International Journal of Modern Physics A
© World Scientific Publishing Company

Development of a Super B-Factory Monolithic Active Pixel Detector -the Continuous Acquisition Pixel Prototypes-

M. Barbero[1], A. Bozek[2], T. Browder[1], F. Fang[1], M. Hazumi[3], A. Igarashi[4], S. Iwaida[4], J. Kennedy[1], N. Kent[1], S. Olsen[1], H. Palka[2], M. Rosen[1], L. Ruckman[1], S. Stanic[4], K. Trabelsi[1], T. Tsuboyama[3], K. Uchida[1], G. Varner[1]

[1] *Univ. of Hawaii, Department of Physics and Astronomy, Watanabe Hall, 2505 Correa Road, Honolulu, Hawaii 96822, USA*
[2] *H. Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences, ul. Radziekowskiego 152, 31-342 Krakow, Poland*
[3] *KEK, High Energy Accelerator Research Organization, 1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305-080, Japan*
[4] *Univ. of Tsukuba, 1-1-1 Tenodai, Tsukuba-shi, Ibaraki-ken, 305-8573, Japan*

Received (Day Month Year)
Revised (Day Month Year)

The innermost layer of the Belle silicon vertex detector operates 1.5cm away from the collision point of the highest luminosity collider in the world. Occupancy in this innermost layer is already 10% and expected to continue increasing with the planned significant luminosity increases. A pair of prototype detectors has been developed to address this problem, based upon the same CMOS camera technology now widely deployed in low-cost consumer devices such as cellular telephones. Problems unique to operating in a high luminosity B-factory environment are discussed. Results from a number of tests are presented, demonstrating the viability of this detector technology.

Keywords: Monolithic Active Pixel Sensor; MAPS; CAPS; Super B-Factory.

1. Introduction: The Prototype Continuous Acquisition Pixel

Even prior to the commissioning of the B-Factory detectors, it was realized that improvements in the vertex performance could be made through the adoption of a pixel detector. The two most important aspects to obtaining improvement in a B-Factory environment are moving closer to the beam pipe and reducing the amount of material[1]. Therefore the thick hybrid pixel technology, employed for the LHC[2], is not viable. As the KEK B-Factory[3] is already the highest luminosity collider in the world, radiation damage close to the interaction point is a major issue. CCD-based detectors[4] remain radiation soft despite efforts to improve their radiation hardness. Meanwhile great strides have been recently made in applying to vertexing the same active pixel sensor technology that has led to the explosion of digital cameras. A pair of prototype devices has been developed in the context of the Super-Belle upgrade. Named the Continuous Acquisition Pixel (CAP) 1 and 2, they are based

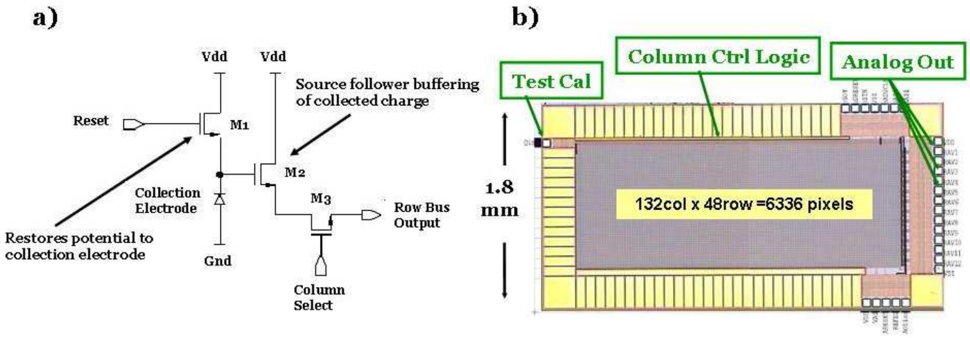

Fig. 1. a) Basic 3-transistor cell. M1 is the reset transistor, M2 senses the gate voltage shift due to collected charge, M3 is the output select. b) Photograph of the CAP1 / CAP2 6336-pixel array.

on a variant of the standard Monolithic Active Pixel Sensor[5] (MAPS). In contrast to conventional hybrid pixel detectors (or Si-strip detectors), the charge is collected by diffusion in a region $\sim 10\mu m$ thick (no high voltage).

