Development of a Sealed-Type Capillary Plate Gas Detector for Thermal Neutron Imaging*)

Haruyasu KONDO, Hiroyuki SUGIYAMA, Masahiro HAYASHI, Teruyuki OKADA, Fuyuki TOKANAI[1)], Ryutaro ITO[1)], Satoshi ISHIZAWA[1)], Yuichiro INOMATA[1)], Kento SUZUKI[1)], Seiji TASAKI[2)], Masanori HIROSE[3)], Masahiro HINO[4)], Ryohei HANAYAMA[5)] and Takayuki SUMIYOSHI[6)]

Hamamatsu Photonics K.K, Iwata, Shizuoka 438-0193, Japan
[1)]*Yamagata University, Yamagata 990-8560, Japan*
[2)]*Graduate School of Engineering, Kyoto University, Nishikyo, Kyoto 615-8530, Japan*
[3)]*Graduate School of Science, Kyoto University, Sakyo, Kyoto 606-8502, Japan*
[4)]*Research Reactor Institute, Kyoto University, Kumatori, Osaka 590-0494, Japan*
[5)]*The Graduate School for the Creation of New Photonics Industries, Hamamatsu, Shizuoka 431-1202, Japan*
[6)]*Tokyo Metropolitan University, Hachioji, Tokyo 192-0397, Japan*

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A capillary plate (CP) gas detector is a type of a hole-type micropattern gaseous detector. The detector displays high spatial resolution characteristics in two-dimensional radiation detection by using a CP with a small channel pitch. In this study, a sealed-type CP gas detector for neutron imaging was developed. The detector converts the incident position of neutrons to an optical image. A novel imaging system was constructed, and it comprised the CP gas detector, an image intensifier unit, and a science-CMOS camera. The system was tested with a compact accelerator driven neutron source, "KUANS." Each signal of charged particles generated by a nuclear reaction between a neutron and a ^{10}B layer was obtained. The results indicated that neutron images were obtained clearly.

Keywords: neutron detector, neutron imaging, capillary plate, micropattern gaseous detector, gas scintillation

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1. Introduction

Neutron radiography is used in various fields including basic science, archeology, and various industries. New measurement methods such as energy resolution imaging, phase contrast, and spatial resolution imaging were developed by previous studies [1], which is expected to improve the performance of Li-ion batteries or in-vehicle radiators. There is an increasing demand for improved spatial resolution and temporal resolution of the detectors used for these measurements. Examples of two-dimensional detectors include imaging plates [2], scintillators [3], two-dimensional gas detectors [4, 5], and fluorescence imaging [6]. Among the aforementioned detectors, the two-dimensional gas detector displays excellent characteristics in terms of spatial and temporal resolution.

This study presents a report on the development of a two-dimensional gas detector by using a capillary plate (CP) for a neutron.

2. Two-Dimensional Gas Detector for Radiation

Several types of gaseous detectors not limited to neutrons that employ an avalanche charge amplification mechanism were developed to detect high-energy particles. Specifically, a micropattern gaseous detector (MPGD) represented by a gas electron multiplier (GEM) [7,8] is termed as a two-dimensional gas detector. A typical GEM-based detector possesses a position resolution approximately of 1 mm [5]. However, practical use of the detector is inconvenient because it is necessary to maintain the flow of fresh gas to ensure that the gas is fresh. Conversely, an MPGD that uses a CP [9] realizes a spatial resolution of 50 μm for X-ray detection [10].

Therefore, the aim of this study is to develop a sealed-type CP gas detector that realizes high spatial resolution for neutrons and that can be easily combined with an optical camera.

