Development of a two-dimensional strip radiation sensor with single-sided silicon processes

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Abstract

A two-dimensional readout micro-strip sensor made by single sided silicon process has been designed and fabricated. Both p^+ and n^+ implants are implemented on one side. The n^+ electrode is surrounded with the p^+ implant strips to make isolation of each n^+ electrode. The test chip has been fabricated at HPK. The detector properties have been measured and basic idea has been proofed. However, a breakdown starts at less than 50V, which is not sufficiently high to achieve deep depletion underneath the n^+ electrodes. The micro-discharge is expected to happen at the crossing point of p and n strips due to the insufficient thickness of SiO_2 insulator layer.

1. Introduction

A two-dimensional position sensor is essential for an imaging radiation detector. A fully depleted CCD detector is one of the ideal X-ray imaging sensors for astrophysics. On the other hand a significant improvement of readout speed and radiation hardness of CCD is desired 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 connection between sensor part and readout electronics. Another approach to obtain a two-dimensional position with single sensor is a double-sided strip sensor. This can be produced by the special fabrication technology of double-sided silicon processes,

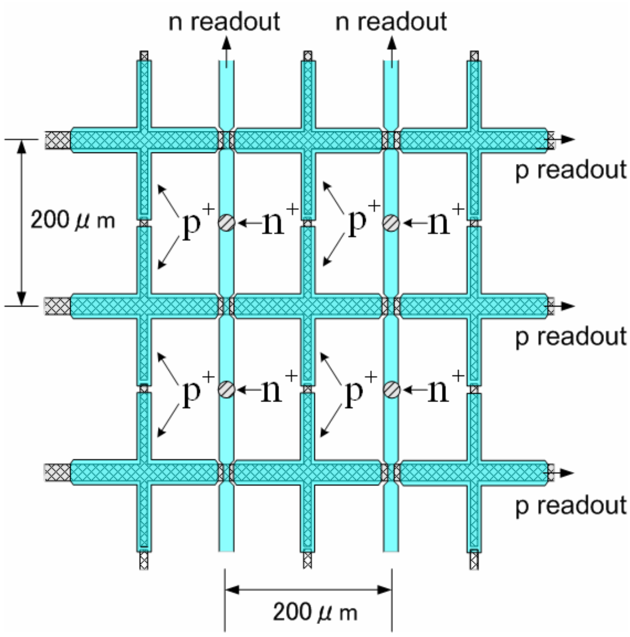

Fig. 1 Top view of the sensor Blue areas are aluminum strips and gray are n+ or p+ implanted areas.

so that production yield is low and hence production cost is high.

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. Fabrication of microstrip sensors with single-sided processes has been established well and excellent production yield & high quality has been reported (1).

2. Design of the two dimensional strip sensor

This sensor is designed on the bases of isolation technology of n^+ strip on n type silicon bulk. An n^+ electrode is surrounded by p+ implants to achieve isolation. The p^+ strips go along X direction together with Y direction short branches. The adjacent p^+ strips with the p^+ branches make an isolated pixel and the n^+ electrode of circular shape is placed at the center of the pixel. Since adjacent p^+ strips should be isolated each other to specify the hit strip and Y position (Y-strip), a 5μm gap between adjacent p^+ branches is installed. So far, the gap distance is not optimized to achieve isolation of the p^+ strips and to minimize capacitance between them. X-positions (X-strips) are measured by Al strips (20μm) that are connecting the n^+ electrodes, and they run perpendicular to the Y strips. The Al X-strips are deposited above the SiO_2 layer and isolated with the p^+ strips implanted underneath the SiO_2 layer. Figure 1 shows the top view of the sensor illustrated. The light blue areas are aluminum strips. The diameter of the n^+ electrodes is 20μm. The p^+ strips are formed with 200μm pitch and have 20μm width. They are covered with the Al electrodes of 29μm wide. The p^+ branches have 8μm width and they are covered with 17μm wide Al strips. Positive holes produced by radiation are collected in p^+ strips and read out just like a strip detector. The Al strips that covered the p^+ implant are wider than that of p^+ implant to suppress the micro-discharge (2). Liberated electrons are collected in n+ electrodes and readout through an X strip. At the crossing regions of the X and Y-strips, the Al X-strips are made narrow (5μm) to reduce the readout capacitance. We list up design parameters in the Table 1.

