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PERFORMANCE MEASUREMENTS OF HYBRID PIN DIODE ARRAYS*

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Abstract

We report the successful development of hybrid PIN diode arrays and a series of room-temperature measurements in a high-energy pion beam at FNAL. A PMOS VLSI 256 × 256 readout array having 30 μm square pixels was indium-bump bonded to a mating PIN diode detector array. Preliminary measurements on the resulting hybrid show excellent signal-to-noise at room temperature.

Introduction

In this paper, we present a progress report on the program to develop two-dimensional silicon PIN diode hybrid arrays which can be used as building blocks for vertex detectors [1,2]. Funded by the SSC Laboratory as part of the Generic Detector Research Program, this development effort has seen the fabrication and testing of three different hybrid arrays [3]. The latest array, a PMOS VLSI 256 × 256 pixel array having 30 μm square pixels, has been tested in a 250 GeV/c pion beam at Fermilab. Preliminary results of these tests will be discussed.

The PMOS Array

The PIN diode array hybrids were implemented by indium-bump bonding PIN diode arrays made by Micron Semiconductor Inc. to mating VLSI readout arrays made by the Hughes Aircraft Co. The first two arrays have been discussed in earlier publications [1,2] and are only briefly described here.

The first array (a 10 × 64 array having pixels 120 μm on a side) has ten readout channels per array, one for each column. The readout structure provides random access to any pixel. There is no power necessary during the time charge is being detected and stored by the array; however, during the read cycle, 10 mW (1 mW per channel) is required. The readout electronics is an NMOS VLSI circuit which has been made radiation hard to 1 MRAD of ^{60}Co gamma rays.

The second array, a 256 × 256 array, having pixels 30 μm on a side, has two readout channels per array. Random access readout is provided via row and column shift registers. Data stored in the pixel represented by the intersection of row and column address is presented to the readout node. No power is necessary for storing data, and only 2 mW is necessary for readout. The readout electronics is an NMOS VLSI circuit, which is not particularly radiation hard.

The third array (fabricated earlier this year) is similar to the second, except that the readout electronics, though identical to the second array, is implemented in a PMOS VLSI circuit. This variation is necessary to preserve the option of using these arrays at room temperature. Traditionally, high-energy physicists employ diode detectors, which collect holes rather than electrons, and the original diode arrays from Micron Semiconductor were of that variety. The PMOS array is more appropriate to collect the holes, rather than the electrons generated by the passage of charged particles through the 300 μm-thick silicon PIN diodes. The PMOS circuit has a much larger dynamic range of operation, and dark current integrated over the time necessary to read the 32,768 pixels on each readout node no longer develops voltages that drive the circuit to its supply rails. Tests were made in the laboratory at the Hughes Aircraft Co.,

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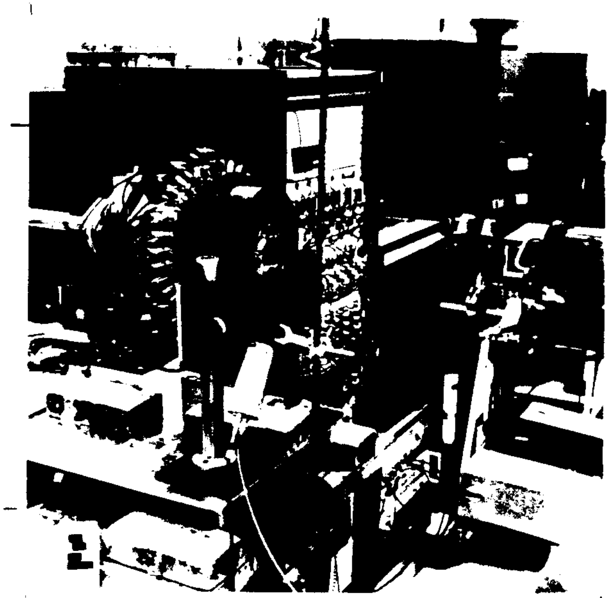

Figure 1. Photograph of two independent test systems in the beam line at Fermilab.

