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# Development of a ceramic-insulated ball-anode element for neutron detection

K. Toh [a,*], T. Nakamura [a], K. Sakasai [a], K. Soyama [a], H. Yamagishi [a,b]

[a] J-PARC Center, Japan Atomic Energy Agency, Tokai 319-1195, Japan
[b] Nippon Advanced Technology, Tokai 319-1112, Japan

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ABSTRACT

A novel ceramic-insulated detector element was developed for two-dimensional neutron measurement, and an irradiation experiment was performed using a Cf-252 neutron source. The element consisted of a ceramic insulator and a ball-shaped anode. It is estimated that a ceramic insulator can suppress the background noise caused by unintentionally scattered neutrons. An electrical field of $1.60 \times 10^{7}$ V/m was obtained based on a calculation at the top of the ball-shaped anode. Neutron signals were clearly observed using the detector element, thus validating its operation.



## 1. Introduction

Neutron scattering experiments using a high-intensity pulsed neutron source are performed at facilities in Japan, the United States, and the United Kingdom [1–3]. Gas-based two-dimensional neutron detectors using a micropattern element [4–7] are promising candidates for certain neutron scattering experiments because these elements can have both a high counting rate and a good spatial resolution. Neutron scattering experiments, such as small-angle neutron scattering and neutron reflectometry, require two-dimensional neutron detectors that have particular features such as a superior signal-to-noise (*S*/*N*) ratio. When a gas-based detector is used in scattering experiments, incident neutrons are usually scattered by both the measuring sample and the gas-based detector itself because the detector has structural materials (a metallic window, fill gas molecules, and a detector element) that act as scatterers. Therefore, neutrons scattered by the detector itself are measured as a background signal (noise) in the gas-based two-dimensional detector. It is difficult to change the thickness of the metallic window and the amount of fill gas because these values strongly influence the detector's performance and are optimized for each scattering experiment.

The micropattern detector element installed in the pressure vessel usually utilizes a polymer as its gaseous amplification structure and/or the signal readout substrate because the element is usually fabricated using the printed circuit board (PCB) technology. In general, the polymer contains many hydrogen molecules, which act as strong neutron scatterers. To suppress background noise from unintentionally scattered neutrons, we are currently developing a novel concept based on a two-dimensional position-sensitive neutron detector element using a ceramic insulator. An additional advantage of ceramics is that outgassing, which affects the long-term stability of the gas-based detector, can be reduced without the use of polymer materials in the pressure vessel. This paper presents the development of a ceramic-insulated detector element for neutron detection and preliminary neutron irradiation experiments performed using it.

## 2. Ceramic-insulated detector element

The ceramic-insulated element consists of a ceramic insulator, cathode lines on the insulator, and ball-shaped anodes. Hereafter, we refer to this detector element as a ceramic-insulated ball-anode (CiB) element. A surface image of the fabricated CiB element obtained using a scanning electron microscope (SEM) and a schematic sectional view of one pixel of a CiB element are shown in Figs. 1 and 2, respectively. An alumina ceramic substrate (A-476, Kyocera) with a thickness of 250 μm was used, and shot blasting was applied to form truncated cone-shaped holes with 400 μm pitch in the substrate to position the anode balls. The diameter of the hole was 210 μm and 300 μm at the surface and underside of the ceramic substrate, respectively. Commercially available Cu balls with a diameter of 250 μm that are widely used for ball grid arrays (BGAs) were used as the anode balls. The cathode lines (made from Cu) were arranged on the surface of the ceramic, as shown in Fig. 1. Anode lines, which were connected to the anode balls, were arranged on the underside of the ceramic. The cathode

* Corresponding author. Tel.: +81 29 282 5344; fax: +81 29 284 3812.
*E-mail address:* toh.kentaro@jaea.go.jp (K. Toh).

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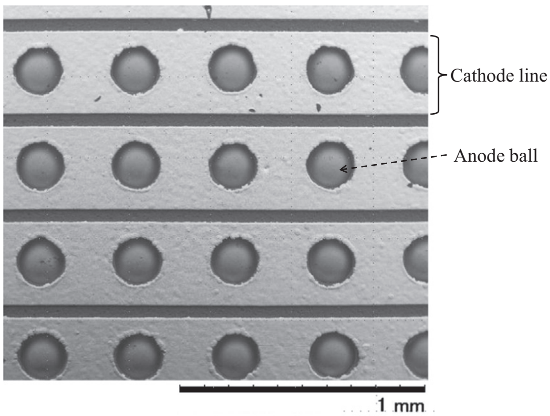


**Fig. 1.** Surface image of a ceramic-insulated ball-anode element using an SEM.

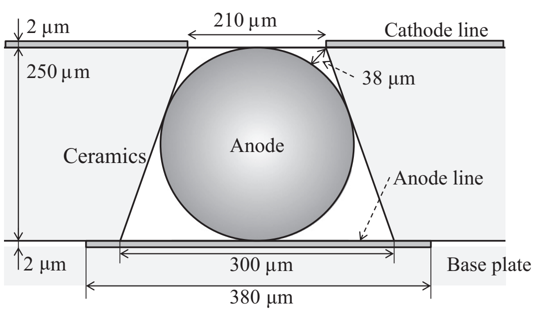


**Fig. 2.** Schematic sectional view of a ceramic-insulated ball-anode element.

and anode lines were of the same width of 380 μm and thickness of 2 μm. Both electrode lines were arranged orthogonally. The pitch between the anodes and cathodes was 400 μm. The shortest distance between the ball anode and cathode was 38 μm, as shown in Fig. 2.