Table 1
Design parameters of the sensor

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

3. Leakage currents and p-n junction capacitance

The leakage currents vs. 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 to ground and all of n^+ strips were provided by positive bias potential via electrometer. Figure 2 shows the leakage currents as a function of bias voltage at three temperatures (0,10,20℃). The typical value of leakage current is 1.6nA (50pA per one strip) at 40V, which is reasonably good and guarantees the high quality silicon process. An evidence of micro-discharge starts around 47V, which may be expected from SiO_2 thickness of 1μm between p+ strips and X readout Al electrodes. For the production of this prototype sensor, we utilized the test production of multiple-ride on single wafer, so that only a standard process of 1μm SiO_2 layer is available between X and Y strip isolation.

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

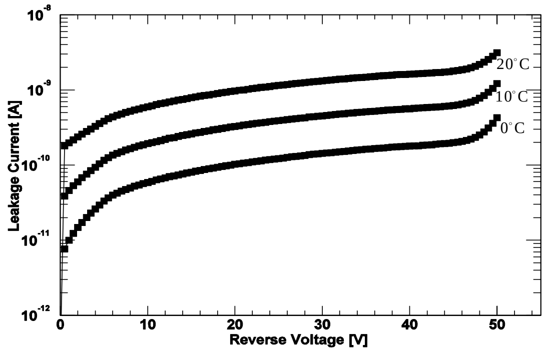

Fig.2 Leakage currents versus reverse voltage on the p and n strips

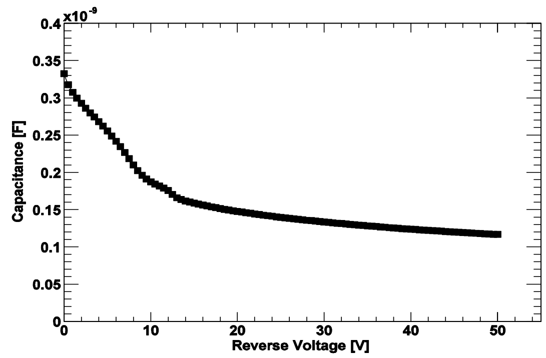

Fig.3 Reverse bias voltage dependence of the p-n junction capacitance

4. The output signals of X-ray

The X-ray spectra of ^{133}Ba has been taken at reverse bias voltage of 40V. The p-strip and n-strip signals are shown in Fig. 4 and 5, respectively. In Fig.4, the peaks corresponding to 32keV and 81keV are seen clearly. In Fig.5 the 32keV peek is clear but 81keV is not clear, which is due to the lower efficiency of n-strips for higher energy X-ray. The reason of lower efficiency of n-strip will be discussed in next section. X-rays are absorbed at small volume via photoelectric effect. Since they deposit an entire energy at the volume, the peak position of X-ray energy is independent of depletion depth. The principle of this sensor has been confirmed and the two dimensional position of

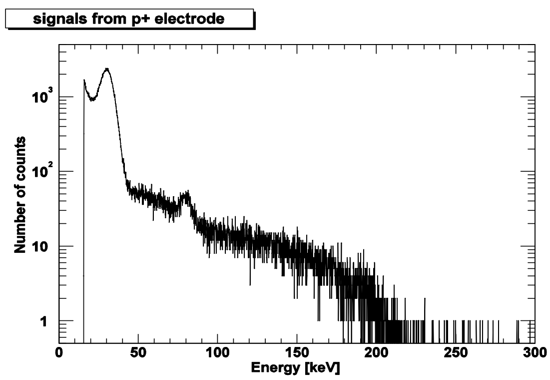

Fig. 4 X-ray spectrum for ^{133}Ba taken from a p strip

X-ray was detected, though detection efficiency was not excellent.

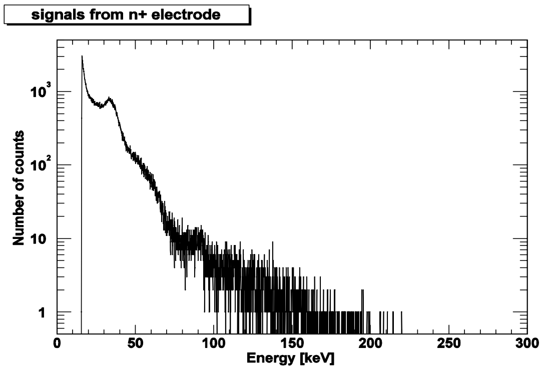

Fig. 5 X-ray spectrum for ^{133}Ba taken from an n strip

5. Field Simulation

Figure 6 shows the potential lines and the depletion region calculated for the cross section of the sensor. In this figure the typical field lines are indicated as allows. We assumed an n-type substrate with $0.5\times10^{12}/cm^3$ impurity concentration and the conductor electrodes of p and n-strips with the reverse bias voltage of 40V for the calculation. Distance between the center of p-strip and n-electrode is chosen to be 100μm. The junction is formed at p^+ strip and extends toward n^+ electrode. As seen in Fig. 6, the depletion depth under the p-strips is much deeper than that under the n-strips. Some of the field lines end up with non-depleted substrate, which means that electron signals of some events will be absorbed in the back plane and lost. Thus the efficiency of the electron signal collected through n^+ electrode is low.

