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OPERATION OF TWO-DIMENSIONAL GAS DETECTOR USING MICRO-PIXEL DETECTOR ELEMENT UNDER HIGH PRESSURE FOR NEUTRON MEASUREMENT

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ABSTRACT

An improved micro-pixel detector element was fabricated, and neutron irradiation experiments were conducted. The micro-pixel detector element was fabricated using printed circuit board (PCB) technologies. Therefore, it is easy to fabricate and reproduce detector element with a large number of pixels. A gas-based neutron detection system capable of individual line readout, consisting of the developed detector element, gas chamber, amplifier-shaper-discriminator boards, optical signal transmission device, and a fast data acquisition device, was constructed for the experiment. The measured gas gain was approximately 280 at the total pressure of 5 atm (4.5 atm of He and 0.5 atm of CF_4), and supplied voltage of 670 V. The gas gain did not decrease (due to the charge-up effect) when the detection system was operated for 150 h. The average gain spread in two-dimensional imaging was 6.2%.

1. Introduction

Serious efforts are being made to perform neutron-scattering experiments involving high-intensity pulsed neutrons at facilities located in Japan, the United States, and the United Kingdom [1-3]. The small-angle neutron scattering experiments and neutron reflectometry performed at these facilities require challenging neutron detectors that have features such as a two-dimensional detection area of more than 100 mm^2, good spatial resolution of less than 1 mm full width at half maximum (FWHM), high detection efficiency higher than 70% for neutron wavelength at 1.8 Å, and a low response time of less than 1 μs. With the objective of finding a neutron detector that satisfies these requirements, we are currently developing a two-dimensional position-sensitive neutron detection system that can read out individual line and consists of a two-dimensional detector element [4-6]. In this system, to achieve spatial resolution of less than 1 mm, it is necessary to ensure that the system pressure corresponds to that of the quenching gas, e.g., 0.15 MPa when the quenching gas is CF_4. When the gas pressure is increased, the supplied voltage must also be increased to get the high gas gain. We are developing a two-dimensional detector element to ensure the safe operation of the detector system even under high voltages. In the present study, we conducted irradiation experiments on the developed micro-pixel detector element using a Cf-252 neutron source.

2. Experiments

The micro-pixel detector element was fabricated using printed circuit board (PCB) technologies; in principle, it is easy to fabricate and reproduce detector elements with a large number of pixels. The micro-pixel detector element comprises of pixel anodes in the shape of pins; these pins serve as the anode, and each pin is located at the center of a circular cathode hole. A photograph of the micro-pixel detector element is shown in Fig. 1. Both electrodes are fabricated from Cu on a polyimide substrate. The pitch between anodes and between cathodes is 0.4 mm.

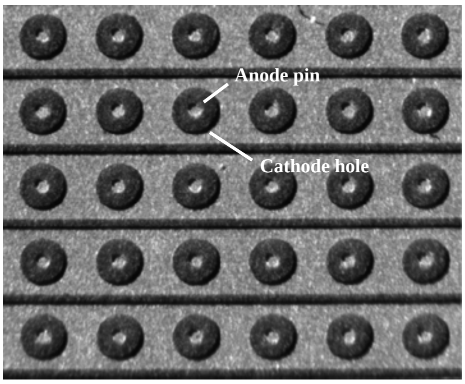

Fig. 1. Photograph of micro-pixel detector element.

