RESULTS FROM AN FPIX0 CHIP BUMP-BONDED TO AN ATLAS PIXEL DETECTOR

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Abstract

Results are presented of tests performed on the first pixel detector readout ASIC designed at Fermilab (FPIX0).

1. INTRODUCTION

An effort has begun at Fermilab to develop a pixel detector readout ASIC appropriate for use at the Fermilab Tevatron collider. The readout ASIC must be radiation hard so that it can be used close to the beamline, and it must be optimized for the 132 ns time between crossings planned for future Tevatron operations. Our development plan calls for a series of test chips, fabricated using standard CMOS technologies. We expect the final design to be realized using the radiation hard Honeywell 0.5μ SOI process. In this paper we report the results of measurements made on our first test chip (FPIX0), which has been indium bump bonded to an ATLAS n^+-on-n pixel sensor [1].

2. FPIX0 DESIGN

The FPIX0 is a column based pixel chip with 50μ × 400μ pixel cells arranged in an array of 64 rows by 12 columns. It has been fabricated using the HP 0.8μ CMOS process. The cell geometry was chosen to be compatible with test pixel sensors designed by the ATLAS collaboration. This first prototype pixel-detector readout chip was designed with three goals: 1) Establish a front end design appropriate for use at the Tevatron collider. 2) Verify that the analog and digital sections of the chip can be isolated from one another. 3) Verify that coupling through the sensor is not a problem (metal 3 is used as a shield between the sensor and the readout chip).

FPIX0 consists of an array of pixel unit cells together with relatively simple digital logic that provides a zero-suppressed readout of the chip. Each unit cell includes an amplifier with test input, a discriminator with programmable kill, a peak detector, and readout logic. The amplifier consists of two folded cascode stages, AC coupled to one another. The first stage is a charge amplifier that uses a current controlled feedback circuit [2]. The feedback current controls the return to baseline time and compensates for sensor leakage current. The second stage provides additional gain and is DC coupled to the discriminator. The discriminator is a classic two stage comparator. When the discriminator fires, a set reset flip flop is set and a fast-OR signal asserted. Upon receipt of a token, the cell places its address on an output bus and connects the output of its peak detection circuit to a global analog output line. An externally controlled token advance signal is used to release the token to the next hit pixel cell. This signal also causes the cell that releases the readout token to reset itself.

Two of the 12 columns contain amplifiers with lower first stage feedback capacitance (10 fF instead of 20fF). These cells have higher gain than the standard cells and correspondingly lower dynamic range.

3. MOUNTING ON SENSOR

Four FPIX0 IC's have been indium bump bonded (by Boeing North America) to ATLAS test sensors. Each sensor consists of an array of 160 rows by 18 columns of 50μ × 400μ pixel cells. The FPIX0 chips have been bonded to one corner of the sensor array, as shown in Figure 1. Eleven of the twelve columns in FPIX0 are bonded to sensor pixels and one column is left unbonded. This allows us to compare the performance of bonded and unbonded cells. Amplifier and discriminator outputs from one row of pixel unit cells are routed directly to pads on two sides of the FPIX0. The outputs from four of these cells are accessible in the bonded assembly. These include three cells bonded to sensor pixels and one unbonded cell.

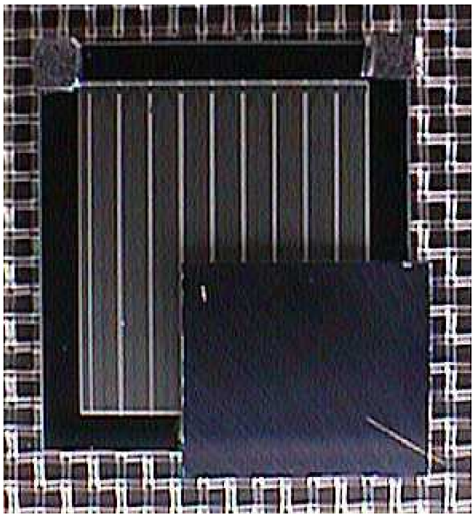

Figure 1. Photograph of an FPIX0 bonded to an ATLAS test pixel sensor.

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All of the measurements reported on here were made on a single FPIX0 bonded to a Seiko test sensor. Plans are being made to beam test the other three devices during the 1999 fixed target run at Fermilab.

4. CONNECTIVITY AND SENSOR IV

The IV characteristic of the bonded Seiko "ST1" [1] and the current in the n-side guard ring are shown in Figure 2. At sensor bias voltages below the full depletion voltage, the guard ring current is very sensitive to the biasing of the guard ring relative to the pixels. These curves show that full depletion is reached at approximately -45 V. All of the tests described below were performed with a sensor bias voltage of -75 V.

