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# An Interdigitated Pixel PIN Detector for Energetic Particle Spectroscopy in Space

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## ABSTRACT

We describe a new two-dimensional position-sensitive detector, now under development, for use in space-borne energetic particle spectrometers. The novel feature of this device is the use of interdigitated pixels to provide both dimensions of position information from a single side of the detector, while a measurement of the energy deposition is derived from the opposite side. An advantage of this approach is that significant reductions in the complexity, power, and weight of the associated read-out electronics can be realized without sacrificing position or energy resolution.

## I. Introduction

Solar flares frequently inject intense fluxes of energetic nuclei into the interplanetary medium. Studies of the composition of these nuclei can provide a direct measure of the present elemental and isotopic composition of the Sun, providing crucial information for understanding the history of solar system material, and for studying solar particle acceleration and transport [see, e.g., Mewaldt, Spalding, and Stone 1984]. Such measurements, however, require instrumentation capable of operation in the hostile environment of the largest solar flares. Similarly, composition measurements in planetary magnetospheres, interplanetary acceleration events, and (presumably) at the solar wind termination shock also require operation in intense radiation environments. We describe the development of a new detector designed to provide the required high resolution measurements in the presence of intense particle fluxes, with greatly reduced weight and power requirements.

One proven technique for energetic particle spectroscopy employs a "telescope" made up of a stack of silicon solid state detectors (wafers of silicon typically ~10 $cm^2$ in area and 0.1 to 1 mm in thickness.) By combining the energy loss measurements from these detectors (see, e.g., Figure 1) it is possible to determine the nuclear charge, mass, and kinetic energy of incident nuclei that slow down and stop in the telescope over the element range from H to Ni (Z = 1 to 28). However, to resolve the isotopes of heavy nuclei ($Z \geq 6$) incident over a wide range of angles it is in practice also necessary to measure their trajectory. To provide this trajectory information, silicon strip detectors can be used as the first elements in the telescope [e.g., Althouse et al. 1978]. In optimizing the design of an improved instrument of this type there are several (often conflicting) requirements on these position-sensitive detectors (PSDs):

1) Because solar flare energy spectra decrease rapidly with increasing energy, it is important to use two-dimensional detectors of large area that can serve as both

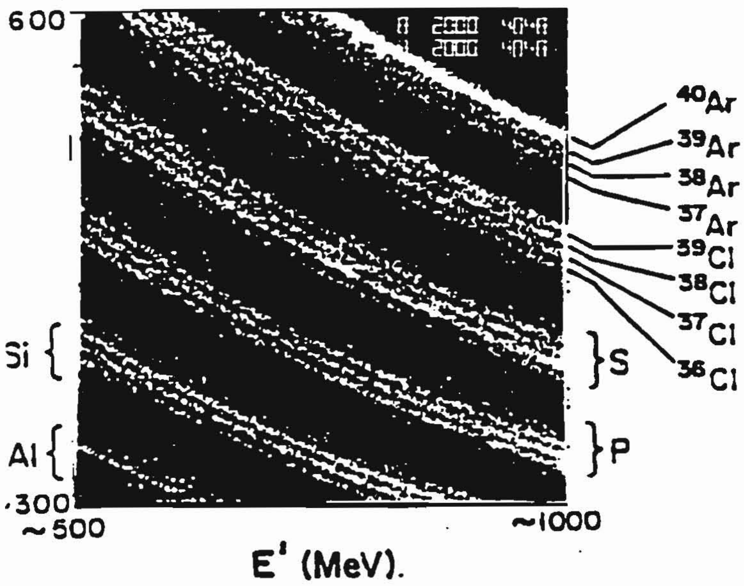


Figure 1: On-line display of data obtained at the LBL Bevalac showing $\Delta E$ (measured in 500 $\mu$m thick silicon detector) vs. the residual energy (E′) measured in a following detector. A beam of ~300 MeV/nuc $^{40}$Ar was incident on a $CH_4$ target that fragmented many of the beam particles into lighter nuclei. Both element and isotope resolution are evident in this display, in which each dot represents an individual stopping particle.

trajectory and energy measuring devices.