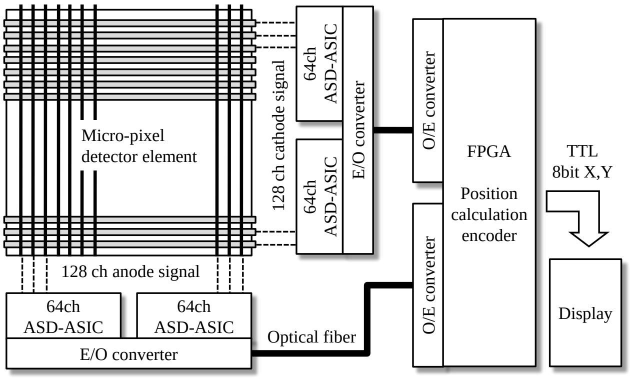

Fig. 2. Schematic view of the experimental system

A neutron detection system, which consisted of the micro-pixel detector element, a gas chamber, amplifier-shaper-discriminator boards, optical signal transmission device, position encoders with field programmable gate arrays, and a device capable of fast data acquisition, was constructed to perform irradiation tests on the detector element. The schematic view of the experimental system is shown in Fig. 2. Experiments were conducted using a gaseous mixture of ^{3}He and CF_4. ^{3}He and CF_4 functioned as the neutron converter and quenching gas, respectively. The detector element was installed in a gas chamber with a conversion gap of 20 mm. The chamber, inside which the detector element was placed, was vacuumed to less than 10^{-5} Pa for more than 40 h, before it was filled with the gaseous mixture; this was done to prevent outgassing from the detector element. Hereafter, we refer to the detector head as a micro-pixel gas chamber (MPGC). In MPGC, the charge signal is generated as a result of the gaseous amplification around each anode pin induced by the strong electric field between the electrodes. Anode lines and cathode lines are arranged orthogonally. The signal corresponding to each line is individually amplified, shaped, and discriminated by amplifier-shaper-discriminator application-specific integrated circuits (ASD-ASICs). The nominal settings of the ASD-ASIC are an amplification factor of 0.8 V/pC, and a decay time of 80 ns [7]. The digital signals converted in the ASD-ASIC transmit to the position encoders through optical fibers as optical signals that are converted by the specially-fabricated E/O-O/E converter. Optical fiber is insensitive to electromagnetic forces and absence of transmission of electrical signals. And, the transmission loss of optical fiber is much smaller than that of conventional electrical cable. Therefore, the distance of signal transmission can be extended by using optical fiber.

Neutron irradiation on the MPGC was performed using a Cf-252 neutron source. The Cf-252 neutron source, whose intensity was 100 MBq, was embedded in a graphite cube with sides of 80 cm. The neutron flux at the surface of the cube was found to be 10^7 n/m^2·s by measurement using an absolutely-calibrated BF_3 counter.

3. Results and discussion

Fig. 3 shows the pulse-height distributions recorded along an anode line using an analog-to-digital converter (ADC; 7072T, Fast ComTec) and a data acquisition system (MPA-3, Fast ComTec.) under neutron irradiation. The He and CF_4 gas pressures were maintained at 0.425 and 0.075 MPa, respectively, and the supplied voltage between the anode and the cathode was 650 V. A signal-pulse peak of neutrons can be clearly observed at the anode line. This result indicates that a majority of the spurious events generated in the lower channels as result of electronic noise and gamma events can be easily suppressed using a discriminator. The output pulse shapes of each line upon neutron irradiation after modification by the preamplifier in ASD-ASIC were measured. Typical pulse shapes at an anode and a cathode lines are shown in Fig. 4. In the figure, open and filled circles present the pulse shapes at gas pressures of 0.45 MPa for He and 0.05 MPa for CF_4 and supplied voltage of 650 V, and open and filled squares present the pulse shape at gas pressures of 0.415 MPa for He and 0.085 MPa for CF_4 and supplied voltage of 700 V. And the open and filled symbols present the pulse shape at an anode and a cathode lines, respectively. It was found that the detector exhibits a fast temporal response; the FWHM of the response time was 160 ns in the anode and cathode, as obtained by measuring the output pulse shapes in each line under neutron irradiation. The difference in signal duration was not observed by varying the gas condition and supplied voltage. This signal was observed sufficiently fast to achieve a fast response time of less than 1 μs.

