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Development of a two-dimensional strip radiation sensor fabricated with normal silicon processes

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Abstract

A two-dimensional readout micro-strip sensor processed with single-sided silicon processes has been designed and fabricated. Both $p^+(X)$ and $n^+(Y)$ electrodes are placed on one side. The n^+ electrode is surrounded with the p^+ strips to make isolation of each n^+ electrode. The test chip was fabricated at HPK. The detector properties have been measured and the basic idea of p^+ and n^+ structure on the sensor has been confirmed. However, a suppression of the breakdown is not sufficient to achieve deep depletion underneath the n^+ electrode. This comes from a too thin isolation SiO_2 layer between the p^+ and n^+ readout-strip at the crossing points.

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Keywords: Silicon detector; Two dimensional position sensor; Two dimensional strip sensor

1. Introduction

Two-dimensional imaging radiation detector is desired for use as an advanced X-ray camera or for making precise measurements of elementary particle experiments. A back-illuminated, fully depleted CCD detector is one of the ideal sensors for the soft X-ray imaging of astrophysics and of medical diagnostics. On the other hand, a significant improvement of readout speed and radiation hardness of the CCD is required for the high-energy particle detector. A pixel sensor with an individual readout will be a solution for the high-energy particle experiments, but it has a fundamental difficulty of one-by-one readout channel connection between the sensor and the readout electronics. Another approach to obtain a two-dimensional position with a single sensor is a double-sided strip sensor, which can be produced by a special fabrication technology of double-sided silicon processes. The low-production yield and high cost are disadvantages of this approach. Some interesting proposals and attempts for 2D and 3D Si detectors have been reported [1–5] to improve performance and productivity or to simplify silicon processes, but they are still far from a perfect solution.

Here we propose to design and produce a pixel detector with X, Y strip readout. One additional requirement for achieving excellent production yield is to produce them with single-sided silicon processes. The single-sided processes have been well established and the excellent production yield of the strip detectors has been reported [6].

2. Design of the two-dimensional strip sensor

This prototype sensor is designed on the bases of isolation technology of n^+ electrode on n-type high-resistive silicon substrate. An n^+ electrode is surrounded by p^+ implant to achieve isolation. The p^+ strips go along X direction with narrow branches running along Y direction. The adjacent p^+ strips with the p^+ branches make an isolated pixel and the n^+ electrode is placed at the

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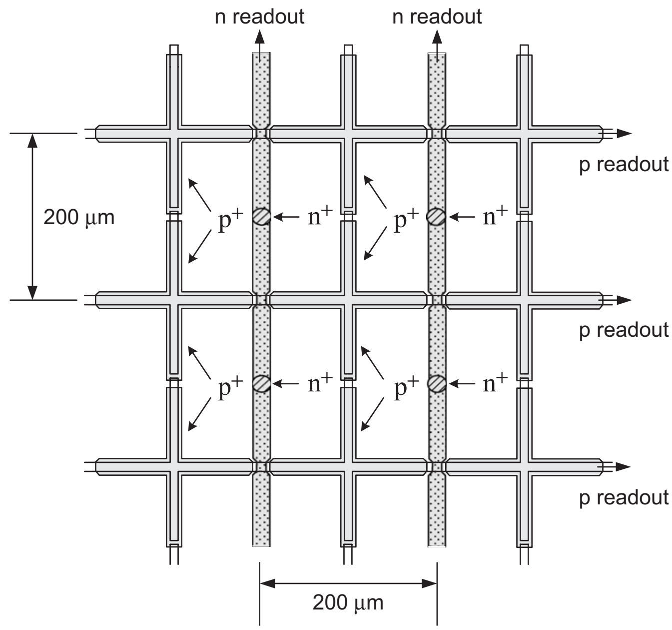

Fig. 1. Top view of the sensor. The dotted area indicates the aluminum strips of the n-readout. The gray area is aluminum covered on the p^+ implant to suppress a micro-discharge and to reduce the impedance of the p-readout strip.

