A Detector for Neutron Imaging

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***Abstract* - A bright neutron source such as the Spallation Neutron Source (SNS) places extreme requirements on detectors such as the highly desirable characteristics of excellent 2-D spatial imaging and high dynamic range. Present imaging detectors have either shown position resolutions that are less than acceptable or they exhibit excessive paralyzing dead times due to the brightness of the source. Detectors that also exhibit high efficiency are necessary to ensure acceptable discrimination and satisfactory statistics. A detector concept known as MicroMegas (MicroMEsh GAseous Structure) has been developed at CERN in Geneva for high-energy physics charged-particle tracking applications and has shown great promise for handling high data rates with a rather low-cost structure. We are attempting to extend the MicroMegas detector concept to make it neutron sensitive by adding a neutron converter (^{10}B) to the structure and have designed a 1-D neutron strip detector which we are presently testing. In addition, we are performing research into the compatibility of various converter coatings. Our goal is to develop a manufacturable detector that could be scaled to a 1m^2, 2-D array for use at the SNS and other facilities.**

I. Introduction

When the high power neutron sources such as High-Flux Isotope Reactor (HFIR), ILL, and ISIS came on line, state-of-the-art neutron detectors were no longer able to deal with the high event rates. Small Angle Neutron Scattering (SANS) Instruments and reflectometers routinely use beam attenuators at these sources which limit the dynamic range. When the new spallation sources, such as SNS, JSNS, and ESS, are built, these detector issues go from serious to severe. Today's detectors can handle only 1% of the expected maximum event rates. Fortunately a new detector technology, the MicroMegas, has been developed at CERN that shows great promise for charged particles. Furthermore, we believe that the basic technique demonstrated by this technology could be used successfully for neutron detection. This will require research and development to address the many differences between charged-particle and neutron detection, as well as overcoming the challenges of true 2-D pixelation.

The detector concept [1, 2] proposed is shown Figure 1. A top drift electrode with a converter such as ^{6}Li or ^{10}B on the inside produces α particles (in addition to ^{7}Li for the boron and a triton for the lithium) from incident neutrons. The inside of the detector is filled with a gas such as P-10 (Ar 90%, methane 10%) at one atmosphere. In our proposed implementation, there is a nickel micromesh situated 73μm above a metallic pixel array whose pixel sizes range from approximately 1mm X 1mm to 5mm X 5mm. The field above the micromesh allows charge production in the fill gas along the path of an α particle and the field beneath the mesh promotes multiplication of the charge arriving at the mesh. This charge is then collected by the nearby pixel elements. The short drift path for the charge ensures low deadtime and the pixelation ensures good spatial resolution.

The scope of our current work is to develop a 1-D strip detector version of the detector as a proof-of-principle device with which to study the various aspects of the detector structure.

II. Technical Approach

The goal of this work was to develop a prototype high (position) resolution, low-dead-time detector. In order to accomplish our goals, two key projects are being undertaken. One is focused on the development of the detector structure and readout electronics while the other is directed towards converter foil research. The detector structure portion of this project will entail building and testing both a 1-D (strip) and 2-D (pixel) detector. Initially a 1-D strip format will be developed since it allows easy electronic readout, while our long-term goals will be to produce a true pixilated 2-D detector. We are limited in scope to small arrays due to the cost of implementing electronic read outs (highly arrayed detectors require custom readout amplifiers because of the small detector element sizes). Our initial efforts reported below show results with only six strips connected to amplifiers. Even with a small number of strips, however, we have been able to demonstrate progress.

A. Fabrication techniques and choice of materials for the 1-D substrate and mesh screen

We have fabricated a detector prototype, shown in Fig. 2, whose anode structure was formed on a quartz substrate using micro-fabrication techniques. A regular array of

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separator columns 73-μm-tall was formed by chemically etching the photo-patterned surface. A shadow mask was then aligned to permit 250-μm-wide chromium anode strips to be evaporated between the columns (shown in Fig. 3). Adjacent strips were spaced 1mm (center-to-center) and were alternately connected to vacuum feedthroughs in the aluminum chamber. A 1000-line-per-inch, 7-μm-thick nickel grid was placed atop the anode structure. Application of high voltage caused the grid be pressed firmly atop the separator columns. A 3-mm printed-circuit board insulator was then used to space a boron- or lithium-coated aluminum converter plate from the grid.

