Characterization of a 3D Medipix2 detector with a micro-focused synchrotron beam

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Summary

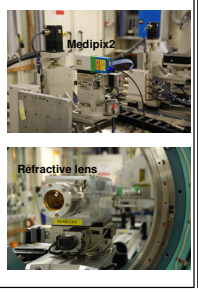
Hybrid silicon photon-counting detectors consisting of arrays of silicon photodiodes bump-bonded to CMOS electronic read-out chips, such as CCD, offer several advantages over traditional X-ray detection technologies used for synchrotron applications. A survey of the requirements for future detectors highlighted the needs for pixel detectors with pixels smaller than 100 µm [1]. However reducing pixel size leads to an increased proportion of charge-sharing between pixels [2, 3] and degrades the energy resolution of the detector. This image quality degradation can be reduced by using 3D silicon sensors [4] bump-bonded to Medipix2 chips [5] with USB readout electronics an Pixelman software [6, 7], where p-type and n-type electrodes pass through the thickness of the silicon sensor. A drawback of 3D sensors structures is the loss of detection efficiency due to the presence in the pixel structure of heavily doped electrode columns which are insensitive to X-ray.

AIM

To study the charge sharing and the low efficiency areas inside a unit cell of two kinds of 3D detectors (n-type and p-type) at two different bias voltages (laterally and fully depleted) in comparison to a planar silicon detector.

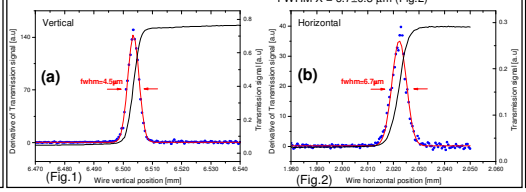
Experimental Set-up

Two types of double sided 3D detectors and a planar silicon detector were scanned by a monochromatic synchrotron beam which was focused to several microns of diameter by using X-ray refractive optics. The scan covered an area of 75x75 µm², centered on a pixel of the detector, in 2.5 µm steps in both x and y, by using a TTL pulse to trigger the acquisition and an xy stage scan (¼ pixel scans done for different bias voltages and Medipix2 energy thresholds). The number of photons per pixel over the full sensor area was recorded for each beam position for three different Medipix2 energy thresholds (25% - 50% - 75%) and 2 bias voltages for 3D detectors (laterally and fully depleted).



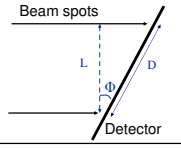
Beam Characteristics

- Test beamline B16 at the Diamond Light Source Ltd, UK
- 3rd generation Synchrotron
- Transmission signal from a gold wire scan (black line Fig.1 & 2)
- 14.5 keV photons, beam spot: FWHM Y = 4.5±0.3 µm (Fig.1)
  FWHM X = 6.7±0.3 µm (Fig.2)



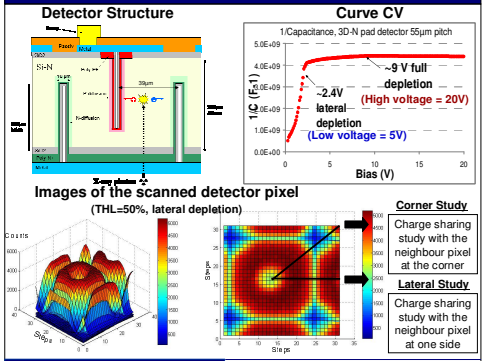
Detector Alignment

- Perpendicular to the beam in order to ensured the beam would enter an leave the silicon inside a column electrode in the 3D detector.
- Move L and measure D as two spots on detector
- To maximize sensitivity rotated detector by ±45º and aligned detector.

