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# Thermal Neutron Detectors with Discrete Anode Pad Readout

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*Abstract*–**A new two-dimensional thermal neutron detector concept that is capable of very high rates is being developed. It is based on neutron conversion in $^{3}$He in an ionization chamber (unity gas gain) that uses only a cathode and anode plane; there is no additional electrode such as a Frisch grid. The cathode is simply the entrance window, and the anode plane is composed of discrete pads, each with their own readout electronics implemented via application specific integrated circuits. The aim is to provide a new generation of detectors with key characteristics that are superior to existing techniques, such as higher count rate capability, better stability, lower sensitivity to background radiation, and more flexible geometries. Such capabilities will improve the performance of neutron scattering instruments at major neutron user facilities. In this paper, we report on progress with the development of a prototype device that has 48 × 48 anode pads and a sensitive area of 24cm × 24cm.**

## I. Introduction

Several new user facilities, with an order of magnitude more neutron flux than previously available, are being built or have been recently commissioned, e.g. J-PARC in Japan, the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory, and the OPAL research reactor at the Australian Nuclear Science and Technology Organization. The beam-lines at these facilities will ultimately require detectors with much higher rate capability than presently achievable [1], with also an emphasis on dynamic studies over wide time-slice scales.

## II. Anode Pad Readout

Our group has broad experience with development of $^{3}$He filled wire chambers for position-sensitive thermal neutron detection [2]. In general, these existing instruments begin to exhibit dead-time losses at global rates above $10^{5}$ $s^{-1}$. Some approaches to improving upon this would be a much higher degree of parallelism in the readout, and ensuring the physics of the signal development will permit high local rates. A highly segmented anode plane and operation of the chamber with unity gas gain are suitable approaches; our initial studies of small ionization chambers with pad readout [3,4] have been successful. The basic features are described below.

Fig. 1 illustrates the detector geometry, the anode taking the form of independent pads (all connected to their own preamplifier), with spacing *a*. The separation of the anode plane from the cathode (or window), *d*, defines the depth of the neutron conversion region. With the orange pad denoted as the sensing electrode (pad), the weighting field concept [5] determines the equipotential lines shown in blue. A uniform field (typically 1kV/cm) is applied across the conversion region, and an electron cloud drifting at constant velocity from the window will therefore induce the majority of its charge only as it closely approaches the sensing pad.

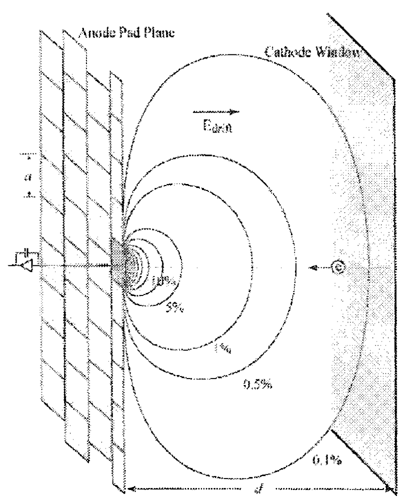


Fig. 1. The blue lines represent the weighting potential inside the detector for the sensing electrode (pad) denoted in orange. An electron cloud drifting in the uniform electric field from the window to the orange pad induces most of its charge on the sensing pad only as it closely approaches that pad.

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This method achieves good pulse height resolution without the need for a Frisch grid between anode and window. It requires that the ratio $d/a$ be considerably larger than one; in Fig. 1, $d/a \sim 8$, the same value used in our experiments.