The CAP1 concept is quite simple: as a first exercise and to gain some experience with MAPS, we took the basic 3-transistor cell (illustrated in Fig.1a) and built an infrastructure around it to read out as fast as possible (the $\sim$ 6k pixel array is shown in Fig.1b). When held at a positive potential relative to the surrounding well and substrate, electrons from deposited ionization are collected on the gate of transistor M2. As this eventually causes the collection potential to be lost due to negative charging, a periodic reset is applied to M1 to restore this potential. For CAP2, 8 storage buffers are implemented in each pixel cell. Thus in CAP2, data can be recorded for the trigger latency time and only the relevant data frames - corresponding to a trigger- will be read out. For these two prototypes, the pixel size is fixed to $22.5\mu m^2$. The method adopted to read out the pixel array is the standard Correlated Double Sampling method[5].

2. Hit resolution measurement

A first measurement of the hit resolution of the CAP prototype was obtained in June 2004 at a beam test in KEK with four CAP1 detectors. This measurement was limited by several parameters, such as the spacing between the detectors and the scattering material. Fig.2a shows a GEANT simulation of the hit resolution (intrinsic resolution + mutiple scattering) as a function of the pion momentum. At 4 GeV/c pion momentum, we determined an upper limit on the hit resolution of $11\mu m$.

3. Radiation hardness results

Radiation hardness of these detectors must be assessed, as they need to survive the very harsh Super B-Factory environment. Irradiation of these devices (^{60}Co) has

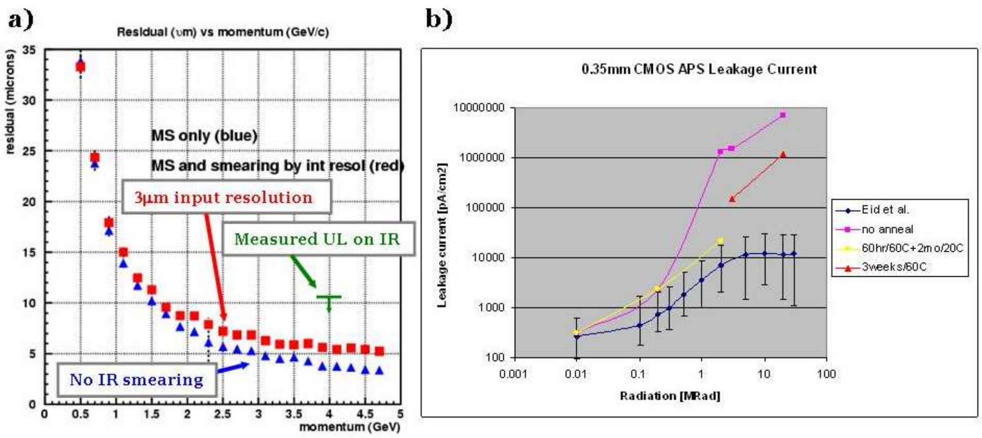

Fig. 2. a) Hit resolution: GEANT expectations (squares) versus measurement (arrow). b) CAP1 leakage current $[pA.cm^{-2}]$ as a function of 1MeV γ radiation dose $[Mrad]$.

been performed to 200 Krad, 2 Mrad, 3 Mrad and 20 Mrad. Fig.2b compares the CAP leakage current with values reported by Eid *et al*[6], which have demonstrated survival up to 30 Mrad. It is interesting to note that this group measured a saturation of the leakage current above 2-5 Mrad. Finally, it should be underlined that in terms of leakage current, with the sampling rate we foresee ($\sim 100kHz$ typical), the reduced Signal to Noise Ratio is acceptable even for 20 Mrad irradiated detectors that are incompletly annealed.

Based on these promising results, a next generation prototype CAP3 is currently being developed that is part of a first iteration for a complete detector system (including readout and data transmission at high frequency).

References

1. G.S. Varner, S.K.Sahu, "Pixels Detectors in B-Factory Environment and thoughts on use in Belle", Proc. of the Second Workshop on Backgrounds at the Machine Detector Interface, World Scientific, p.162 March 1997.
2. M. Barbero *et al.*, "Design and test of the CMS pixel readout chip", Nucl. Instr. and Meth. A **517** (2004), pp 349-359, and references therein.
3. S. Kurokawa *et al.*, "Overview of the KEKB Accelerators", NIM A499 (2001), and other papers in this volume.
4. C.J.S Damerell *et al.*, "A CCD-Based Particle Detector for SLD", Nucl. Instr. and Meth. A **288** (1990) pp 236-239.
5. For example: G. Claus *et al.*, "Particle tracking using CMOS monolithic active pixel sensor", Nucl. Instr. and Meth. A **465** (2001) pp 120-124, and references therein.
6. E-S Eid *et al.*, "Design and Characterization of Ionizing Radiation-Tolerant CMOS APS Image Sensor up to 30 Mrd (Si) Total Dose", IEEE Trans. Nucl. Sci.**48**: 1796-1806,2001.