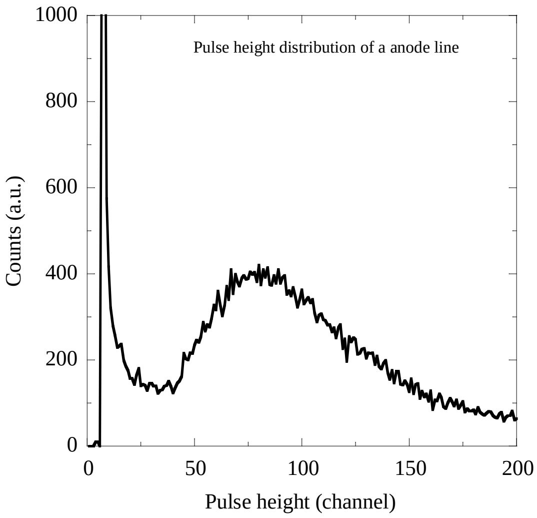

Fig. 3. Pulse-height distribution of output signal along anode line. The gas pressures are 0.425 MPa of He and 0.075 MPa of CF_4, and the supplied voltage is 650 V.

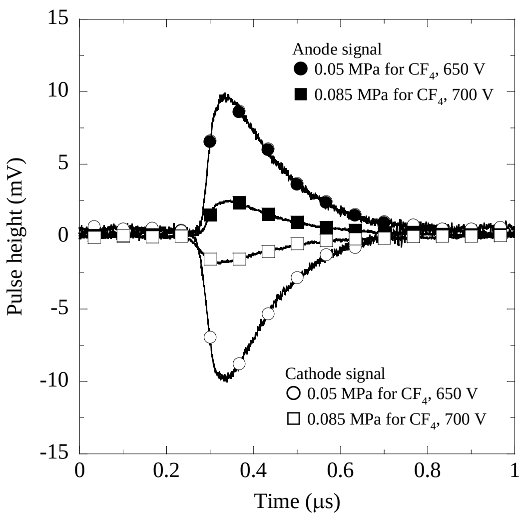

Fig. 4. Neutron-induced output pulses at an anode and a cathode line.

The gas gain of the detector element was measured using MPA-3 and the ADC. Fig. 5 shows the measured gas gain as a function of the supplied voltage at the pressures of 0.05, 0.75, and 0.85 MPa for CF_4. At gas pressures of 0.05 MPa for CF_4, the gas gain increased with increasing the supplied voltage, and reached approximately 280 at a voltage of 670 V. The thermal neutron detection efficiency was estimated to be approximately 73% at the gas pressure of 0.45 MPa for He and 0.05 MPa for CF_4; this efficiency was calculated by taking into consideration the nuclear reaction cross section of ^{3}He gas and the conversion gap of 20 mm. The developed element could operate at higher CF_4 pressure, and the gas gain at the voltage of 710 V was found to be approximately 97, and 56 at CF_4 pressure of 0.075, and 0.085 MPa, respectively. We continuously operated our MPGC for 150 h to confirm the gas gain stability to the voltage. The elapsed time dependence of gas gain after applying the voltage is shown in Fig. 6. It was observed that the gas gain did not decrease during the operation and the element exhibit 19% gain increase because of a polarization effects in dielectric.

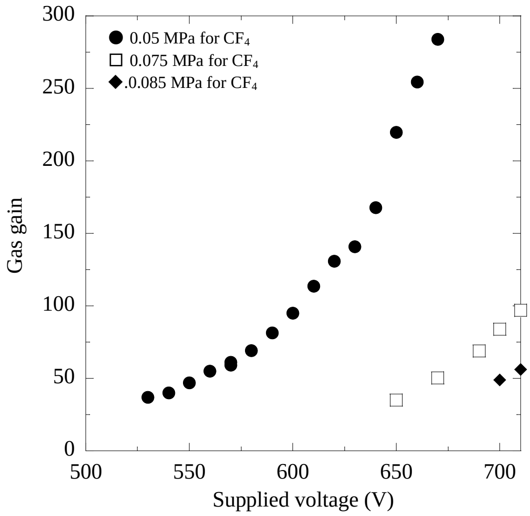

Fig. 5. Gas gain of micro-pixel detector element measured under neutron irradiation

