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The CMS preshower silicon sensors: Technology development and production in India

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Abstract

A specific research and development program has been carried out in India by Bhabha Atomic Research Centre to develop the technology for 32-strip silicon sensors which will be used as Preshower sensors in the CMS experiment at the Large Hadron Collider (LHC), CERN. The technology development was targeted to produce sensors which would qualify for reliable operation in a high radiation environment of LHC. As an outcome of this R&D effort, silicon sensors with very good performance have been produced and the production of thousand sensors for the CMS Preshower has been completed. In this paper, we present a summary of the R&D carried out to develop the technology of the silicon sensors. We report on various aspects such as sensor design, process development and characterization. The results of various tests carried out for evaluating the performance of the sensors during technology development and production phase have been presented.

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1. Introduction

Silicon sensors are being increasingly used for detection of particles in physics experiments due to their superior performance such as fast response time, high detection efficiency, and compactness. High special resolution in 1D or 2D can be easily obtained by segmenting the sensors into strips, microstrips or pixels. Moreover, application of the well-established silicon integrated technology for sensor fabrication has enabled realization of high performance sensors with very good uniformity and low cost of production. In the past few years, Bhabha Atomic Research Centre (BARC) has carried out an R&D to develop the technology for 32-strip silicon sensors using the fabrication facilities of the silicon foundries in India [1–3]. The goal of this work was to produce thousand sensors of an area about 40 cm^2 to be used in the Preshower of the Compact Muon Solenoid (CMS) experiment at the Large Hadron Collider (LHC) at CERN. The design of the sensors, the complete mask layout and process parameter optimization have been done by BARC. The fabrication of the sensors has been carried out using the IC fabrication facility of Bharat Electronics Limited (BEL), Bangalore as per the process outline provided by BARC. The technology development was aimed to fabricate sensors with very good electrical and mechanical specifications so that these sensors can be operated without failure for 10 years in high radiation environment of the LHC. A large variety of silicon sensors with different geometries suitable for various applications such as nuclear physics experiments and radiation monitoring have been also fabricated as the ‘spin of’ of this development work.

Subsequent to technology development, the production of thousand silicon sensors has been recently completed. These sensors have been characterized using several quality control tests. The design of the sensors along with

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processing issues and sensor characterization are discussed in the subsequent sections of this paper. The results of various tests performed during the technology development and production phase are also presented.

2. Sensor design

Three types of dedicated wafer layouts containing 32-strip silicon sensors have been designed during various phases of technology development and production of sensors. Fig. 1 shows picture of the wafer fabricated using one of the mask design. Test structures such as PIN diodes of various geometries, MOS capacitors, gated diodes, etc. have been incorporated in the mask design for carrying out process diagnosis and process optimization during fabrication. The final version of the sensor has been designed for the geometry of 63×63 mm, with strips of width of 1.78 mm and pitch of 1.9 mm [1]. Features such as floating field guard rings, metal overhang over the P^+ strips, and rounded corners have been incorporated in these designs to increase breakdown voltage of the strips. The floating field guard rings are known to reduce the surface electric fields and hence increase the breakdown voltages of the strips [4–5]. All the 32 P^+ strips are enclosed by four floating field guard rings. The last guard ring is located at a safe distance from the dicing edge so that mechanical defects due to dicing do not affect the leakage currents. The space along the periphery of the sensor has been utilized for fabricating various types of baby detectors, test structures and PIN diodes. These devices were designed for evaluating radiation hardness of the sensors in neutron and γ-radiation background, for physics experiments and radiation monitoring applications.

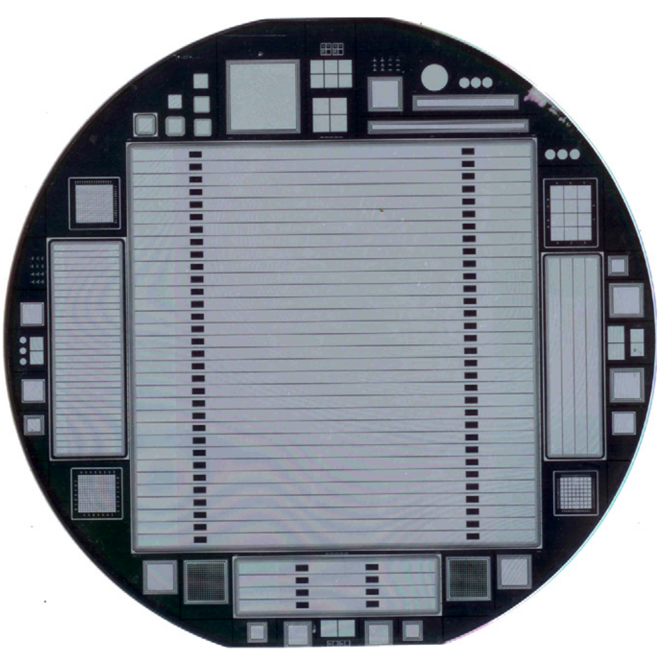

Fig. 1. Picture of the fabricated wafer showing silicon sensor and other test devices.

3. Characterization of sensors

The performance of the sensors was mainly evaluated by leakage current vs. voltage (IV) and capacitance vs. voltage (CV) measurements of each strip of the sensor. The measurements were carried out using automated setups incorporating programmable instruments (Keithely 6517, Keithely 237 and HP4284) interfaced to a PC using LabView. During the measurements, the high voltage was applied at the backside of the sensors and current/capacitance of each strip was measured simultaneously through a 32-channel multiplexer. IV measurements have been carried out for measuring leakage current per strip, the total leakage current of the 32 strips and the breakdown voltage of each strip (V_{BD}). The CV data was analyzed to calculate the full depletion voltage (V_{FD}) and to obtain the full depletion capacitance of each strip. The IV and CV data were used to qualify the sensors for the following specifications [6]:

- Full depletion voltage of the strips ($55 < V_{FD} < 150$ V).
- Breakdown voltage of each strip (>300 V).
- Total leakage current of the sensor $<5\,\mu$A at V_{FD} and $<10\,\mu$A at 300 V.
- Uniformity of leakage current for the strips—only one strip with leakage current $>1\,\mu$A at V_{FD} and $>5\,\mu$A at 300 V.

In addition to electrical measurements, mechanical dimensions (thickness, length, and width) and dicing quality were also monitored during quality control. The dicing process has been optimized so that no chipping occurs during dicing and the tolerance of 100 μm is achieved over the length and width of the sensors.

In order to ensure that the sensors would operate reliably in the radiation environment of LHC, the radiation hardness of the sensors was tested by irradiating them to fast neutrons up to a neutron fluence of 2×10^{14} n/cm^2 in a reactor (at BARC, India and at Dubna, Russia) and using a 24 GeV proton beam at CERN. The leakage current, breakdown voltage, and full depletion voltage were measured after successive doses of fast neutrons. As the leakage currents increase excessively due to the neutron radiation damage, the measurements after neutron irradiation were carried out at lower temperatures.

4. Preshower sensor technology development

The R&D for fabrication of silicon sensors has been carried out using the fabrication facility of BEL which is also the production center for production of silicon sensors and micromodule assembly in India. The technology development of the silicon sensors was challenging as it required control of properties such as leakage currents and