center of the pixel. Since adjacent p^+ strips should be isolated from each other to specify the hit strip and Y position, a 5 μm gap between adjacent p^+ branches is installed. So far, the gap distance is not optimized to achieve isolation of adjacent p^+ strips and to minimize capacitance between them. The n-strip measuring X position is formed by the Al strip that is connecting the n^+ electrodes and runs perpendicular to the Y readout strips. The Al strips are deposited above the SiO_2 layer and isolated at crossing points with the p^+ strips underneath the SiO_2 layer. Fig. 1 shows the top view of the sensor illustrated. The diameter of the n^+ electrode is only 20 μm but the MOS structure of Al strip helps to make a better potential map. The p^+ implant strips 20 μm wide are placed by 200 μm pitch. These are covered by Al electrodes of 29 μm wide to prevent edge breakdown [7,8]. The p^+ branch is 8 μm wide and it is covered by Al electrode of 17 μm wide. The signal readout scheme is like a double-sided strip detector. Positive holes collected are readout with the p(Y) strips and electrons collected are readout from the n(X) strips. The crossing regions of X and Y strips are made narrow (5 μm) to reduce the readout capacitance. The design parameters of this prototype are listed in Table 1.

3. Leakage currents and p–n junction capacitance

The leakage currents as a function of reverse bias voltage have been measured to evaluate basic properties of the prototype sensor. To measure the leakage current, all of p-strips were connected with a ground and all of the n-strips were connected to positive bias via an electrometer.

Table 1
Design parameters of the prototype sensor

Chip size	8.5 mm × 8.5 mm
Effective area	6.2 mm × 6.2 mm
Number of strips	32 × 32
Number of pixels	1K
Strip pitch	200 μm
Width of p^+ strip	20 μm
Width of p^+ branch	8 μm
Diameter of n^+ impurity	20 μm

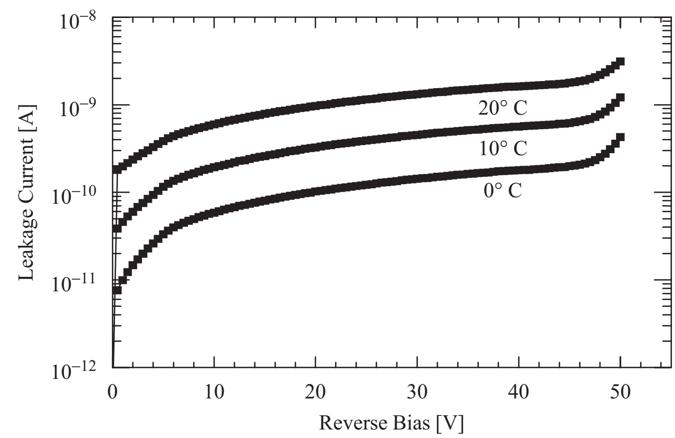

Fig. 2. Leakage current as a function of reverse bias voltage.

Fig. 2 shows the leakage currents vs. bias voltage of one chip at three different temperatures: 0, 10, and 20 °C. A typical value of leakage current is 1.6 nA (50 pA per one strip) at 40 V, which is reasonably good and guarantees high-quality silicon processes. An evidence of micro-discharge starts at around 47 V, which can be expected from a SiO_2 thickness of 1 μm between p^+ strips and n(X) readout Al electrodes. For the fabrication of this prototype sensor, we utilized test production of multiple rides on a single wafer so that only a standard process using a 1 μm SiO_2 layer was available between X and Y strip isolation.

Fig. 3 shows the body capacitance as the function of reverse bias voltage to see the depletion depth in the substrate. The depletion layer extends from the p^+ strips to the n^+ electrodes. The capacitance curve shows that the depletion layer has reached to the n^+ electrodes around 13 V and gradually extends toward other side of substrate. At the bias voltage of 47 V, the starting voltage of micro-discharge, the bulk capacitance is ~120 pF and still decreasing. This means that the detector is not fully depleted at the starting voltage of micro-discharge. Therefore, we have measured following properties of the prototype detector at the bias voltage of 40 V.

4. The X-ray and γ-ray spectra of ^{133}Ba

The X-ray and γ-ray spectra of ^{133}Ba sources have been taken at the reverse bias voltage of 40 V. The preamplifier and shaper amplifier used for this test are CLEAR-PULSE