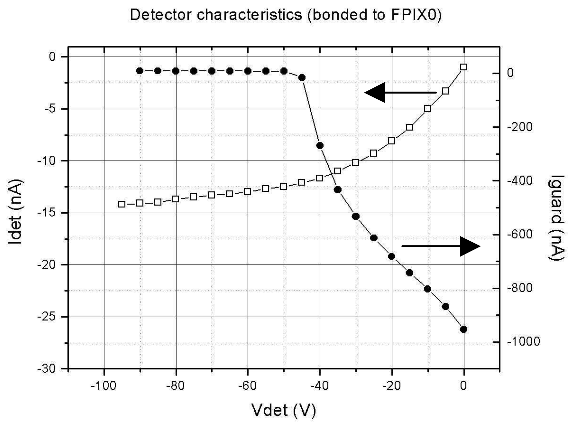

Figure 2. Detector leakage current and n-side guard ring current as a function of applied detector bias voltage.

The bump bond yield was measured by illuminating the sensor with a Sr^{90} source and plotting the number of times each pixel unit cell registered a pulse above a threshold of ~3000 e^-. All pixels were found to be connected and no pixel was noisy.

5. NOISE AND DISCRIMINATOR THRESHOLD MEASUREMENTS

Fluorescence x-rays from a number of metal foils were used to provide an absolute calibration of the FPIX0. For example, the sensor was illuminated with Terbium x-rays, and a pulse height spectrum was collected using one of the direct amplifier outputs. The $K\alpha_1$ peak (44.5 keV) was easily identified. Since a 44.5 keV x-ray creates 12300 mobile e-hole pairs in depleted silicon, the peak in the spectrum can be interpreted in terms of the number of electrons input to the amplifier. The rms noise observed with no source illuminating the sensor also can be converted directly into an equivalent number of electrons input to the amplifier (these measurements agree with the noise values inferred from the discriminator threshold scans described below). We have also verified the linearity of the FPIX0 amplifier response to small input signals using a variety of characteristic x-rays.

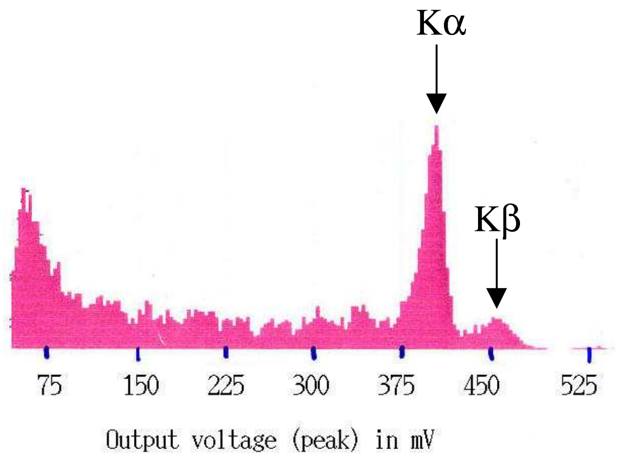

Figure 3. Terbium x-ray spectrum.

The x-ray spectra obtained using the three direct amplifier output signals also allow us to interpret the response to an injected test signal in terms of electrons input to the amplifier, or equivalently, to determine the value of the charge injection capacitor. This, in turn, allows us to rigorously interpret discriminator threshold scans of all of the pixel cells in the array in terms of electrons input to the amplifiers (assuming only that $C_{injection}$ is the same for all cells). It also allows us to interpret the dynamic range of the amplifier in terms of the input in electrons. For FPIX0 cells with Cf=20 fF, the dynamic range is approximately 52000 electrons at the input.

A discriminator threshold scan was performed for each pixel cell by holding the discriminator threshold constant and scanning the injected test pulse voltage through the threshold. The fraction of the time that the discriminator fired was recorded for each value of the injected pulse. The resulting curves were fit to the integral of a Gaussian distribution, yielding an rms noise and discriminator threshold (50% point). The discriminator threshold rms was calculated directly from the resulting distribution of 50% points.

