SOI based High Energy Particle Imaging with Continuous Time Integration Type Variable Gain Pixel

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Abstract High energy particle imaging requires a detector with wide bandpass spectral response and high hit position pixel readout time. This paper presents the event driven wide dynamic range high energy particle detector for astronomical application. Silicon on insulator (SOI) based fully depleted pixel detector with high charge collection efficiency and high conversion gain has a pixel circuit with in-pixel event detection circuit and variable gain selection logic. Event detection circuit detects the incoming of the high energy particle in the detector. Strength of the detected signal is then compared within the circuit with minimum threshold energy for the amplification. In-pixel gain for an incoming energy is applied for low noise and wide dynamic range X-ray imaging.

Keywords: SOI pixel detector, High energy particle imaging, Event driven pixel, In-pixel gain

1. Introduction

X-ray detector with wide bandpass spectral response and high hit position readout time is highly desirable for high energy particle imaging. It should also be able to detect wide energy range from 0.3-40 [keV] [1][2]. Silicon on insulator (SOI) based monolithic pixel detector is shown in figure 1. It uses fully depleted SOI (FD-SOI) for the electrical circuitry and a high resistivity handle wafer for the detector [3]. By using FD-SOI layer for the electrical circuitry one chip monolithic X-ray pixel sensor device can be obtained and by using the high resistivity handle wafer a wider depletion sensor to various X-ray energy can be embedded. Thus SOI-based fully depleted pixel detectors and SOI CMOS circuits for in-pixel processing and readout offers an ideal solution for high energy particle detection [4][5]. The developed fully depleted SOI pixel detector has high conversion gain and high charge collection efficiency [6].

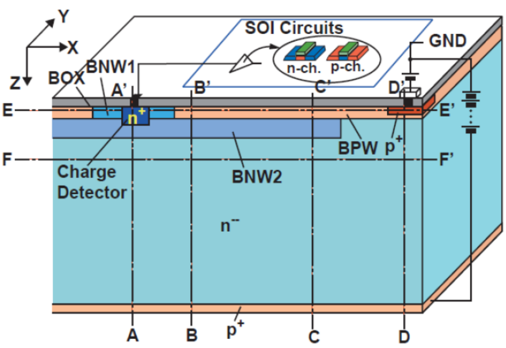

Fig. 1 SOI Pixel Detector

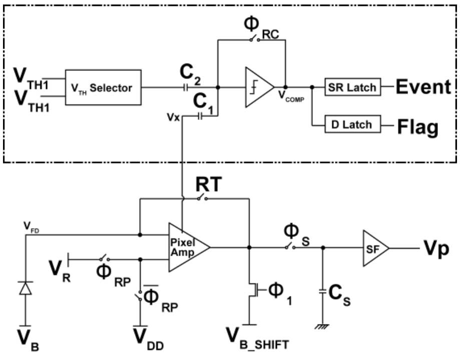

Fig. 2 Event Driven Pixel Circuit

2. Event Driven Detector

Figure 2 shows the circuit diagram of the pixel circuit for an event driven detector. Pixel circuit is functionally divided into two parts: Signal sensing circuit and event detection circuit. During the reset phase, reset signal is sampled. Event signal from the event detection circuit is continuously scanned. When the detector absorbs the X-ray energy greater then minimum threshold voltage, an event signal is triggered. After the event is detected, threshold voltage is changed for the evaluation of the signal strength. Flag signal from the event detection part of the pixel circuit is used for the indication of the signal strength.

Detection of the signal strength is used for the selection of the in-pixel gain. High gain is provided to the weak incoming signal. If g_m is the transconductance of the input transistor of the pixel amplifier with a bias current I_{PIX}, sampling capacitor C_S and integration time

T_{int} for achieving the desired gain, the output voltage V_O is given by equation 1.

$$V_O(T_{int}) = \frac{g_m T_{int}}{C_S} V_{in} \quad (1)$$

Figure 3 shows the output response of the pixel with respect to the time for different input voltages. During the time period T_1 to T_2, C_S discharges to fix potential V_{B_SHIFT}. For the time period T_2 to T_3, Φ_1 is turned OFF and current starts to flow to the capacitor C_S proportional to the input voltage. Gain is directly depended on integration time T_{int} within the time period of T_2 to T_3.

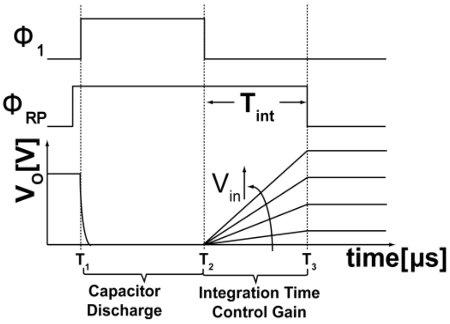

Fig. 3 Output Response of Pixel with Integration Time

3. Results

Figure 4 shows the simulation result for the event-driven pixel circuit. Pixel response for wide range of energy range (0~60 [keV]) is simulated. Time is varied from 0.1 [μs] to 4 [μs] and the response of the pixel output was observed. Higher integration time shows linearly increasing output response. However, peak to peak output voltage swing is limited by readout circuitry. Readout circuitry is designed with 1 [V] output swing with a supply voltage of 1.8 [V].

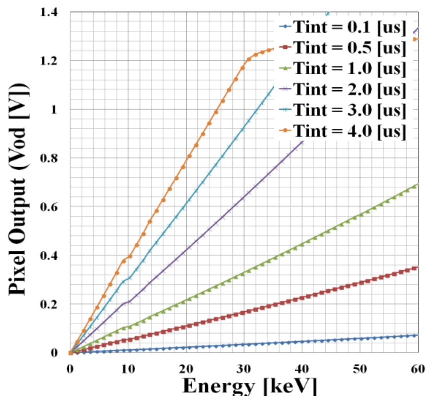

Fig. 4 Output Characteristics of Pixel Circuit

Figure 5 shows the gain linearity curve. Gain increases linearly with the increase in the time. Gain can be dynamically adjusted over the range of 1 to 30 by changing the integration time of in-pixel amplifier. If the incident energy spectrum is high enough we provide the gain of 1 and if the incident energy has very low energy spectrum high gain (e.g. 30) is provided.

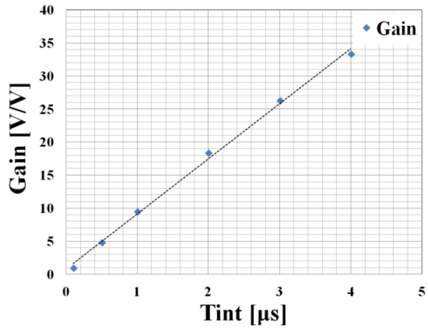

Fig. 5 Gain Linearity Curve

4. Conclusions

An event driven detector was implanted with a variable gain selection technique using continuous time integration in-pixel amplifier circuit. Gain varies linearly with the integration time. 0.2 [μm] SOI pixel detector with high conversion gain and high charge collection efficiency was used. FD-SOI is a promising structure to realize high performance and reliable X-ray pixel sensor. Adjustable gain selection with event trigger pixel circuit makes it suitable for the wide range X-ray imaging.

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