Neutron conversion in $^3$He occurs via the nuclear reaction: $^3He + n \rightarrow {}^3H + p$. The 191 keV triton and 573 keV proton form an ionization trail with a cumulative charge of nearly 5 fC. If the thermal neutron absorption depth is small compared to $d$, almost all of the 5 fC will be induced on a pad, or adjacent pads, easily detectable with low noise electronics if no more than a few pads are involved. However, the ionization trail following neutron conversion has a finite length, and in a few bar of only pure helium would be so large that the combination of ballistic deficit and spread of the charge over many pads would render the technique difficult to utilize. Thus, a stopping gas is required to reduce the proton/triton path length; in the studies to date, propane has been used for this. In the simplest readout form, each pad is its own pixel, and position resolution is equal to the pad pitch; with suitable selection of the proton/triton path length, sharing of the 5 fC between two or three adjacent pads would lead to position resolution about half the pad pitch.

A dedicated application specific integrated circuit (ASIC) with 64 channels has been designed for the readout [6]. Its noise is less than 150 electrons rms at 2μs shaping time when loaded with a few pF represented by each pad. It provides amplitude, timing and address measurements for each event, so that adjacent pads that share charge from a single neutron conversion can be identified and a more accurate neutron position determined.

## III. Detector Hardware

The goal of the present work is to construct a prototype detector for neutron scattering studies, with a pad spacing, $a$, of 5mm, and a pad array of 48×48, corresponding to a sensitive area of 24cm × 24cm. The pad electrode is fabricated as a 9-layer printed circuit board using high frequency circuit material. Fig. 2 shows the front (pad) side; each of the 2304 pads has a blind via that connects, via appropriate inner layers, to an input pin on the nearest ASIC. Fig. 3 shows a close-up of one corner of the anode board (before gold-plating of the copper) with an 8 × 8 pad section (served by one ASIC) outlined in red. Every other pad column is displaced by $a/2$ with respect to its neighbor so that ultimately the electron cloud may be shared between no more than three pads. Fig. 4 shows the rear side of the anode board; in the present set of measurements only 16 out of 36 ASICs were implemented.

The prototype detector has a depth, $d$, of 4cm, providing high conversion efficiency for thermal neutrons with modest pressures of $^3$He, two to three bar. The charge from each neutron conversion is collected by the corresponding pad, or group of adjacent pads, and the amplitude, timing and pad address is multiplexed via the SANSROC (SANS Read-Out Card), directly underneath the pad board, to a data acquisition card in a standard PC on the outside. The detector assembly is shown in Fig. 5, where the anode pads without ASICs are shielded with ground planes that can be seen in each of the four corners. A field cage around the perimeter of the pad board maintains a uniform drift field. The detector is filled with 3 bar He and varying pressures (0.5 to 2 bar) of propane. In the present studies, the He was a mixture of 2.5 bar $^4$He and 0.5 bar of $^3$He, in order to reduce the cost of the "test" filling.

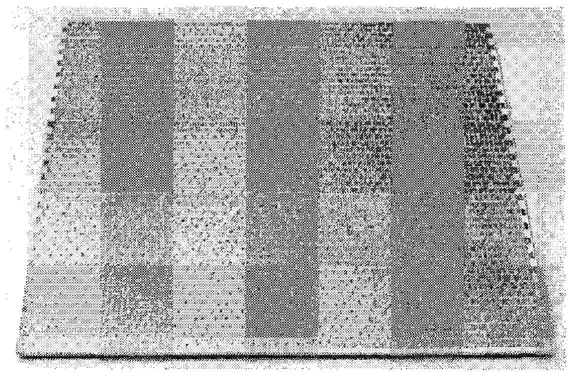

Fig. 2. This shows the 48 × 48 pad board, viewed from the pad side. The pad pitch, $a$, is 5mm. Each pad has a blind via that makes electrical connection to the input pin of an ASIC on the other side of the board.