3. CP Gas Detector

3.1 CP gas detector for neutron imaging

Figure 1 shows the operating principle of a CP gas detector for neutron imaging. The detector comprises a ^{10}B

author's e-mail: haruyasu@etd.hpk.co.jp

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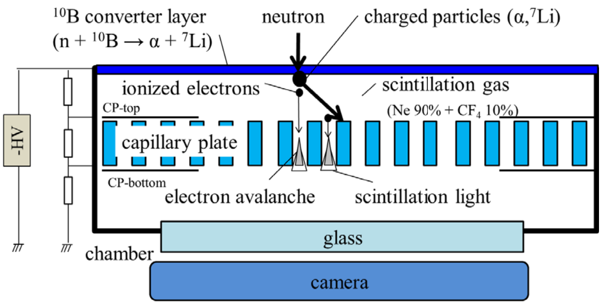

Fig. 1 Schematic view of a CP gas detector for neutron imaging.

converter layer, a CP, and a chamber. A CP is a circular glass plate on which tiny glass capillaries are arrayed in two-dimensions at regular intervals. A CP is made by the same method as a Micro Channel Plate (MCP). The chamber is filled with scintillation gas. The roles of the scintillation gas include generating electrons, multiplying electrons, and emitting scintillation light. First, charged particles are generated by a nuclear reaction with the ^{10}B layer when neutrons are incident.

The charged particles ionize the gas and create ionized electrons. The electrons move toward the CP by an electric field. An electron avalanche occurs in each hole of the CP, and scintillation light is emitted [10]. The lights pass through a glass window and are acquired by using the camera. This process converts the incident position of neutrons to an optical image.

3.2 Sealed-type CP gas detector for neutron imaging

Figure 2 (a) depicts the developed detector, whose diameter is 70 mm. The silver part at the center is the sensor part. Figure 2 (b) shows the cross-section of the sensor part. The ^{10}B layer was spattered on the aluminum plate that acts as a window. The thickness and the diameter of the ^{10}B layer is 3 µm [11] and 18 mm, respectively. The ^{10}B layer is in close proximity with the top surface of the CP, and the distance was 300 µm. The effective diameter and the thickness of the CP were 27 mm and 300 µm, respectively. The diameter and pitch of each capillary is 50 µm and 58 µm, respectively, as shown in Fig. 2 (c). Conductive layers are spattered on the top and bottom surfaces of the CP and act as electrodes to generate electric fields for electron multiplication.

The detector was filled with a gas mixture of 90% of Ne and 10% of CF_4 at 1 atm [12]. A sealed-type detector without additional gas tubes was adopted given the practicality considerations. The gas in the detector was contaminated by outgassing from the constituent material. The detector comprised materials with low outgassing to prevent contamination of the filled gas.

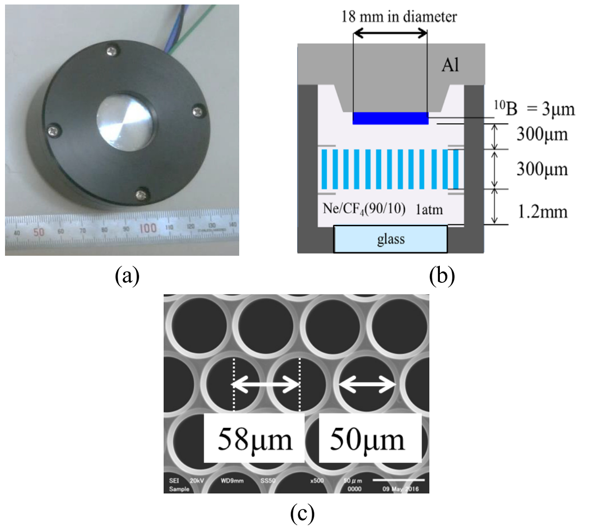

Fig. 2 (a) Sealed-type CP gas detector. (b) Cross-section of the detector comprises a ^{10}B layer, a CP, and a sealed chamber filled with Ne (90%) + CF_4 (10%) at 1 atm. (c) SEM image of the CP with 50-µm diameter holes and a 58-µm pitch.