2) Studies of rare isotopes require operation in the very largest solar events when up to $10^5$ to $10^6$ low energy (~1 MeV) protons per second may hit the front detector. During such periods, "pulse pileup" involving accidental coincidences between low energy protons and the heavy nuclei of interest may result in incorrect trajectories, incorrect pulse height measurements, or both. Thus, to preserve isotope resolution in a large solar flare it is necessary to track multiple particles in the PSDs.

3) Finally, because space missions usually place a premium on weight and power requirements, the electronics required to instrument the PSDs should be minimized while at the same time maintaining adequate position and energy resolution.

Two alternative approaches to this problem have been attempted. The "brute-force" approach [e.g., Althouse et al. 1978] of individually instrumenting each strip provides the required position and energy loss information on all particles, but leads to significant penalties in weight, power, and electronic complexity when the size of the detectors is increased, given that the number of strips can be several hundred. A second approach that minimizes electronic complexity by attaching the strips to a resistive divider [e.g., Lamport et al. 1980] does not resolve multiple particle trajectories and is subject to pileup effects in even small flares.

In a collaborative effort involving Caltech and JPL (for a more detailed discription, see Cook et al. 1993a), we are developing a new "Interdigitated Pixel PIN Detector" (IPPD) in which two-dimensional position information will be available from a single side of the detector, while the signal from the opposite side will be employed solely for precise measurement of the energy deposition. Thus, only a single high precision pulse height analysis chain is needed to read out the energy signal, while individual x-y strips on the pixelated side can be read out with amplifier-discriminators implemented in low power, high density, custom VLSI. This approach can provide significant savings in mass, power, and overall system complexity.

## 2. Technical Approach

Position information from the IPPD will be derived from a two-dimensional array of pixels covering one side of the device (see Figure 2). Each pixel is divided into two sub-pixels, one associated with the "row" coordinate and the other with the "column" coordinate. The sub-pixels form a pair of interdigitated contacts, which should have a finger spacing smaller than the lateral spread of the electron-hole plasma generated by a typical particle of interest to ensure charge sharing between the row and column sub-pixel. All "row" sub-pixels in a given row are connected to a row wire; these row wires are brought out to the edge of the array. The "column" sub-pixels are connected in a similar manner. A particle impact at any given pixel will deposit charge on both the row and column sub-pixels at that location, which is carried to the edge of the detector along one row wire and one column wire. The detector readout electronics discriminate which row and which column have "fired", yielding the coordinates of the impact. The electronics can be designed to record multiple particle positions.