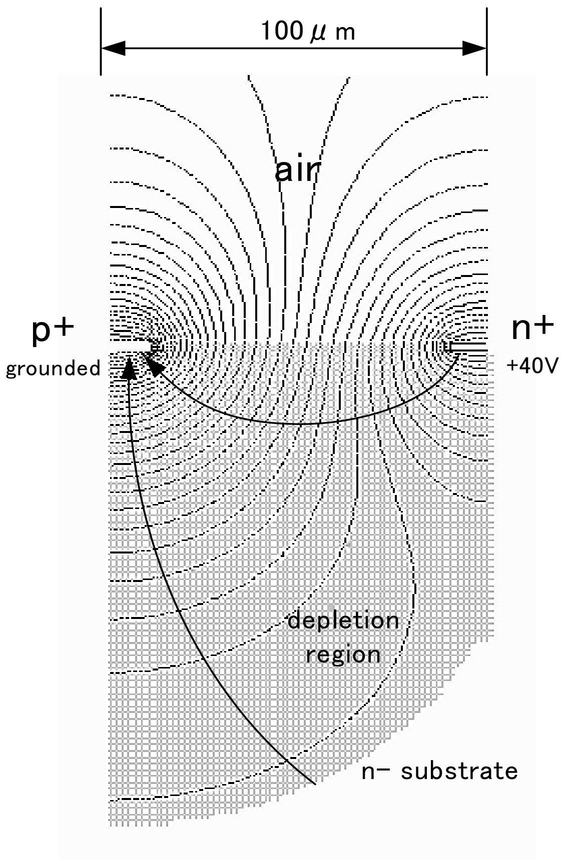

Fig.6 Potential lines and depletion region for the cross section of the sensor

6. The signals of infrared laser pulse

In order to evaluate the depletion depth of various position of the detector, we used the infrared laser having the wavelength of 1064 nm (IR) which corresponds to 1.167eV and is very close to the silicon band gap energy (3). Since the absorption length of this IR light in silicon is more than detector thickness (300μm), the output signal height by shining a short IR pulse beam should indicate the thickness of depletion along a IR trajectory. Figure 7 shows the pulse height (ADC unit) taken from a p-strip for each position. Since the pulse height is expected to be nearly proportional to depletion depth, large pulse height indicates deep depletion. The position close to the p^+ strip has deeper depletion and the position closed to the n^+

electrode has shallow depletion depth. The narrow p^+ branch has a weaker power to deplete substrate in comparison with thick p^+ strip. The n^+ electrode should be larger size to absorb more field line and make thicker depletion depth. Another approach to improve the depletion of n^+ side is to make deep implant of n^+ channel.

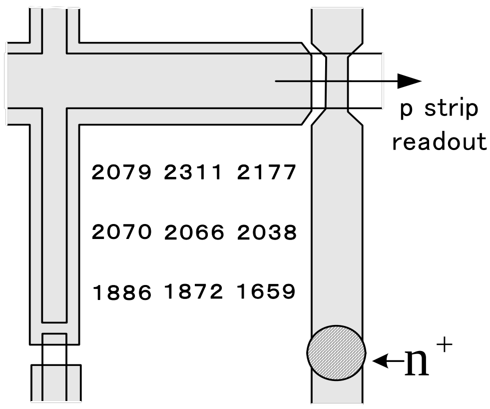

Fig.7 Position dependences of the ADC peak values taken from a p strip

7. Conclusion

We have confirmed that the idea of a two-dimensional position sensor made with single sided silicon process can work. However, significant improvement of micro-discharge voltage is needed for obtaining sufficient depletion depth and sufficient detection efficiency of the n^+ electrodes. The efficiency difference between p^+ and n^+ electrodes are analyzed and explained to be the difference of depletion depth with field calculation. To confirm the explanation with depletion depth underneath the p^+ and n^+ electrode, we have used the infrared laser (1064 nm) pulse beam. Starting voltage of the breakdown is not sufficiently high to achieve deep depletion underneath the n^+ electrode. The crossing region of p^+ and n^+ strips has the highest field and it is the weakest area for micro-discharge. Only ~1μm thick SiO_2 layer is not sufficient to suppress micro-discharge. We should make thicker SiO_2 layer (more than 3μm) by using the double metal layer technique (4).

Acknowledgements

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