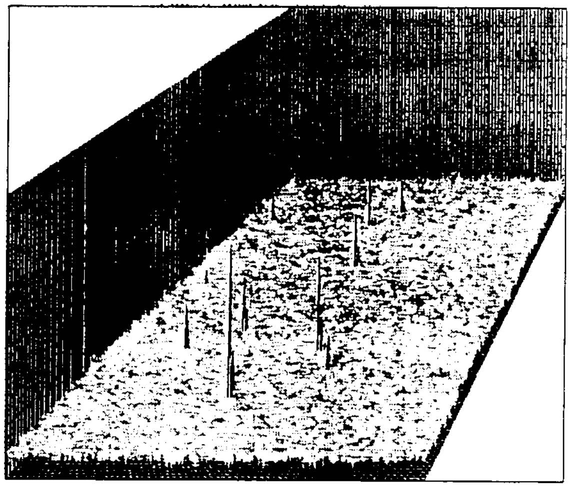

Figure 2. A three-dimensional plot of minimum ionizing particles incident on a detector array, demonstrating excellent signal-to-noise and the power of two-dimensional arrays to eliminate confusion in complex events.

Carlsbad, and at the Space Sciences Laboratory of the University of California, Berkeley, confirming their operation at room temperature, prior to our beam tests at FNAL.

Beam Tests at FNAL

The data being presented were obtained in a test performed at FNAL in a high-energy pion beam in August 1990. Two separate and independent readout systems were employed, one fabricated by the Hughes Aircraft Co., and one fabricated by the SSL/SLAC collaboration. Several detector arrays were tested in each system, one at a time. All of the arrays worked well. Data were taken using 250 GeV/c pions, impinging perpendicular to the arrays and at 15 degrees to the array normal. Data were also taken with material placed in front of the arrays to generate showers and jets, and—as a final calibration—alphas and 59.5 KeV photons from $^{241}A_m$ were collected.

Figure 1 is a photograph of the two Dewars, each containing an array, one behind the other, in the beam line. The beam is incident from the right. Although the arrays were operated at room temperature, they were contained and supported in Dewars capable of operation at cryogenic temperatures. During these runs, power line surges and electromagnetic pickup were detected which caused hardware failures and some excess noise. The runs were successful in demonstrating the detection of high-energy particles, using a room temperature detector with a good signal-to-noise ratio.

The two readout systems which were employed reflect the differing uses to which they are normally put. The Hughes system is a copy of a system used for testing arrays. This system takes data slowly, at frame rates of up to 120 per second, but has the flexibility to measure array parameters should that be necessary. The SSL/SLAC system is more typical of a high-energy physics data acquisition system.

Figure 2 is a three-dimensional display of a number of high-energy pions incident perpendicular to the array. Evident in this presentation of the data is the good signal-to-noise ratio of each detected pion. Also evident is the power inherent in two-dimensional arrays to eliminate confusion normally present when a large number of particles are incident on a single detector. The arrays used in this detector have 256 $\times$ 256 pixels each 30 μm square; thus the arrays are about 7.5 mm on a side or 0.5 cm^2 in area.

Figure 3 is a two-dimensional representation of a track (probably a delta ray) angling its way through the array. From the uniform staircase-like track, one can get a feel for the ultimate spatial resolution which will be available with these detectors, once they are properly calibrated.

Figure 4 is another two-dimensional representation of what is believed to be a nuclear fragmentation event. Events like this are rare; only one like it was detected in the thousands of events recorded. The gray scale shows the pulse height information that is retained by each pixel. The black area to the side of the cluster is an artifact of the readout electronics external to the hybrid array. This artifact can be removed in the data analysis. The electronics will be modified later to remove this effect.

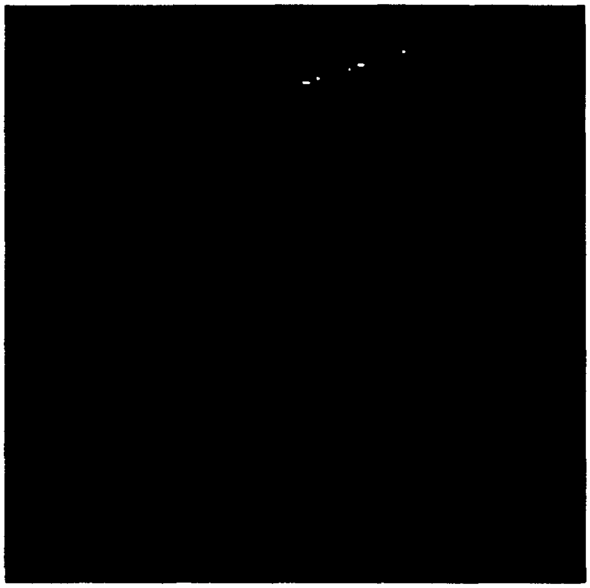

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Figure 3. A two-dimensional plot of a minimum ionizing track traversing the detector array at an angle, demonstrating potentially excellent spatial resolution.