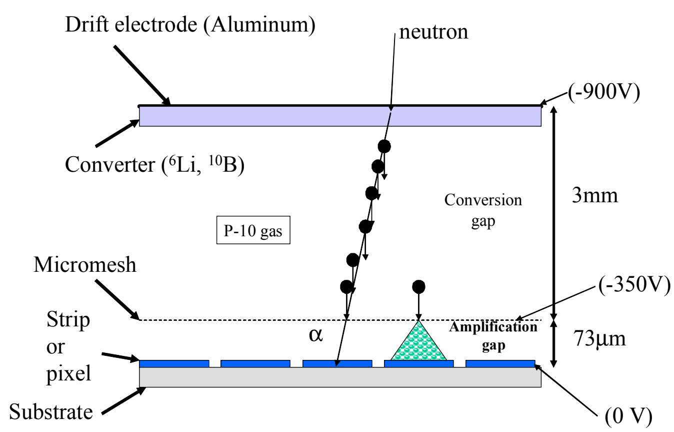

Fig. 1. Neutron detector concept.

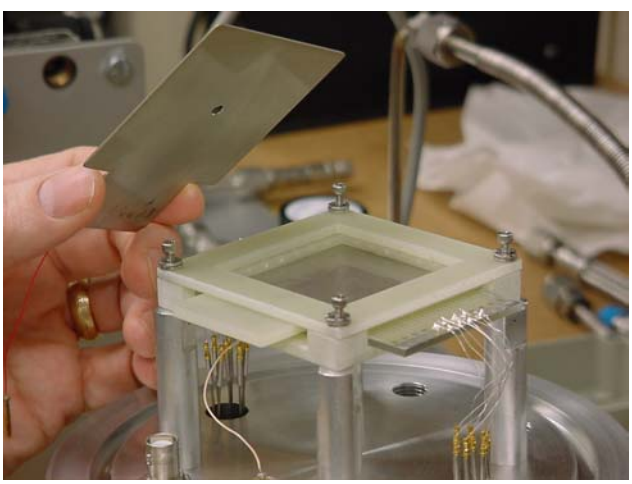

Fig. 2. Detail of detector construction.

B. Fabrication and evaluation of neutron conversion films

The main objective of the converter work thus far has been to develop the techniques required to fabricate the converter foils as well as understanding and manipulating the chemical or electrochemical stability of these foils. This is essential to successfully building a stable, high-efficiency detector. To this end we have been very successful in meeting our goals.

Converter films consisting of naturally abundant elements have been prepared utilizing a variety of physical deposition techniques. Due to the air and moisture sensitivity of these materials all film growths were carried out in a deposition system contained within an argon filled dry box. Thin-films of boron (1-2 μm) and gadolinium (1-2 μm) have been prepared utilizing r.f. and d.c. sputtering techniques respectively, while lithium films were deposited by thermally evaporating elemental Li (3-100 μm). These thickness ranges were chosen from the literature for reasonable detector efficiency. The deposition conditions were optimized (i.e. argon pressure, power, distances between the targets and substrates, rate and choice of substrates) in order to minimize the film impurities as well as reduce any potential mixing of the reactants due to the energetic nature of the deposition process. By optimizing the deposition conditions we have effectively reduced the impurity content to below 5 atomic %.

