quality control involves electrical measurements to check leakage currents & breakdown voltages and full depletion voltages of strips. Geometrical measurements are carried out to check the tolerance of 100 microns over detector length and width and measurement of the thickness (within 300μm-340μm). All the tests are being carried out in a class 10,000 environment with controlled humidity and temperature.

Figure 3 and Figure 4 show the statistical distribution of breakdown voltage and total leakage current at 300V for about 800 sensors. As can be seen, the breakdown voltage exceeds 500V for majority of the detectors. The total leakage current of the detector is less than 1.0μA for most of the detectors though this tolerance is 10.0μA
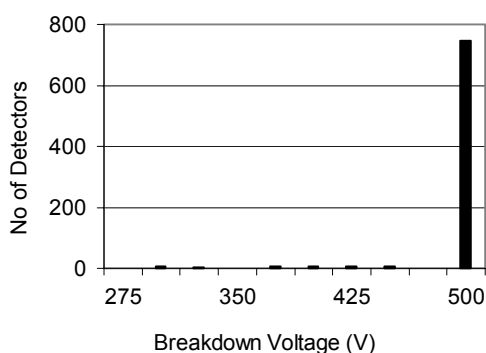
Figure 3 Distribution of the breakdown voltage for 800 detectors
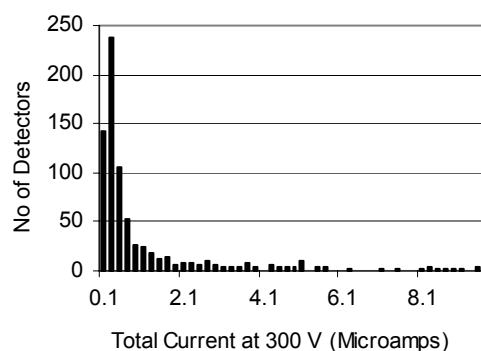
Figure 4 Distribution of the total leakage current at 300V for 800 detectors

The silicon strip detectors are assembled in the form of detector modules so as to integrate the front end electronics hybrid to the detector. The assembly of detectors involves very precise mechanical alignment and gluing of the detectors to the ceramic tile which carries the hybrid and the ceramic is glued to the aluminum tile. Prototype modules have been made in India and the detector performance has been observed to be stable during assembly.

5. Summary

BARC has developed the demanding technology for fabrication of strip detectors with good uniformity, low leakage currents and high breakdown voltage. The detectors also meet the radiation hardness requirements for operation at LHC. Subsequent to the development of technology, the full scale production of the detectors has been started in India so as to produce 1000 detector modules for the preshower of CMS and more than 90% of the production has been completed.

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