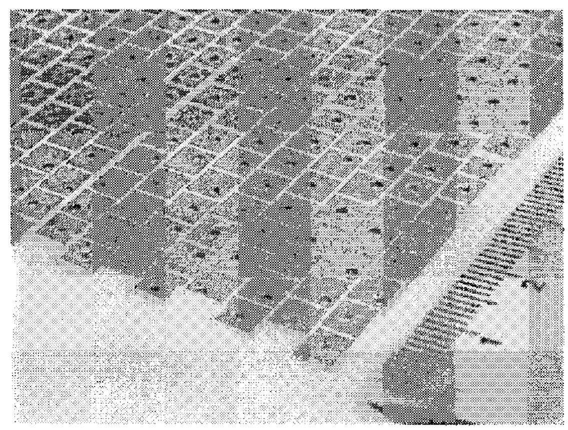

Fig. 3. This shows a close-up image of one corner of the anode pad board (taken before gold plating of the copper), illustrating the array of 8×8 pads that is served by one ASIC, on the underside. The blind via associated with each pad can be clearly seen.

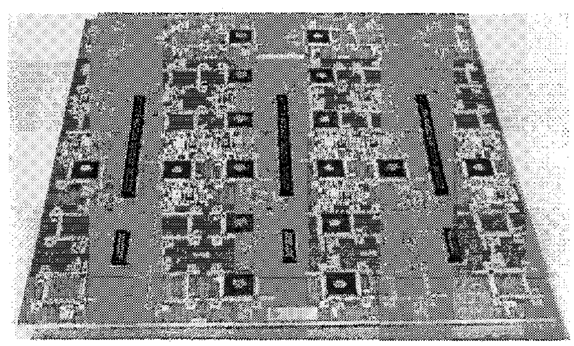

Fig. 4. This shows the rear-side of the 48 × 48 pad board, with 16 of 36 ASICs installed. The three columns of connectors are for communication with the SANSROC board.

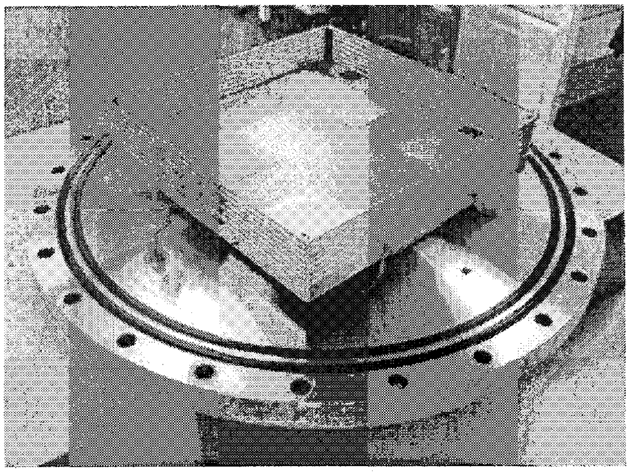

Fig. 5. This shows the anode pad board mounted atop a stainless steel flange. In each of the four corners, a copper plated board at ground potential is placed over the pads without ASICs (reflecting the non-implemented ASICs in Fig. 4), to avoid possible drift field disturbance. Not visible is the SANSROC, nestled underneath the pad board, that multiplexes signals to the outside via two 25-pin D connectors welded into the flange. There is a field cage around the perimeter of the anode board to help maintain uniformity of the linear electric field.

## IV. Experimental Results

We have chosen to carry out initial investigations with partial propane pressures in the range 0.5 to 2 bar. Based on evaluations using SRIM [7], this should result in combined proton and triton track lengths ranging from 10mm or so to about half the pad spacing.

Fig. 6 shows the complete detector housing placed in front of a thermal neutron source (moderated Am/Be). This enables neutron illumination of the entire detecting area. The data are recorded in list mode in the external PC, from which a two-dimensional histogram of events can be generated, as shown in Fig. 7. A fall-off in neutron intensity from the center of the histogram can be seen, which is real and due to the closeness of the source to the detector. The few pads that generate no response, or a low charge collection, represent only about 2% of the implemented channels, and are due to known issues on the multilayer board. We expect these to be rectified fully in the next pad board fabrication, presently under way.