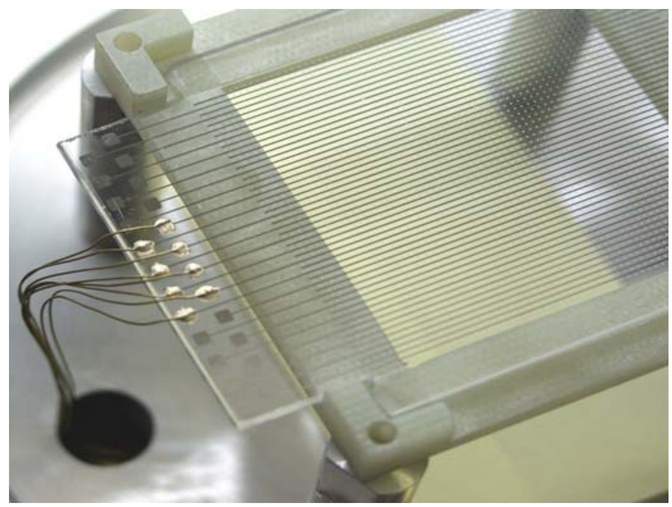

Fig. 3. Close-up photograph of strip construction.

The interdiffusion between the converter materials and the substrate at the film interface was investigated utilizing Rutherford Backscattering (RBS). In all of the films there appears to be some degree of interdiffusion between the metals. Further investigations are being planned in order to study any long term alloying, and what affect this would have on detector performance.

Experiments to explore the electrochemical alloying between Li and a variety of candidate substrate/electrode materials were also undertaken. Experimental data indicate that there is little to no change in the electrical resistivity when Li is in contact with V, W, Co, Cu, Ni and Zn indicating that either no alloying is occurring or that any alloying is not deleterious to the electrical properties. However, dramatic changes in the resistivity are observed for Li and Au, Cr, Sn, Ti and Si. Recent calculations indicated that Al is the preferred substrate for the detector. Therefore, studies to investigate the reaction between the Li and Al are presently underway.

The long term stability of the converter foils with the detector gas was also examined. Every conceivable combination of converter foils was prepared and stored in an evacuated quartz tube. The tube was then back filled with P-10 detector gas. The samples were left in this environment for several weeks in order to determine if the films would react with the gas. After several weeks there was no visible reaction between the foils and the gas, indicating the probable stability of the foils to the detector environment. In the future, the films will be analyzed using a combination of scanning-electron microscopy/energy-dispersive x-ray analysis techniques to access any non-apparent reactions.

III. Summary of Detector Prototype Testing

We instrumented the detector with six channels of preamplifier-shapers plus a multichannel data-acquisition system (DAQ). The preamplifier was charge-sensitive, originally designed for diode readout. The shaper was designed for this setup and the DAQ was designed originally for an eight-channel detector system. Our testing included:

A. Critical Voltage ($\mathcal{E}_{crit}$) testing

We temporarily replaced the converter element inside the detector with a ^{241}Am source to simulate a 'point' source of alpha particles instead of using neutron-induced alphas for preliminary testing. This allowed us to evaluate both the detector structure under various voltages and the data acquisition system with a known stable source of particles. The critical voltage $\mathcal{E}_{crit}$ is the voltage when electron multiplication begins for a given gas and detector geometry. Calculations for our geometry at 1 atm. of P-10 predicted a value of $\mathcal{E}_{crit}$ =350V for our multiplying grid voltage. Our measurements showed a value of approximately 330V, demonstrating excellent agreement with the design value as shown in Fig. 4..

B. Detector position mapping with ^{241}Am

With the DAQ we simultaneously read out each of the six instrumented channels of strips in two different modes. Mode 1 was a conventional asynchronous multi-channel analyzer (MCA) mode in which any channel that gets an event at any time was converted and histogrammed (analogous to having six independent MCAs). Data from a representative run is shown In Fig. 5. For these tests, the source was located above the instrumented detectors in the approximate center. This can be seen by the largest number of events in channel 4 (center channel) and fewer events in adjacent channels. The output from one of the preamplifiers is shown in Fig. 6.