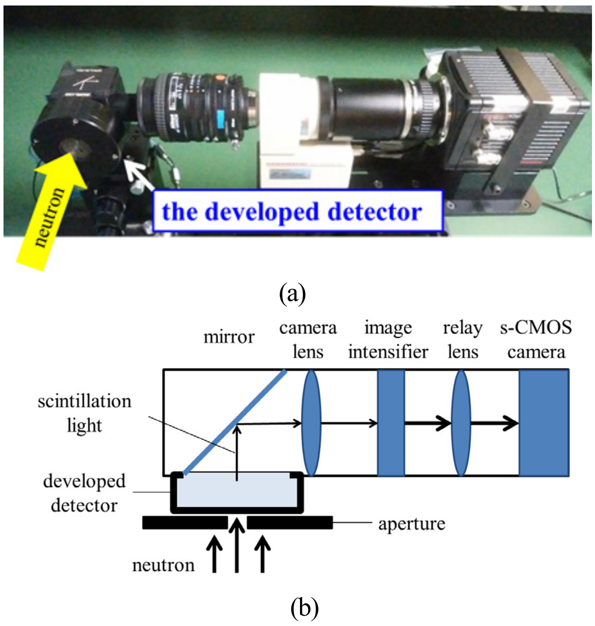

Fig. 3 Experimental setup of the neutron imaging system.

3.3 Imaging system

The above detector is used in combination with a high sensitivity camera. Figure 3 (a) shows the actual setup of a neutron imaging system that consists of the developed detector, a mirror, a lens, an image intensifier unit (Hamamatsu C9016-02), a relay lens (Hamamatsu A4539), and a s-CMOS camera (Hamamatsu C13440-20CU).

4. Performance Evaluation

4.1 Experimental setup

The neutron imaging was demonstrated at the Kyoto University Accelerator based Neutron Source (KUANS) [13]. Neutrons are generated by the reaction between a Be target and accelerated protons. They are thermalized by a polyethylene moderator in ambient temperature. Since KUANS is an accelerator based source, fast-neutron component is relatively high. The ratio of the number of fast-neutrons having more than about 100 meV to that of thermal-neutrons obtained using a Li-glass scintillator [13] is approximately 1 to 5. The above imaging system was placed at the exit of the beam. The distance between the imaging system and the surface of the moderator was 3.06 m. The estimated thermal neutron flux was 450 n/cm^2/s at the imaging system.

4.2 Detection of neutron signal

The response of the detector was investigated when neutrons were incident. An aperture was placed in front of the detector as shown in Fig. 3 (b). The aperture was composed of B_4C silicone rubber with a 10-mm square hole. The B_4C shields thermal neutrons. The applied voltage between the top and bottom surfaces of the CP was 615 V. One hundred images with an exposure time of 1 s were obtained on the incident neutron. Similarly, images without neutrons were obtained. As a result, signals were successfully obtained as shown in Fig. 4. An average of 19 signals were observed inside the 10-mm square. The region corresponds to the aperture region. Conversely, an average of 0.8 signals was observed when neutrons were not incident.

The right side of Fig. 4 depicts an enlarged view of the signal. The signal has a linear shape. A two-dimensional gas detector can observe a track image of a charged particle passed through the gas [14]. Therefore, it was considered to be the track image of a charged particle (α or ^{7}Li) generated by a nuclear reaction between neutrons and the ^{10}B converter.

Given the same, it was considered that the obtained signals originated from incident neutrons.

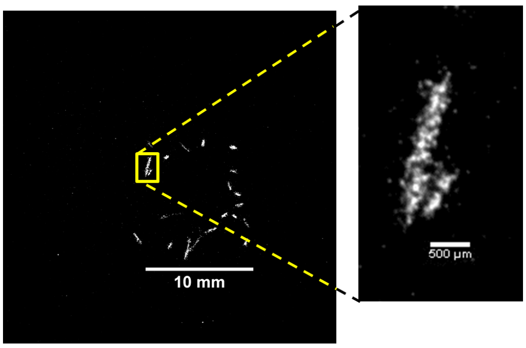

Fig. 4 Images of charged particles with the B_4C aperture with an exposure time of 1 s.

4.3 Neutron image acquisition experiment

As shown above, approximately 20 signals were obtained in 1 s in the setup. In order to acquire images, it was assumed that several hundred seconds of exposure time are necessary. Signals were accumulated by a method of integrating 1 s images. Images were integrated for 180 s on incident neutrons. An aperture with a Japanese character shape as shown in the upper left of Fig. 5 was placed in front of the detector. The aperture was composed of Gd shielding thermal neutrons, and its thickness was 0.25 mm. As a result, an image of the clear shape of the aperture was successfully acquired as shown in Fig. 5.