An arbitrary pad was selected for analysis of pulse height information, taken during the uniform illumination. Fig. 8 shows pulse height spectra as a function of propane partial pressure, showing clearly that as the propane pressure increases the fraction of events that recorded in the neutron peak increases. Figure 9 shows this fraction as a function of the propane pressure; we believe that 2 bar of propane (corresponding to just over 30% of events having their charge collected by a single pad) will represent the best partial pressure, with the remaining events shared between either two or, at most, three pads. Higher hydrocarbons are also being evaluated, in order to achieve the equivalent stopping power of propane at a lower pressure.

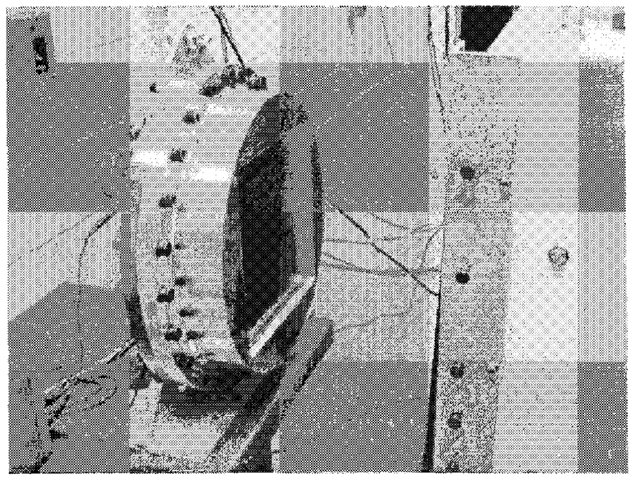

Fig. 6. The pressure vessel containing the fully assembled detector is seen at left, with neutrons irradiating it from the moderated Am/Be source at right. The only external equipment required is a power supply (bottom left) and personal computer (not shown).

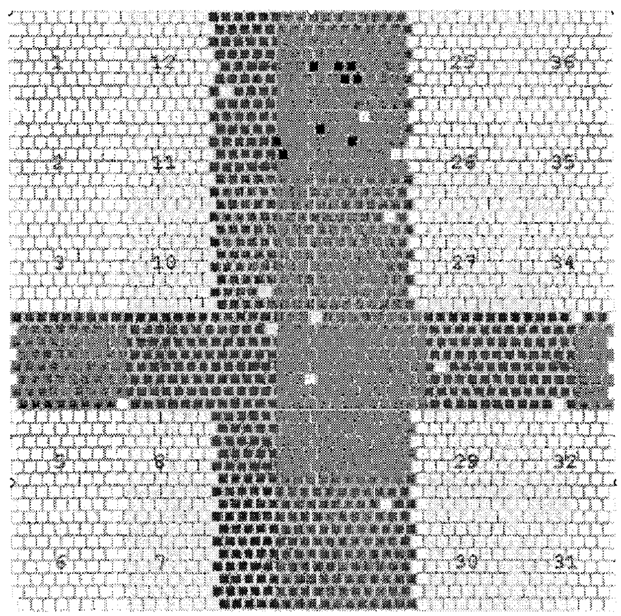

Fig. 7. Two-dimensional histogram generated by uniform illumination of the detector. Increasing red brightness corresponds to increasing counts, and a fall-off in the number of counts from the center reflects the true intensity from the nearby neutron source. As detailed in the text, 20 ASICs (10 on the left, 10 on the right) were not implemented in these initial measurements. Black pixels indicate low charge collection.

In each of the spectra in Fig. 8, there are three important regions to distinguish. At low amplitude, there is an increase in counts which eventually is cut off by the lower threshold setting. These are not noise, but rather induction signals from events in which an adjacent pad actually collected the charge. There is a broad plateau of events with amplitudes ranging up to that of the neutron peak, corresponding to this particular pad's signal from shared events. Then there is the full neutron peak, whose intensity depends upon propane partial pressure.

