Development of a Super B-Factory Monolithic Active Pixel Detector – the Continuous Acquisition Pixel (CAP) Prototypes

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ABSTRACT

Future vertex detection at an upgraded KEK-B Factory, currently the highest luminosity collider in the world, will require a detector technology capable of withstanding the increased track densities and larger radiation exposures. Near the beampipe the current silicon strip detectors have projected occupancies in excess of 100%. Recent advances in deep sub-micron Monolithic Active Pixel Sensors (MAPS) look very promising to address this problem. These devices are also quite attractive due to the possibility of making them very thin – essential for improved tracking and vertexing in the low momenta environment of the B-Factory. In the context of an upgrade to the Belle vertex detector, the major obstacles to realizing such a device have been concerns about radiation hardness and readout speed. Two prototypes implemented in the TSMC 0.35µm process have been developed to address these issues. Denoted the Continuous Acquisition Pixel, or CAP, the two variants of this architecture are distinguished in that CAP2 includes an 8-deep sampling pipeline within each 22.5µm^2 pixel. Experience with this deep sub-micron process indicates tolerable threshold voltage shifts for ionizing radiation doses in excess of 20MRad. In order to maintain low occupancy and insensitivity to radiation-induced increased leakage current, Correlated Double Sampling with a 10µs frame period is desired. Signal-to-Noise Ratios, resolution and cluster finding efficiency results are presented for cosmic rays, radioactive sources and test beams. Significant improvement in intrinsic hit resolution with respect to 50µm pitch silicon strip detector is shown. Damage results from irradiation exposures are given. Based upon these results plans for the realization of a full-scale detector are outlined.

Keywords: Active Pixel Sensor, CMOS Monolithic Sensor, vertex detector, B-Factory

1. Introduction

Even prior to the commissioning of the B-Factory accelerators, it was realized that improvements in the vertex performance could be made through the adoption of a pixel detector at the innermost tracking layer. Since such an improvement in vertexing was not required for observing CP-violation in the gold-plated $B \rightarrow J/\psi\ K_S$ decay mode, it was not actively pursued. Outcomes of these preliminary studies [1] indicated that the two most important aspects to obtaining improvement in a B-Factory environment are moving closer to the interaction point and reducing the amount of material. For this reason the massive hybrid pixel detectors that are being employed for the LHC are not optimal. As the KEKB machine is the highest luminosity collider in the world, radiation damage close to the interaction point is a major issue. So far CCD-based detectors, so impressively deployed in the SLD experiment and the baseline in a number of linear collider detector conceptual designs, are very radiation soft despite great efforts to improve their radiation hardness. Meanwhile, great strides have been made recently in applying to vertexing the same active pixel sensor technology that has led to the proliferation of CMOS cameras [2]. A pair of prototype devices has been developed in the context of the Super-Belle upgrade. Test results and future prospects are described in this note.

2. The CAP Architecture

There are a number of challenges unique to operation in a B-factory environment. As the electron-positron bunches collide with as little as 2ns separation, the beam is almost DC in terms of timing structure as observed in the detector. The currents of several Amperes in each beam lead to potentially severe radiation doses for operation close to the beampipe. In contrast with a hadron machine, however, the bulk damage effects are usually negligible. Occupancy of the innermost silicon layer in the current vertex detector is now 10%. Expectations of 20 times higher backgrounds at projected future luminosities will render such a device unusable. Earlier efforts to develop a hybrid pixel detector for lower luminosity operation, based upon bump bonding of a thinned detector with thin readout electronics [3], were abandoned. Based upon experience gained by other groups and considering the Belle constraints, a variant of the standard Monolithic Active Pixel Sensor, denoted the Continuous Acquisition Pixel (CAP), was proposed.

2.1. The CAP1 Design

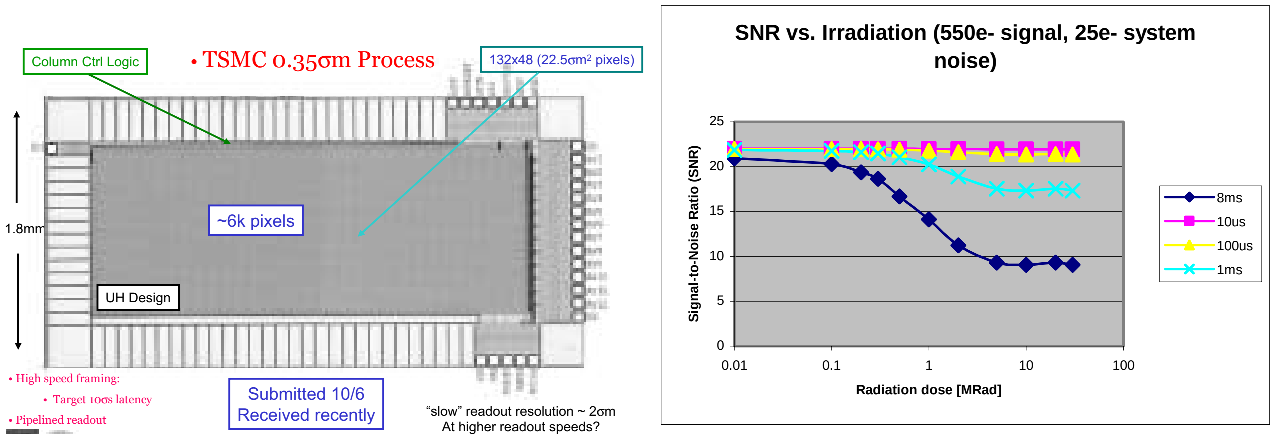

Figure 1: At left a photograph and key elements of the CAP1 pixel prototype chip, at the right, Signal-to-Noise Ratio performance expectations based upon observed signals, measured degradation, and extrapolation to high doses based upon the published literature [5,6] for enclosed geometry transistor structures [4].

Cosmic and radioactive source testing indicates a SNR of ~20 on most pixels for 25e- of system noise. Results of a beam test at KEK in June 2004 as well as radiation damage studies are presented. In order to handle the high occupancy and readout bandwidth requirements, a mini-pipeline has been placed in each pixel. Test results from this novel architecture are presented. A system architecture capable of meeting the speed and occupancy requirements of a Super B-Factory detector is outlined.

3.References

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