Design and Operation of a 2D Thin Film Semiconductor Neutron Detector for use as a Beamport Monitor

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ABSTRACT

Silicon based diodes coated with a thin film of neutron reactive materials have been shown to produce excellent low efficiency neutron detectors. This work employs the same technology, but groups 25 equally sized and spaced diodes on a single 29 mm by 29 mm chip. A 5x5 chip was fabricated and coated with a thin film of ^{6}LiF for use as a low efficiency neutron beam monitor. The 5x5 neutron detector array is coupled to an array of amplifiers allowing the response to be interpreted using a LabVIEW FPGA. The 5x5 array has been characterized in a diffracted neutron beam. This work is part of on-going research to develop various designs of high and low efficient semiconductor neutron detectors [1-3].

INTRODUCTION

Coated semiconductor diodes have been used as neutron detectors for many decades. The typical design consists of a Schottky barrier or P-N junction diode that has a neutron reactive coating, such as ^{10}B or ^{6}LiF, applied over the top of the device. Low cost, compact size, low power requirement, ruggedness and the ability to be easily tailored for the end user are all advantages that coated diodes have as compared to other types of neutron detectors.

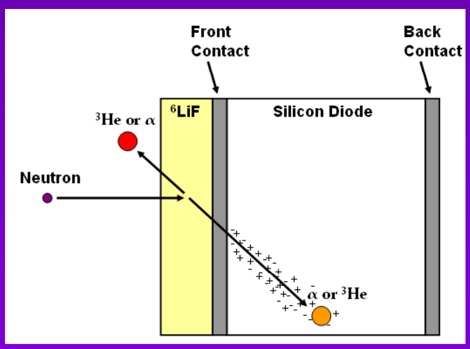
This work specifically focuses on developing a low efficiency 2-D Silicon based neutron detector for use as a beam monitor at a nuclear reactor's beam port. The general idea is to operate the detector upstream of other experiments in a neutron beam and be able to monitor any reactor transients that may be occurring in real time while performing experiments. The small amount of ^{6}LiF coupled with the small cross section of the silicon diode will allow the neutron beam to remain relatively unperturbed so that the effect on the experiment will be negligible, therefore yielding valuable information about the beam characteristics and how they may affect the experiment.

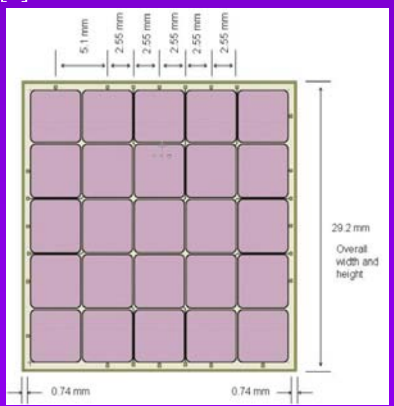
THEORY

Semiconductor neutron detectors are nothing more then planer semiconductor diodes with a thin film of neutron reactive material attached to the surface. These charged particle detectors work on the principal that since neutrons have no electric charge, the detector relies on secondary effects from the neutron interacting with the neutron reactive material. One such reaction is that with ^{6}Li.

$$^{6}Li + {}_{0}^{1}n \rightarrow {}^{3}H \text{ (at 2.73 MeV)} + \alpha \text{ (at 2.05 MeV)}$$

Pure ^{6}Li is particularly reactive and corrosive so a more stable compound of ^{6}LiF is typically used. Other coatings can be used, however ^{6}LiF has the most energetic secondary reaction products of the alternatives. The secondary reaction emits the 2 charged particles in opposite directions. As such, only one particle can be measured in the detector. The efficiency of the detector varies with the film thickness [1].