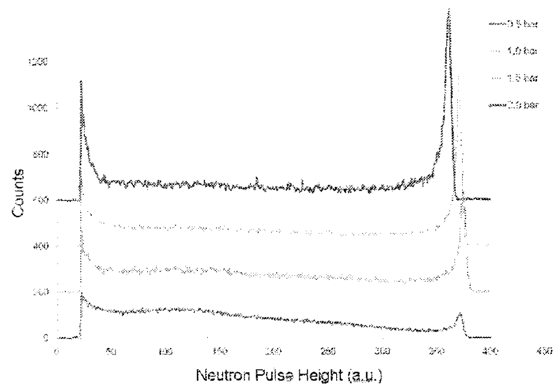


Fig. 8. Pulse height distribution from one anode pad, as a function of propane partial pressure. As the propane pressure increases, a larger percentage of events is recorded in the full neutron peak.

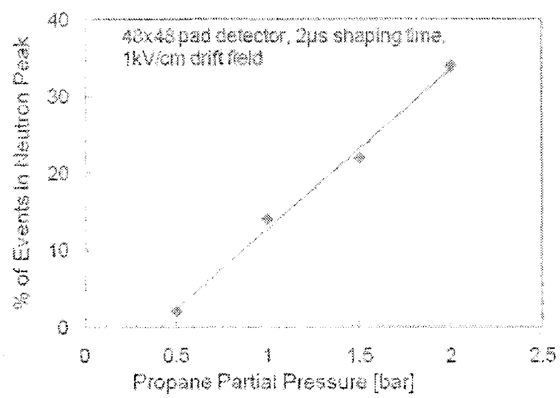


Fig. 9. Percentage of events in full neutron peak as a function of propane partial pressure.

The low noise of each preamplifier within the ASICs results in excellent energy resolution. Figure 10 shows the pad pulse height spectrum from a prolonged data run with 3 bar of helium and 2 bar of propane. A FWHM of 1.8% is achieved. This is one of the best ever recorded for thermal neutrons in a gas, and as far as we know it is the best in a detector that operates without a Frisch grid. The relative contribution of preamplifer noise is approximately 1% FWHM, as represented by the red peak generated by injection of 5fC from a pulser.

Notable results of energy resolution from other work are 2.5% FWHM in a detector measuring scintillation from a helium/xenon mixture [8], and around 1.6% in a $^3$He spectrometer [9] using a Frisch grid to separate the conversion region from the signal region.

## V. Conclusion

A new position-sensitive neutron detection technique is being developed based on neutron conversion in $^3$He and operation in the ionization mode, i.e. unity gas gain. This will result in almost complete removal of the aging effects that sometimes degrade the performance of proportional chambers, and also contribute to stable and reliable operation. Pixel with dimensions of a few mm on a side (perhaps as small as 2mm) will be practical, and certain construction techniques may lead to flexible geometries that reduce parallax. Very high count rate capability will be achievable, of order $10^5$ $s^{-1}$ per pixel; the technique is reliant on the use of low noise ASICs. Future work will explore the limits of pad density and counting rate using this technique.

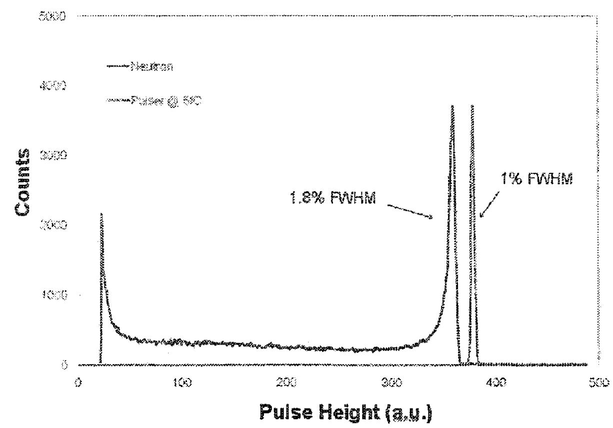


Fig. 10. Neutron pulse height resolution from a single pad (blue curve), and response from a charge injection of 5 fC from a pulser (red curve).

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