Figure 4 shows noise distributions inferred from these measurements for three columns of pixel cells. The top histogram corresponds to a column of bonded pixel cells with the higher gain version of the amplifier. The middle histogram is for a standard bonded column. The bottom histogram shows the noise of the unbonded column of pixel unit cells. Two conclusions can be drawn. First, there is a trade-off between the larger dynamic range associated with the standard front end and the lower noise and reduced discriminator threshold dispersion of the higher gain front end. Second, the bonded cells are only slightly noisier than identical unbonded cells. If all of this noise difference is attributed to the difference in input capacitance, then a SPICE simulation indicates that the total input capacitance of the sensor pixel and bump bond is approximately 180 fF.

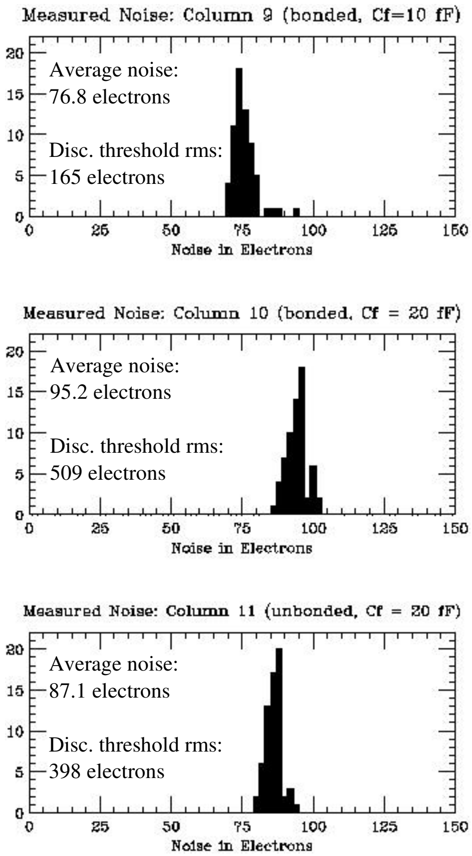

Figure 4. Amplifier noise inferred from discriminator threshold scans (rms variations in discriminator thresholds are also given).

6. ANALOG READOUT

We have verified that the normal readout sequence (including the analog information) works as designed, except that the token fails to get reset after readout. This means that a chip reset must be issued after each event is read out. This operation involves only the resetting of a single flip flop.

7. PICKUP AND CROSS TALK

We have not been able to measure any pickup of the digital activity associated with readout. With the metal 3 shield grounded there is no significant coupling through the detector. The capacitance between the metal 3 shield and a sensor pixel has been inferred to be approximately 1.8 aF/μ^2. This capacitance was deduced by disconnecting the shield from its ground, injecting a pulse on the shield, and measuring the output voltage from a single pixel unit cell.

We have measured the pixel to pixel cross talk both in the short direction of the pixel cells and in the long direction. When a pulse is injected into an FPIX0 front end which is bonded to a sensor pixel, the neighboring cell in the long direction registers a signal ~2% as large as the cell which received the charge injection. When an unbonded cell is selected, the cross talk to the neighbor in the long direction is ~1%. This indicates that the cross talk through the sensor is ~1%. We believe that the balance of the cross talk occurs through the charge injection network itself. Cross talk has also been measured on several bare FPIX0 chips (not bonded to sensors). In this case, the cross talk in the short direction is almost exactly the same as for the bonded chip.

8. CONCLUSIONS

Results have been presented from an FPIX0 prototype pixel readout chip bump bonded to an ATLAS pixel sensor. With these results in hand, we are continuing our effort to develop a readout chip optimized for use at the Tevatron collider. Subsequent designs will use an amplifier design based on the FPIX0 front end, probably using even lower feedback capacitance (than in the high gain cells of FPIX0) to further decrease noise and discriminator threshold variation, at the expense of dynamic range.

FPIX0 chips bonded to ATLAS sensors will be used in beam tests during the 1999 Fermilab fixed target run to study the use of analog information to improve spatial resolution using charge sharing information. Simulations done by the BTeV collaboration indicate that a significant improvement in resolution over binary readout can be obtained by a very coarse digitization of the analog information [3].

9. REFERENCES

[1] The ATLAS Collaboration, ATLAS TDR 5, CERN/LHCC/97-17, and T. Rohe, *et al.*, “Sensor Design for the ATLAS Pixel Detector,” Nucl. Instrum. Meth. A409, pp. 224-229, 1998.

[2] Blanquart, *et al.*, “Pixel analog cells prototypes for ATLAS in DMILL technology,” Nucl. Instrum. Meth. A395, pp. 313-317, 1997.

[3] M. Artuso and J. Wang, “Some Further Studies on Factors Affecting the Pixel Resolution,” BTeV-int-98/13 (BTeV internal note).