Indigenous Development of 128-Strip Silicon Strip Sensors using Thin, Six Inch Diameter Silicon Wafers

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Introduction

Position sensitive silicon sensors segmented into strips, microstrips, pads, etc., are being increasingly used for the precise measurement of energy and position of charged particles in nuclear and high energy physics experiments. These detectors have advantages such as high energy resolution, low voltage of operation and most importantly suitability to build compact detector systems requiring a large number of readout channels. Adopting well established silicon integrated circuit technology, these detectors can be manufactured in a large scale with good uniformity. We have earlier developed large area silicon strip sensors, double sided strip sensors, pad sensors and microstrip sensors for physics experiments on four inch silicon wafer process line [1-3]. Considering the international advancements in silicon sensor technology, the development of large area silicon strip sensors in a six inch wafer foundry was undertaken. The indigenous technology development for 128-strip silicon strip sensors with geometry of ~10 cm x 10 cm has been recently completed. The sensors were fabricated using six inch diameter wafers with a thickness of 300 µm. As the standard thickness of six inch wafers is 675 µm, fabrication on 300 µm thin wafers was very challenging. The fabricated sensors have very good uniformity, low leakage currents and high breakdown voltage exceeding 500 V. The details of the design of the sensors, fabrication process and static characteristics are presented in this paper.

Design of Silicon Strip Sensors

The silicon strip sensors were designed to have geometry of about 10 cm × 10 cm. The sensors comprise 128 strips at a pitch of 0.7 mm. For enabling the operation of the detector in high radiation environments for a long time, it is necessary to increase the breakdown voltage of the strips to few hundred volts. Hence, features such as multiple floating field guard rings, metal overhang on the strips, etc., were incorporated in the design for increasing the surface breakdown voltage. Based on the fabrication process, a five layer mask was designed to pattern various layers during the fabrication. The mask design also included several test structures to evaluate the process quality during the fabrication.

Fabrication Process

The development of large area silicon strip sensor on six inch wafer was very demanding due to thickness of 300 µm of the wafers and requirement of uniformity of all parameters over a large area of about 100 cm^2. The reduction of electronics noise of the sensor during operation demands optimization of fabrication process and substrate wafer parameters for minimization of the capacitance and leakage current of the sensor. The sensors were fabricated using high resistivity, N type, FZ, high resistivity wafers of six inch diameter with thickness 300 µm. The wafers with a life time of a few ms were chosen as it is a very effective parameter indicating the concentration of defects in the wafers. For a particular bias voltage, high resistivity of wafers allows higher depletion depth resulting in lower capacitance. The process sequence included several process steps such as; i) Field oxidation for silicon surface passivation, ii) Back side phosphorous implants, implant anneal & drive in, iii) Front side boron implant, implant anneal & drive in, iv) Contact opening and metallization, v) Passivation and pad opening, vi) Dicing and packaging. The initial process parameters were chosen based on the process and device simulation study. The fabrication process parameters were optimized so as to realize the desired breakdown voltage and leakage currents. The fabricated sensor is shown in Fig. 1.

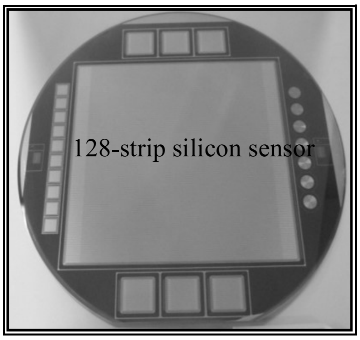

Fig. 1. Fabricated wafer showing 128-strip silicon sensor along with test structures.

The wafers were initially tested for leakage current and breakdown voltage measurements using a wafer prober. The final batch of wafers which met the desired specifications was diced and the sensors were packaged on a package to provide contact to 128 front side strips and backside of the detector. The package of the sensor was designed so that the sensor is suitable for integration with multi-channel preamplifiers and amplifiers in a physics experiment.

Static Characterization of the Sensor

The static characterization of the silicon sensor was carried out by leakage current measurements at various bias voltages. A multi-channel I-V measurement setup with automated measurements was developed to measure the leakage current of every strip. The typical I-V characteristics of a sensor are presented in Fig. 2. As can be seen, more than 98 % of the strips show very low leakage currents of about a few nano-amperes up to the measured voltage of 500 V and only three strips exhibit higher leakage of about a few microamperes. The total leakage current of the sensor of active area of about100 cm^2 is observed to be 32 µA at 500 V which is an indicator of the excellent quality of the sensor. The energy resolution with alpha particles was measured using 100 mm^2 PIN diodes fabricated using the same process as that of the strip sensor. The observed energy resolution is about 0.5 % with alpha particles of 5.5 MeV energy (Fig. 3). The strips are expected to exhibit better energy resolution due to their lower leakage current and capacitance compared to the PIN diode.

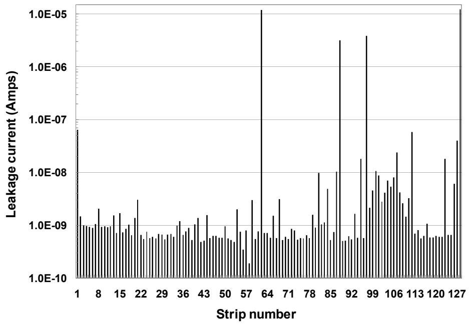

Fig. 2. Leakage currents for 128 strips at 500 V bias voltage.

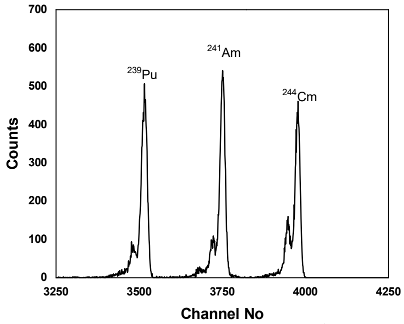

Fig. 3. Alpha spectrum of a 100 mm^2 PIN diode.

Conclusions and Outlook

Indigenous technology for the fabrication of large area strip sensors on six inch size wafers has been developed. The sensors show excellent uniformity with breakdown voltage exceeding 500 V. Further experiments will be carried out to study the performance using charged particle beams.

References

[1] Nucl. Instr. and Meth. A, 585 121 (2008).
[2] BARC News Letter, 290, 2, (2008).
[3] Nucl. Instr. and Meth. A, 834, 205 (2016).