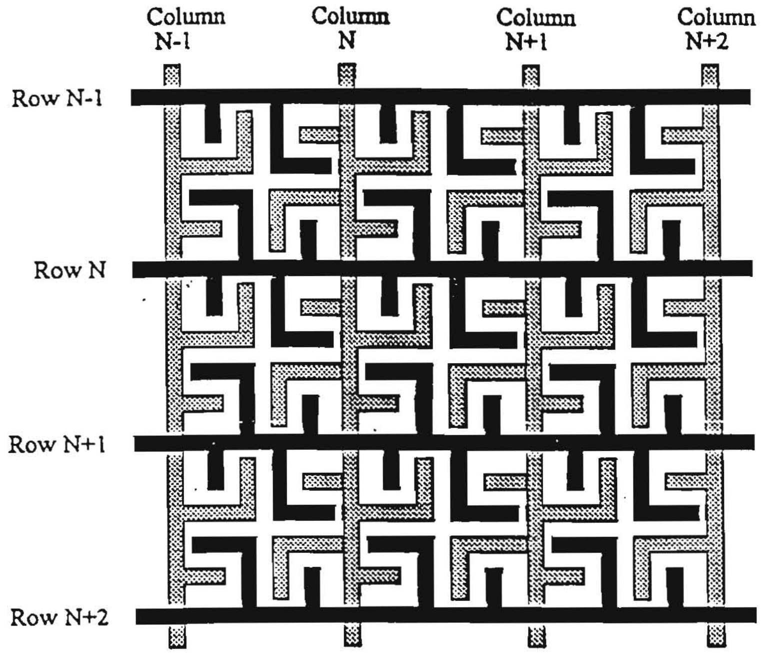


Figure 2: Top view of a conceptual 3x3 IPPD array.

The operation of each sub-pixel in this array is identical to that of conventional fully depleted PIN detectors. As illustrated in Figure 2, a high resistivity (nominally intrinsic or "i" type) silicon wafer has a p-doped region introduced on one side and an n-doped region introduced on the other side. By applying a reverse bias sufficient to fully deplete the nominally undoped region (~35 volts), one obtains a detector in which all of the generated electrons throughout the entire thickness of the wafer are collected at the n-doped contact, and all the holes are collected at the p-doped contact.

The other side this detector is a full area contact that collects all of the deposited charge independent of the position of the particle impact. Precision pulse-height analysis of this electrode will accurately determine the total energy loss of the particle. To recover individual pulseheights of multiple particle events, an eventual detector

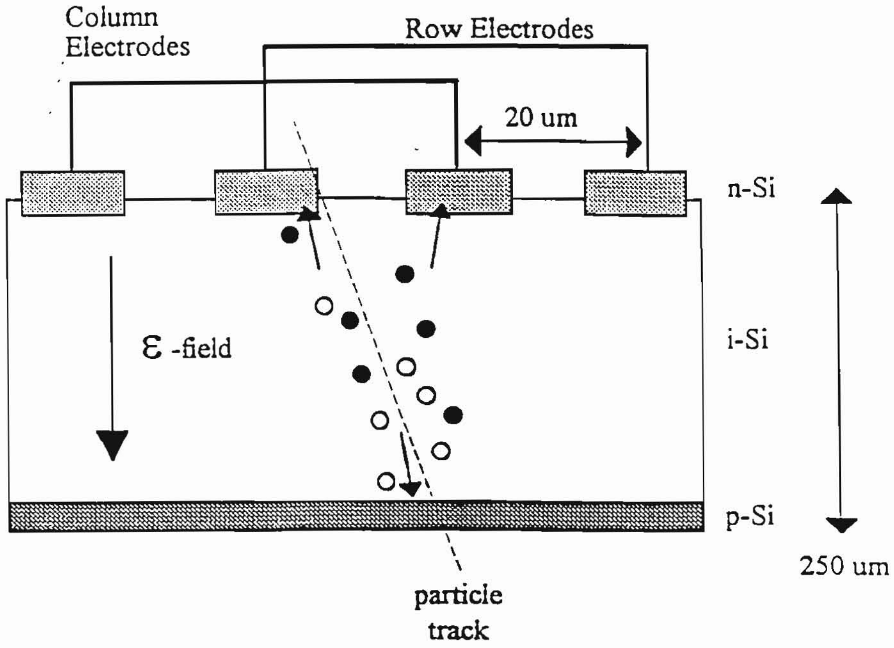


Figure 3: Schematic cross section of an IPPD pixel. The passage of a charged particle leads to electron collection at the interdigitated row and column electrodes (n-doped) and hole collection at the p-doped contact at the opposite side of the device.

might have several segments on this back electrode.

Detector Characteristics

We are presently developing a prototype detector that will test the IPPD concept. We discuss below some of the desired characteristics of this detector.

Size: Although an eventual detector diameter of ~5 to 10 cm is desirable, a prototype size of ~1 cm is sufficient to demonstrate the approach.

