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X-ray detection with 3D Medipix2 devices

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Abstract

A set of double-sided 3D silicon detectors have been fabricated, bump bonded to single-photon-counting Medipix2 readout chips, and tested using X-ray sources. When tested with monochromatic X-rays, the 3D detectors show reduced charge sharing compared to standard planar pixel detectors.

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1. Introduction

3D detectors [1] are photodiode detectors with n- and p-type electrode columns passing through a silicon substrate. Using this structure, the spacing between electrodes can be made much smaller than the substrate thickness, greatly reducing the collection time and operating voltage of the sensor. Furthermore, the electric field lines running parallel to the surface provide some self-shielding to the pixel structure, reducing the charge sharing between adjacent pixels and improving the image quality. This reduced charge sharing makes these detectors potentially useful for diffraction experiments in X-ray synchrotrons.

2. Double-sided 3D Medipix2 detectors

A variation of the 3D design, intended to simplify the fabrication process, is the "double sided" configuration [2]. The "double-sided" 3D structure has both n and p-type columnar electrodes. The columns do not pass through the full thickness of the substrate, the holes of one doping type being etched from the front side of the wafer, and the holes of the other type from the back side. Simulations [3] have shown that the double-sided 3D structure shows similar electrostatic behavior to full 3D, giving a low depletion voltage and fast charge collection. However, there are low electric field regions around the front and back surfaces where the charge deposited is collected less quickly, though still rapidly compared with a planar geometry device.

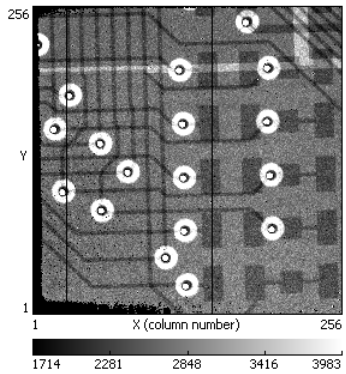


Fig. 1. X-ray image of a PCB obtained with a double-sided Medipix 3D detector.

The 3D detectors used in this study were produced by IMB-CNM (Spain) using 300µm-thick high resistivity n-type FZ-silicon wafers. The readout electrodes, etched from the front side of the wafer, are p^+, and the biasing electrodes, on the back side, are n^+ and are all connected together by polysilicon and metal layers that provide the back contact. The columns have a diameter of 10µm and a depth of 250µm. A more detailed description of the devices and the fabrication technology can be found in [2].

The detectors were bump bonded to Medipix2 [4] readout chips at VTT (Finland) and mounted to chipboards. The readout was done via the USB 1.1 interface developed by IEAP-Czech Technical University, Prague [5].

3. Characterization and comparison with planar Medipix2

To demonstrate the imaging capabilities of the double sided 3D detectors an X-ray image of a PCB was obtained. It can be seen in Fig. 1. The image was taken with the 60kVp voltage setting on a dental X-ray tube with a Tungsten target (X-ray peak at about 30keV). The lower internal threshold (THL) of the Medipix2 chip was set to 300 –from source scans, it was found to be equivalent to an energy of 20 keV. The vertical lines in the picture correspond to dead columns in the readout chip. The insensitive regions in the left and bottom sides are due to detached bumps on this sensor. This was observed in two of the three 3D detectors that were tested and is probably due to the curvature in the detector wafers induced by the polysilicon

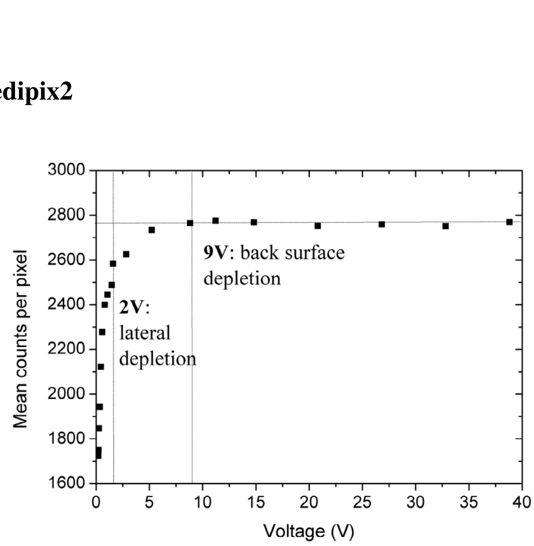


Fig. 2. Count rate vs. bias voltage of the 3D Medipix2 detector.

deposition. This fabrication step needs to be carefully monitored as the curvature of the wafers could substantially reduce the number of good detectors in a production run.