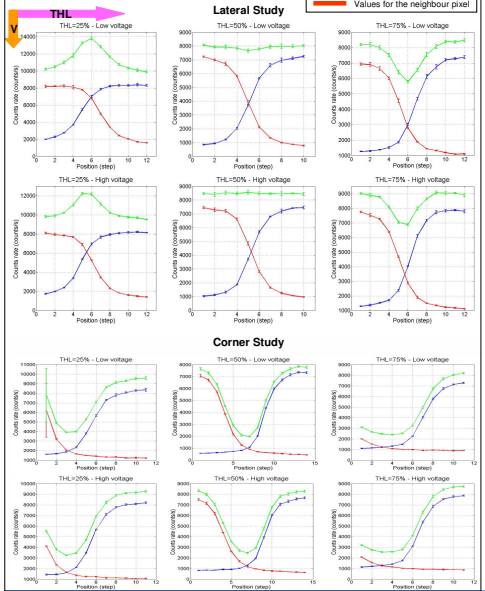


$$\cos \Phi = \frac{L}{D}$$

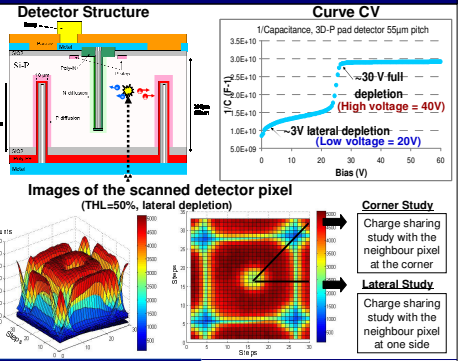
N-type 3D detector



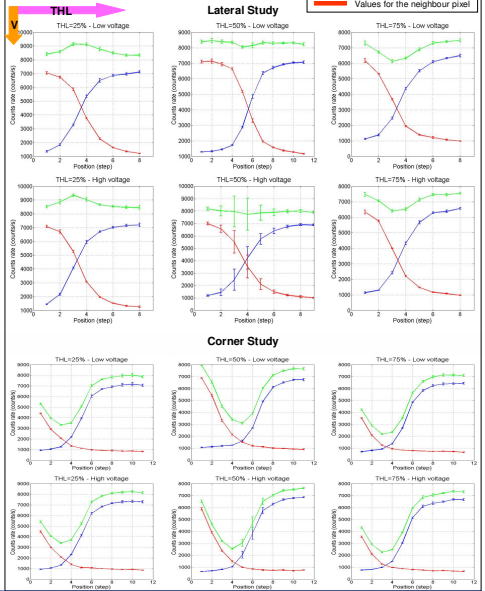
Charge Sharing Study



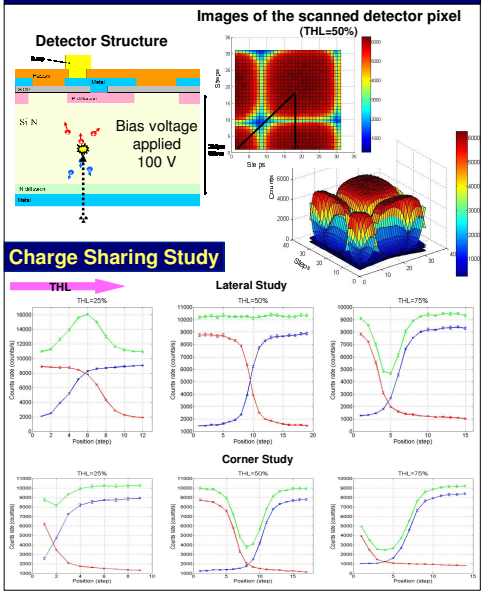
P-type 3D Detector



Charge Sharing Study

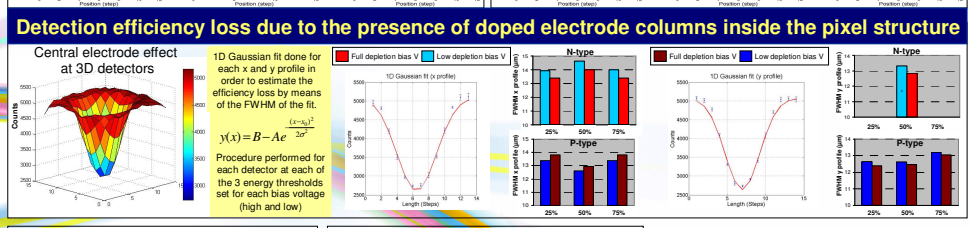


Planar



Charge Sharing Study

Detection efficiency loss due to the presence of doped electrode columns inside the pixel structure



Conclusions

◆ For the 3 silicon detectors under study (n-type 3D, p-type 3D and planar) charge sharing between pixels was investigated by scanning a narrow 15 keV X-ray beam across pixel boundaries. For a threshold set at 50% of X-ray energy, results show that the width of the charge sharing region between 2 pixels is reduced by the 3D electrode structure (~ 12.5 µm) compared to planar structure (~ 17.5 µm).

◆ When X-ray energy threshold is set at 75% (i.e. in order to suppress low energy fluorescence background from diffracted patterns) charge sharing between pixels translates into count loss at edges and corners of pixels. This count loss is reduced in the 3D structure detectors at the edge of the pixels.

◆ In general, the 3D detector with p-type structure shows less charge sharing than n-type.

◆ However, for 3D hybrid silicon detectors, the results show that detection efficiency is reduced as a direct consequence of the presence in the pixel structure of heavily doped electrode columns that pass through the thickness of the silicon sensor. The profile of a central electrode fits to a Gaussian with a FWHM of 13.4 µm diameter and FWTM diameter of 21.3 µm in an area located at the centre of the pixel (independent of the 3D detector type and the applied bias voltage).

[1] S.f. Parker et al., Nucl. Instr. and Meth. A 395 (3) (1997) 328.
[2] D. Pennicard et al. Nucl. Instr. and Meth. A 604 (2009) 412–415
[3] K. Mathieson et al. Nucl. Instr. and Meth. A 487 (2002) 113–122
[4] G. Pellegrini et al. Nucl. Instr. and Meth. A 592 (1–2) (2008), 38.
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[6] Z. Vykydal et al., Nucl. Instr. and Meth. A 563 (1) (2006), p. 112.
[7] http://www.utef.cvut.cz/

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