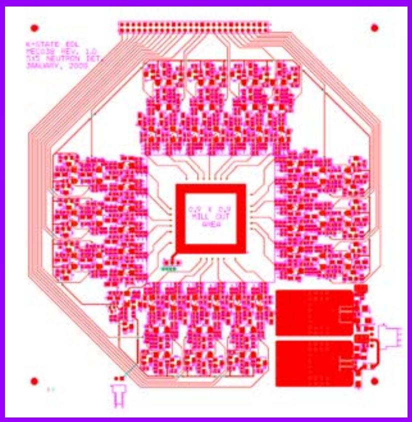


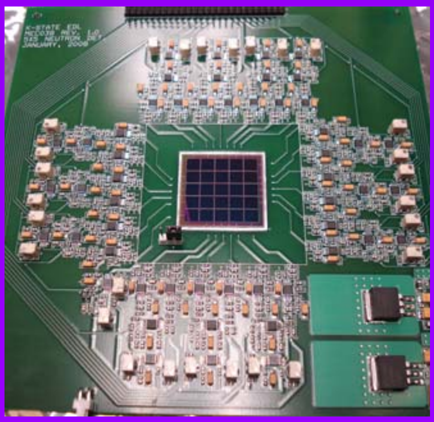
DEVICE FABRICATION

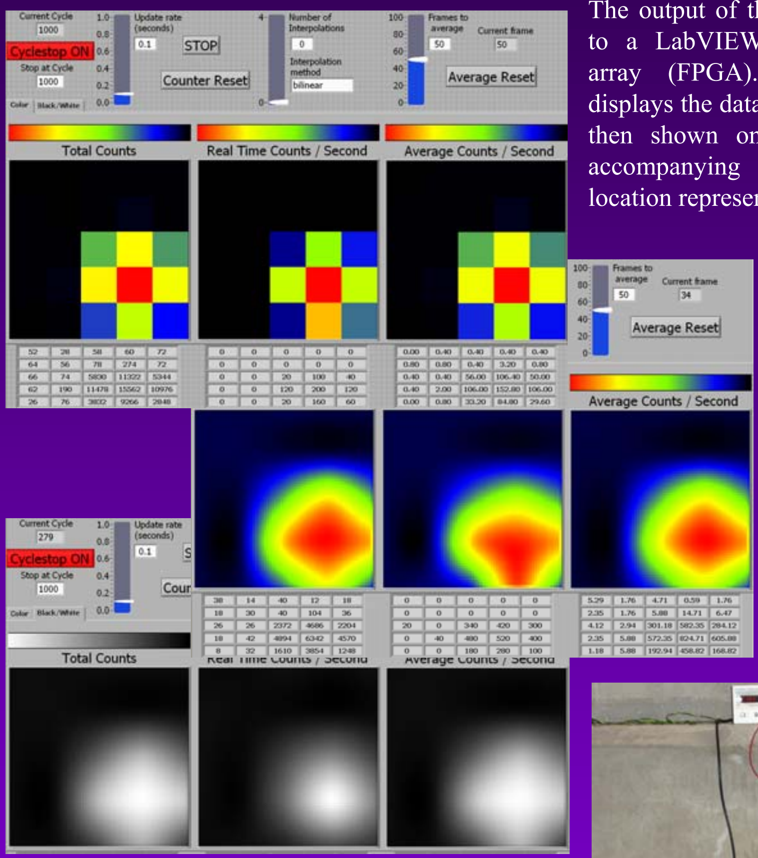
All processing starts with float zone, single-side polished, >10kΩ-cm, n-type Silicon wafers 76 mm in diameter and approximately 400 µm thick. The wafers are first put through typical VLSI processing steps to produce diodes. After the diodes are complete they are coated with a thin film of ^{6}LiF approximately 1µm thick. The chips are then given a conformal protective coating and are then ready to be mounted to an amplifier board.

AMPLIFIER BOARD

The board consists of 25 identical amplifier circuits each with an adjustable threshold voltage that allows for individual adjustments of each channel to compensate for different noise levels between channels. The overall threshold voltage for the entire chip can also be changed via a single potentiometer. The board is designed to allow a bias to be applied, however for all testing it is operated with no bias applied.



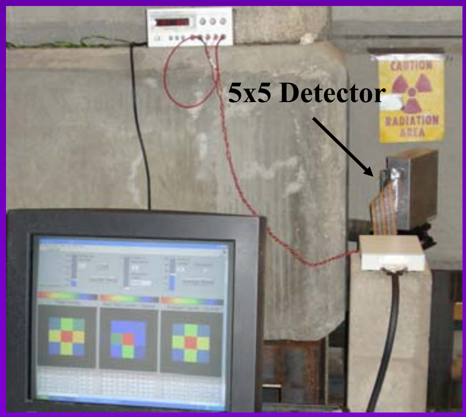




COMPUTER READOUT

The output of the amplifier board is wired to a LabVIEW field-programmable gate array (FPGA). A LabVIEW program displays the data in a 2-D array. The data is then shown on 3 intensity graphs with accompanying 5x5 matrices where each location represents a pixel on the detector.

The 3 graphs show the cumulative counts, the instantaneous counts per second, and the average counts per second over a user selected time interval. The intensity graphs are user selectable between color and black/white and feature several interpolation routines for easier viewing.

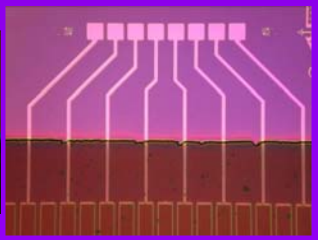


TESTING

The 2-D neutron detector was tested in a 0.5in. diameter diffracted neutron beam located at the Kansas State University TRIGA Mark II nuclear reactor. The detector was first positioned so the center pixel was in the middle of the neutron beam. Each remaining pixel with then positioned in the center of the neutron beam to check for detection uniformity across the device. Appropriate scaling factors were then assigned to each pixel.

OTHER APPLICATIONS

The design of these detectors on Silicon substrates means that virtually any size or shape of array can be constructed. This is particularly useful for any beam-line experiments. One such array, a high efficiency 1-D 1024 channel array, has been constructed for the Spallation Neutron Source at Oak Ridge National Laboratory for use in small-angle neutron scattering experiments [3].



CONCLUSION

A 5x5 neutron beam monitor has been designed, constructed, and then tested in a neutron beam. Scaling factors have been programmed into each pixel to yield a real time, uniform, 5x5 neutron detection array. This basic design demonstrates the concept that can be applied to any user specified requirements.

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