3.1. Pixel count rate vs voltage

The dependency of the pixel count rate with the bias voltage was measured with the dental Bremsstrahlung source at 60 kVp and a 0.84s exposure.

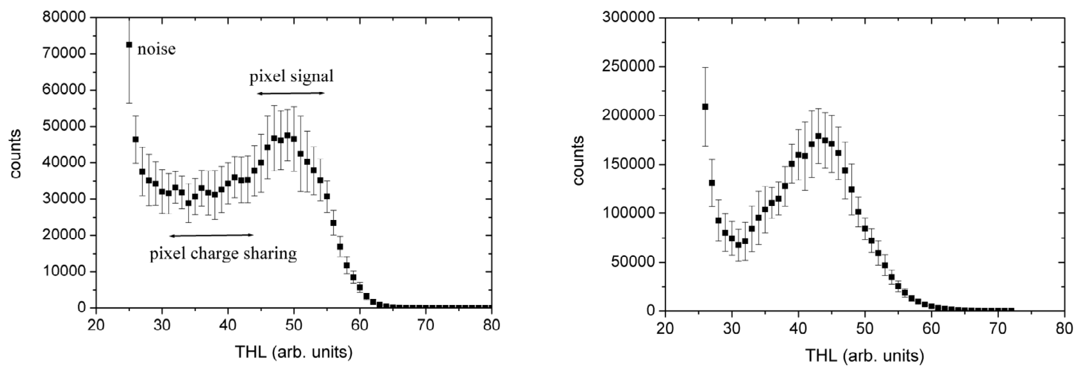
Previous measurements of the noise spectrum at 16V and 40V, scanning THL through the noise level without using any source, had shown a shift in the spectrum of about 5 THL units towards lower THL values, presumably due to the increased leakage current at higher bias. Consequently, the THL settings were adjusted during the test to make sure that the equivalent energy of the threshold was the same for all bias conditions, 20 keV.

The resulting plot is shown in Fig. 2. The count rate rises rapidly from 0 to 2V as the depletion region grows horizontally and vertically outwards from the p+ electrodes, until the region where the columns overlap is fully depleted, as shown by the device simulations [3]. From 2 to 9V the increase in count rate is slower as the depleted area progresses from the tip of columns to the back surface. For V>9 V the count rate is constant which indicates that the detector volume is fully depleted.

3.2. Signal and charge sharing with monochromatic X-rays

THL scans were performed on a 3D Medipix2 detector to find the signal spectrum. A 300μm planar Medipix2 was also tested for comparison. The spectra were obtained by scanning the lower threshold of the chip DAC then taking the gradient of the mean number of counts.

The plots in Fig. 3 show the spectra obtained with monochromatic 8keV X-rays produced by a X-ray tube with a Cu target. The THL values in the x-axis have been displaced so that the noise centroid is in THL=0 in both plots. The spectra peak at about the same THL value, which means that both detectors have comparable signals. However, the 3D detector has reduced charge sharing with respect to the equivalent planar detector, as demonstrated by the lower count rate for energies below the 8keV peak.



a) b)

Fig. 3. Spectra of an 8keV monochromatic X-ray source obtained with the Medipix2 detectors. a) Planar, 100V. b) 3D, 22V.

4. Conclusions

Medipix2 double-sided 3D detectors have been succesfully fabricated and tested using X-ray sources. Pixel count rate vs voltage tests show that the devices are fully depleted for V>9V. The first results of their characterization with monochromatic 8keV X-rays show substantially reduced charge sharing compared to standard planar photodiodes.

Acknowledgments

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