C. ^{252}Cf Testing (neutron testing)

Data were taken for several coatings including 1- and 2-μm boron and 26-μm lithium. Mode 2 of the DAQ allowed us to stop and read all channels any time when one of the strips had an event. This allowed position determination of an incident neutron in 1-D. Data shown in Fig. 7 was collected using external ^{252}Cf (in Lucite to thermalize the neutrons) as a neutron source with a 1μm-thick boron converter plate. The DAQ was configured in Mode 1 for integrating counts. Fig 8 is the data acquired in Mode 2 (stop-and-read). Note that some adjacent strips show charge sharing which we expected from earlier Monte-Carlo analyses.

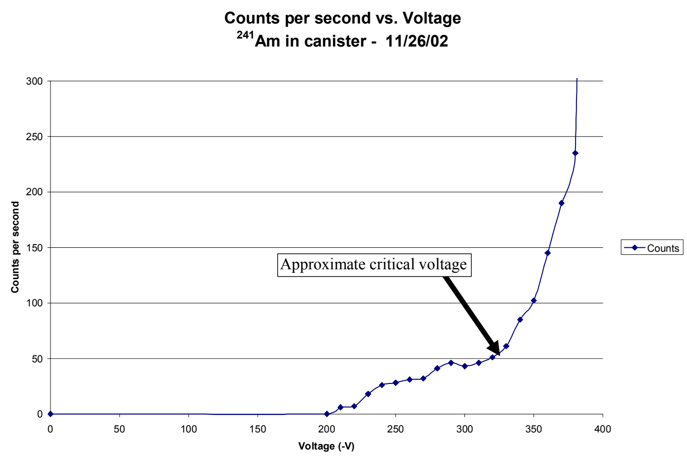

Fig. 4. Plot of critical voltage measurements..

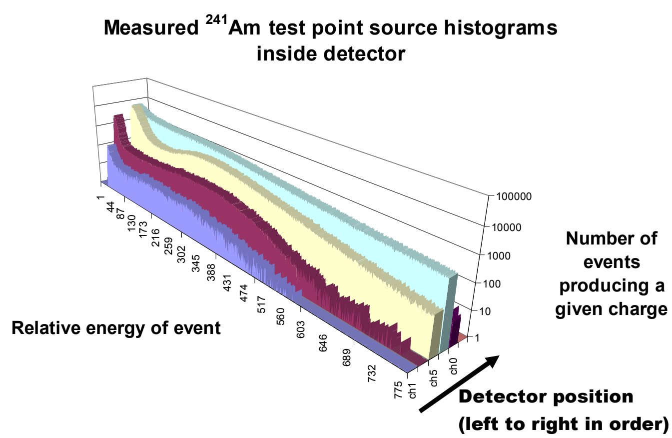

Fig. 5. Point source ^{241}Am data.

We tested the detector at the Californium User's Facility at HFIR in Oak Ridge. The detector was mounted directly in front of the beam from the ^{252}Cf source. The rate measured by the detector was 17,926 events on the six strips in 3436 seconds giving a rate of 5.22 n/s. The strip geometric area was 0.25mm x 50mm or 0.125 cm^2. The total beam area was 50 cm^2 and the total neutron rate for the beam 10^4 n/s. This predicts a flux of 200 n/s/cm^2. The geometric area of the strips is 6 x 0.125 = 0.75 cm^2. A 100% efficient detector would have recorded 0.75 x 200 x 3436 or 5.15 x 10^5 neutrons. The efficiency was therefore 17,926/5.15 x 10^5 = 3.5%. This number is consistent with a 2-µm boron film and a lower-level dicriminator cutoff of 400keV[3]. A theoretical lower-level discriminator (LLD) threshold of 110keV was obtained from Monte Carlo simulations for this detector[2, 4] but, because of the unknown number of high-energy neutrons in the flux, the LLD is somewhat in question.