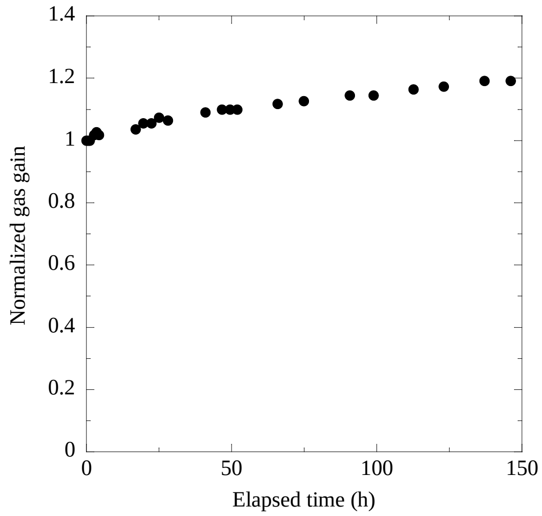

Fig. 6. Variation of gas gain as a function of elapsed time after applying the voltage.

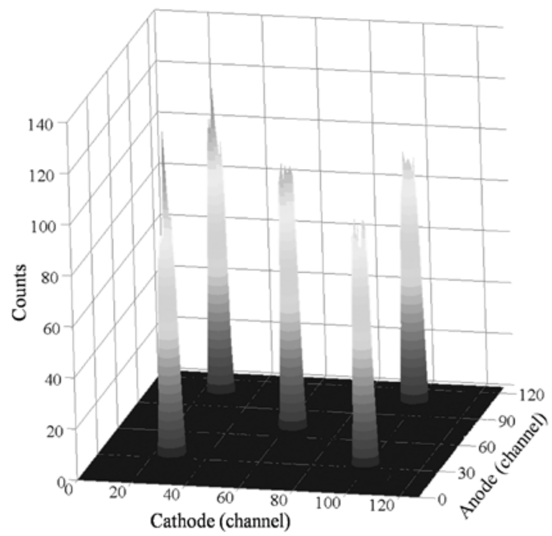

Fig. 7. Two-dimensional response obtained using a collimated neutron beam with a size of 0.3×0.3 mm^2.

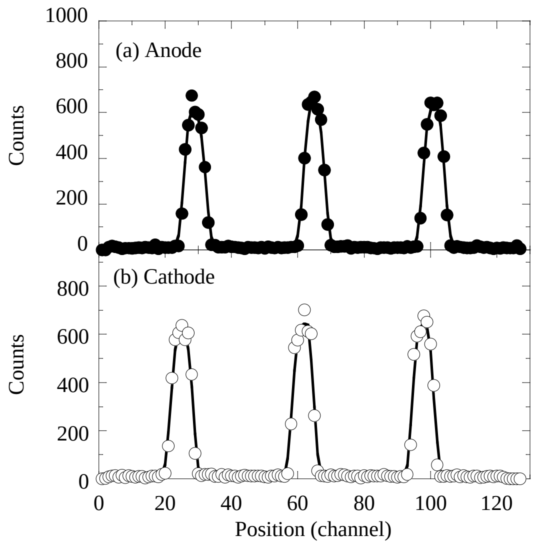

Fig. 8. One-dimensional response of 0.3×0.3 mm^2 collimated neutron beam: (a) anode and (b) cathode.