Furthermore, background signals other than the shape of the aperture were present. They were restricted inside a circle with a diameter of 18 mm. The area of the region was equal to that of the ^{10}B layer. Thus, all signals were generated from the ^{10}B layer. From this viewpoint, it is considered that the images in Figs. 4 and 5 are images of neutrons.

4.4 Adjustment of intensity of scintillation light

In order to confirm that the operation of the CP corresponded to the electron multiplying section, the relationship between the applied voltage to the CP and the intensity of the scintillation light was investigated. The intensity depends on the electron multiplication, and this depends on the voltage applied between the top and bottom surfaces of the CP. Therefore, it is considered that the intensity of scintillation light increases with increases in the applied voltage. The images in Fig. 6 show images that were integrated for 180 s by using the B_4C aperture. The horizontal axis represents the applied voltage, and the vertical axis represents the intensity of the scintillation light. The plotted points indicate changes in the light intensity with variations in the applied voltage. Specifically, it is possible to adjust the intensity of images by changing the applied voltage for the CP.

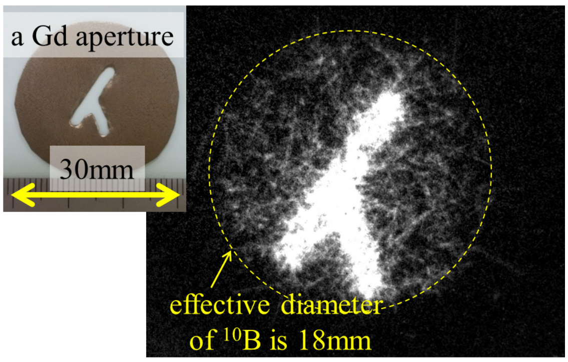

Fig. 5 Neutron image with a Gd aperture is obtained with integration times of 180 s.

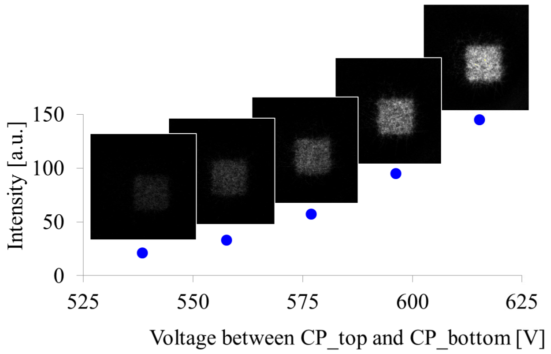

Fig. 6 Intensity as a function of the applied voltage between the top and bottom surfaces of the CP.

5. Discussion

A verification was performed as to whether the images shown in Figs. 4–6 are the signals caused by neutrons. As shown in Fig. 5, a circular background signal exists. This is a circle with a diameter of 18 mm. The area of the region is equal to that of the ^{10}B layer. This implies that the signal was produced from the ^{10}B layer. Signals were not obtained when a neutron was not injected. Additionally, neutrons generated by KUANS include fast neutrons [13]. The Gd possesses a low shielding ability relative to fast neutrons. Therefore, the background signal in Fig. 5 is considered as a neutron image transmitted through a Gd with a thickness of 0.25 mm. Given this, it is considered that the images obtained in the experiment corresponded to neutron images.

Moreover, a spatial resolution of 50 µm is expected from a CP gas detector with a small channel pitch [10]. Specifically, X-ray detection reveals a spatial resolution of 50 µm. As shown in Figs. 4–6, the length of the trajectory limits the resolution. Therefore, it is not possible to derive the expected resolution.

6. Conclusion

In this study, a sealed-type CP gas detector for neutron imaging was developed. This detector converts a two-dimensional neutron image to an optical image. This is followed by composing a neutron imaging system by using the developed detector and high sensitive optional imaging system. The developed detector includes the following features:

– The optical camera can be combined in a compact and easy manner because it corresponds to a sealed-type detector.
– The use of a high dense CP realizes high spatial resolution. Sensitivity as high as a single track of charged particle can be detected.
– The light intensity is controlled by changing the applied voltage for CP.

These features were confirmed by using experimental results involving the use of a compact accelerator driven neutron source. A two-dimensional neutron image was successfully acquired by the developed detector. The future development is focused on improvement of the spatial resolution and extraction of neutron image with proper discrimination.

Acknowledgments

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