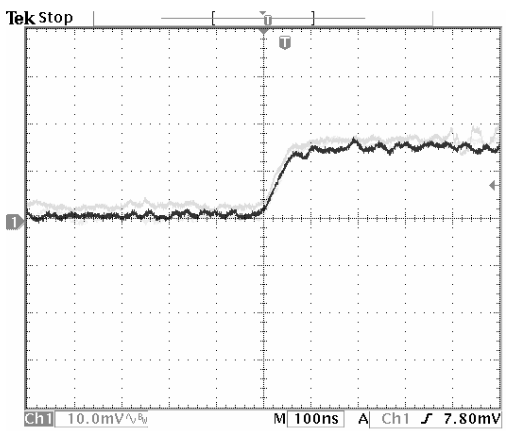

Fig. 6. Preamplifier-detector risetime with ^{241}Am.

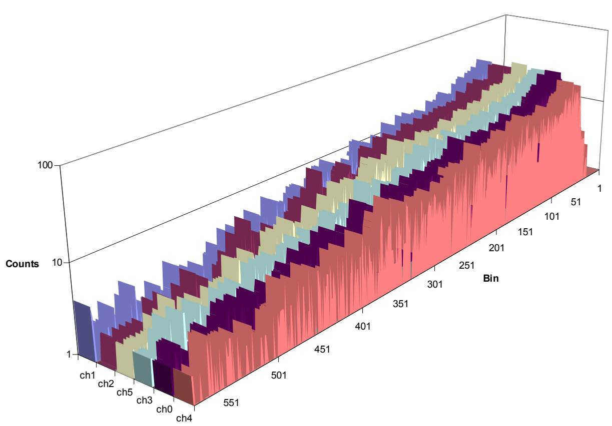

Fig. 7. MCA (Mode 1) data, 1µm boron converter using thermalized neutrons.

D. Knife-Edge Testing

To estimate the resolution of the detector with a ^{10}B converter, half of the active area of the detector was covered with a 1-in thick piece of neutron absorbing material, B_4C. This material shielded three of the anode strips. The data from this test are shown in Fig. 9. The total counts on each strip are represented by the red dots. The resolution from an edge is typically represented by a line spread function, LSF. To obtain the LSF, the data were fit with a transition function. After performing this analysis the LSF (resolution) was found to be 3.3 mm.

III. Conclusion

We have designed, constructed, and tested a six-strip prototype neutron detector whose concept is an excellent candidate for high-rate neutron imaging. The next step is to take this detector concept and construct a small, 2-D pixel array. This will occur during 2003-2004.

IV. Acknowledgements

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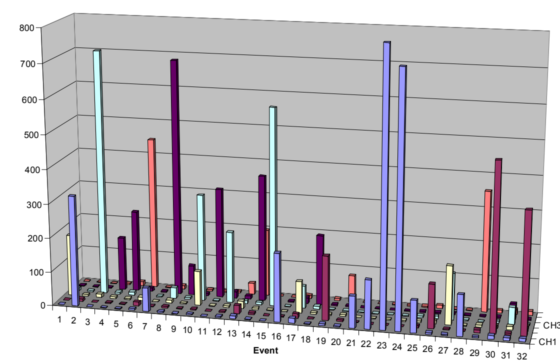

Fig. 8. Mode 2 data, 1µm boron, thermalized neutrons.

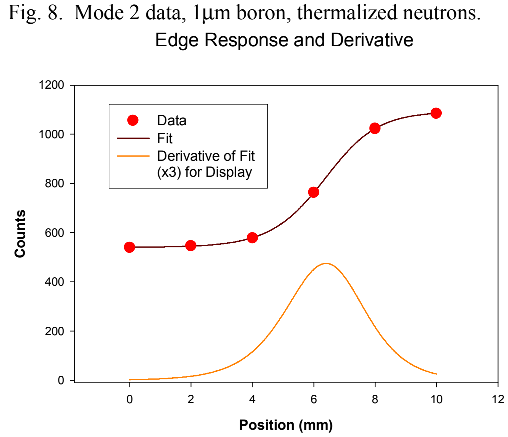

Fig. 9. Edge response of the detector with thermalized neutrons.

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