Fig. 7 shows a typical two-dimensional image of our detection system irradiated by a neutron beam. The detection system is irradiated with a collimated neutron beam of 0.3×0.3 mm^2 cross section by scanning the detection area. Figs. 8 (a) and (b) show the one-dimensional projection of the collimated neutron beam in the anode and cathode directions, respectively. Our detection system exhibits similar spatial resolutions, of about 2.5 mm FWHM, in both the anode and cathode directions at gas pressures of 0.45 MPa for He and 0.05 MPa for CF_4. Considering the Monte Carlo simulation results, this value appears to be reasonable. To achieve spatial resolution less than 1 mm which is a requirement of small angle neutron scattering experiments, it is necessary to increase the pressure of the quenching gas, e.g. to 0.15 MPa for CF_4. However, when the gas pressure is increased, the supplied voltage must be increased to increase the gas gain. We are developing and fabricating a detector element that can operate safely at the high voltage needed to satisfy this requirement.

The flat-field image was measured to confirm the homogeneity of our detection system. The image appears to be homogeneous across the entire sensitive area, which also reflects the gain homogeneity. Fig. 9 shows the histogram of the pixel contents of the obtained flat-field image. The histogram was evaluated by fitting with a Gaussian function. The average pixel content is 292 counts with a standard deviation of σ = 18.0, corresponding to an average gain spread of about 6.2%.

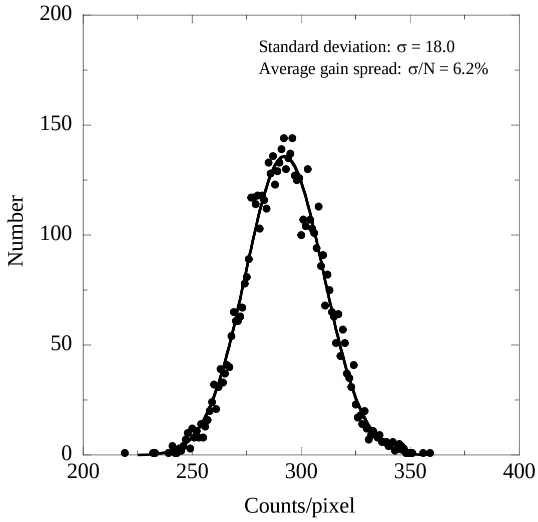

Fig. 9. Histogram of count distribution of flat-field image and the Gaussian fit of the histogram

4. Summary

A micro-pixel detector element was developed and an irradiation test was carried out using neutrons. The detector exhibited short pulse duration of 160 ns FWHM. The gas gain of the detector element was about 280 with a supply voltage of 670 V and a total pressure of 0.5 MPa (0.45 MPa for He and 0.05 MPa for CF_4). The element demonstrated stable long-term operation at high voltage during more than 150 h with a 19% gain increase due to dielectric polarization. The spatial resolution in the anode and cathode directions was 2.5 mm FWHM under these gas conditions and the average gain spread in two-dimensional imaging was 6.2%. The neutron detection system using the detector element capable of individual line readout could identified signal pulse peaks of neutrons, and neutron signals could easily be distinguished from the background noise.

References

1. http://j-parc.jp/index-e.html.
2. http://www.sns.gov.
3. http://www.isis.rl.ac.uk.
4. H. Yamagishi, T. Nakamura, S. Masaoka, K. Soyama, and K. Aizawa, *Nucl. Instrum. Meth. A* **529** (2004) 365.
5. H. Tanaka, H. Yamagishi, and T. Nakamura, *Rev. Sci. Instrum.* **76** (2005) 093302.
6. T. Nakamura, H. Tanaka, H. Yamagishi, S. Masaoka, K. Soyama, K. Aizawa, A. Ochi, and T. Tanimori, *Nucl. Instrum. Meth.* A **573** (2007) 187.
7. R. Orito, O. Sasaki, H. Kubo, K. Miuchi, T. Nagayoshi, Y. Okada, A. Takada, A. Takeda, T. Tanimori, and M. Ueno, IEEE Trans. Nucl. Sci. **51** (2004) 1337.
8. K. Toh, H. Yamagishi, K. Sakasai, T. Nakamura, K. Soyama, A. Ochi, T. Tanimori, IEEE Trans. Nucl. Sci. **56** (2009) 2410.