Thickness: The prototype devices will be 250μm thick; potential applications might involve thicknesses anywhere from ~50μm to 1 mm.

Pixel Size: A pixel size of ~0.5 to 1 mm should provide the required position resolution for the present application. Smaller pixel sizes are possible.

Interdigitation feature size: The width of the interdigitating fingers of a pixel must be small enough to ensure that the charge signal from a vertically incident nucleus is adequately shared between row and column. Prototypes are being fabricated with finger spacings of 20, 40, and 80 μm to allow assessment of the charge sharing efficiency. Figure 4 shows an example of the interdigitated finger pattern for a single pixel.

## III. Detector Readout

Readout of the detector array will be performed using custom VLSI circuits now under development. Each row and column will be pulse-height analyzed with an independent linear chain consisting of a low-noise charge-sensitive preamp, gated integrator, sample and hold, and Wilkinson-type ADC. We expect sixteen complete pulse height analysis chains to fit on a single integrated circuit, with each chain consuming only ~5 mW. The energy signal from the other side of the detector will be

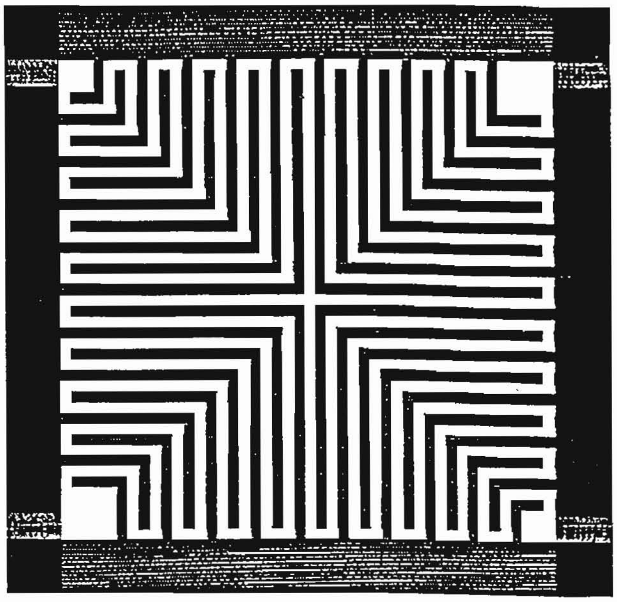

Figure 4: Interdigitated row and column pattern within a single 1 mm x 1 mm pixel. The electrode pitch is 40 μm.

pulse height analyzed with a standard circuit consuming ~40 mW. Thus, a typical detector for space flight application having 50 rows and 50 columns could be instrumented with a small number of integrated circuits consuming only ~0.5 watt.

As an example, we consider the Solar Isotope Spectrometer (SIS) now under development for the Advanced Composition Spectrometer (ACE) mission (Stone et al., 1989), which contains a trajectory system with a total of four PSDs, each having 64 strips on both sides of the devices, for a total of 512 individually analyzed strips. If these 512 strips were pulse-height-analyzed using custom hybridized circuits such as those in the MAST instrument launched in 1992 on SAMPEX (Cook et al. 1993b), the total power associated with the readout of these four devices would be 512 strips x 110 mW/ADC chain ≃ 56 W, a prohibitive amount. If instrumented using the custom VLSI circuits under development for ACE (Cook et al. 1993c), the required power would be 512 strips x 20 mW ≃ 10 W. If the SIS multistrip devices were to be replaced with pixelated devices of the design described here, we estimate that the required power for the trajectory system could be reduced to 512 x 5 mW + 4 x 40 mW ≃ 2.7 W.

In summary, the interdigitated pixel detector described here promises to provide both two-dimensional position resolution and excellent energy resolution with significantly reduced electronic complexity, leading to applications in future space-borne instruments that study energetic heavy nuclei in a solar flare or magnetospheric environment. This device may also have applications in other areas of astrophysics, and in nuclear and high energy physics.

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