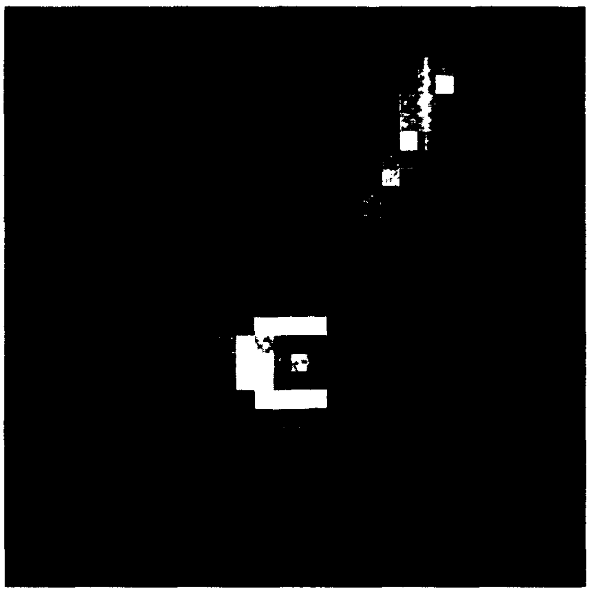

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Figure 4. Data containing a nuclear fragmentation event, demonstrating the pattern recognition power of retaining the pulse height information available in each pixel.

Figure 5 represents preliminary data. There has not been time in the preparation of this paper to analyze the data in detail. However, the main features of the data are quite clear. Figure 5 is a histogram of the pulse heights of the minimum ionizing particles, as they traverse the array.

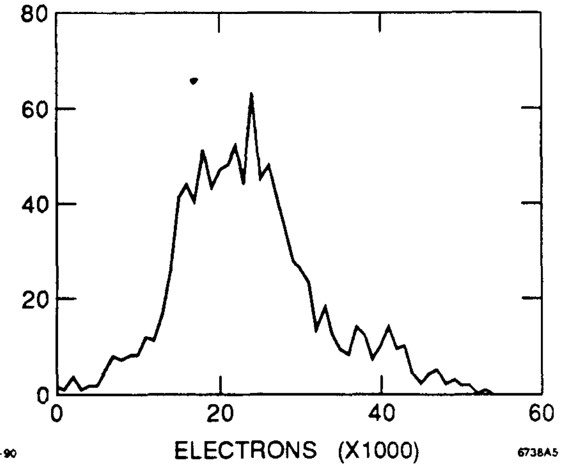

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Figure 5. A histogram of pulse height for a data set containing minimum ionizing particles traversing the array normally.

It must be emphasized that no gain calibration has been attempted, as of this time. No correction has been applied to equalize the gains from each of the two chip outputs, nor has the variation of gain across the face of the array been studied. Noise attributable to the integration of dark current during the 50 ms readout time has not been minimized in this analysis. All this notwithstanding, the peak of the pulse-height spectrum for the minimum ionizing particles is in the proper ratio to the observed peak in the 59.5 KeV photon spectrum from Americium data.

In conclusion, the test run at FNAL demonstrated room-temperature operation of a two-dimensional array of pixels. The signal-to-noise ratio was good, approximately 50:1. The data has not been fully analyzed, and the arrays are not yet calibrated; but there is consistency between the minimum ionizing data and the 59.5 KeV photon data.

References

[1] S. Shapiro, W. Dunwoodie, J. Arens, J. Gernigan, and S. Gaalema, "Silicon PIN Diode Array Hybrids for Charged Particle Detection," Nucl. Instrum. Methods **A275**, 580 (1989).

[2] S. Gaalema, G. Kramer, S. L. Shapiro, W. Dunwoodie, J. Arens, and J. G. Jernigan, "Silicon PIN Diode Hybrid Arrays for Charged Particle Detection: Building Blocks for Vertex Detectors at the SSC," Proc. Int. Industrial Symposium on the Supercollider, New Orleans, LA, 1989, p. 173.

[3] J. G. Jernigan, J. Arens, G. Kramer, T. Collins, J. Herring, S. L. Shapiro, and C. Wilburn, "Performance Measurements of Hybrid PIN Diode Arrays," presented at the 1990 Int. Industrial Symposium on the Supercollider, Miami Beach, Fl, 1990, SLAC–PUB–5211.