For the preliminary irradiation experiments, a small-sized test element with eight channels for the anode and cathode lines was fabricated. The measured diameter of the shot-blasted hole of the fabricated element was $210 \pm 12$ and $300 \pm 20$ μm at the surface and underside of the ceramic substrate, respectively. Irradiation experiments for the CiB element were performed using a neutron detection system consisting of a pressure vessel, amplifier-shaper-discriminator (ASD) boards, optical signal transmission devices, position encoders with field-programmable gate arrays (FPGAs), and a data acquisition device. A schematic view of the neutron detection system is shown in Fig. 3. The CiB element was arranged on the base plate in the pressure vessel with 20 mm conversion gap. The base plate had multichannel connectors for signal transmission from the CiB element to signal processing electronics mounted outside of the pressure vessel. The pressure vessel could withstand pressures of up to 1.1 MPa with helium leakage of less than $10^{-8}$ Pa $m^3$/s. The charge signals collected by the CiB element were amplified, shaped, and discriminated by ASD application-specific integrated circuits (ASD-ASICs). Using optical fibers, digital signals from the ASD-ASIC were transmitted to the position encoders as optical signals of wavelength 850 nm, which were converted by specially fabricated electrical/optical (E/O)–O/E converters. The optical fiber is insensitive to electromagnetic fields and electrical noise. Further, optical fibers can significantly extend signal transmission distance due to the low transmission loss compared to that of conventional electrical cables. Therefore, optical devices have been incorporated in our system for insulation between the detector heads in an irradiation area and the signal processing circuits in the data acquisition area, and further long-distance signal transmission. Neutron irradiation of the CiB element was performed by embedding a Cf-252 neutron source with an intensity of 100 MBq

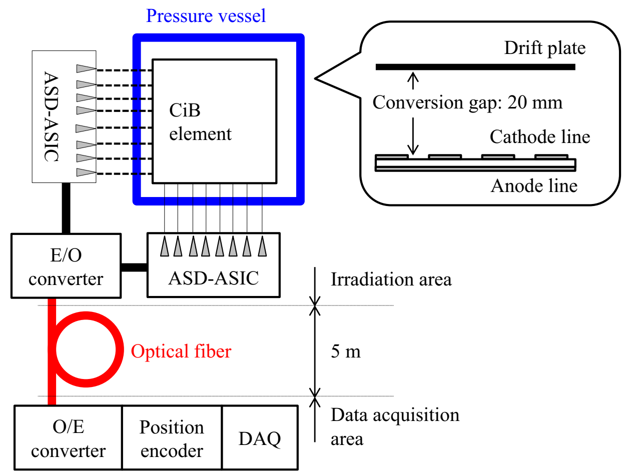


**Fig. 3.** Schematic view of the neutron detection system and the arrangement of the drift plate and the CiB element.

in a graphite cube with dimensions of 80 cm. Using an absolutely calibrated $BF_3$ counter, the neutron flux at the surface of the cube was found to be $10^7$ n/$m^2$ s. A detailed description of the setup is provided elsewhere [8,9].

The neutron-induced signal was collected by the CiB element using the following methodology. When a neutron entered the $^3$He-filled pressure vessel, a nuclear reaction between the neutron and a $^3$He molecule occurred. This reaction resulted in the generation of secondary particles: a 574-keV proton and a 191-keV triton. The fill gas was ionized by the generated secondary particles, and the electrons subsequently drifted toward the anodes. Gaseous amplification around each anode ball was induced by the strong electric field between the anode ball and cathode line. The electrons and positively charged particles (generated by the gaseous amplification) were collected at the anodes and cathodes, respectively. Finally, the analog current signal was individually read out in each electrode line.

## 3. Evaluation

Incident neutrons were usually scattered by the CiB element itself because this element acts as a scatterer. To estimate the effects of scattering, we calculated the amount of neutrons scattered by the CiB element. The calculation was performed based on a Monte Carlo simulation using PHITS (a multi-purpose particle and heavy ion transport code system) [10]. This Monte Carlo code can simulate the transport and interaction processes of neutrons, photons, electrons, and charged particles in an arbitrary three-dimensional geometry system. In the simulation, a perpendicular pencil beam of thermal neutrons irradiated the CiB element, and the density of the alumina ceramic (3.97 g/$cm^3$), the geometry of the element (with a 400-μm pitch and a 250-μm thickness), and the 20 mm conversion gap were used as the parameters. The simulated result of neutrons scattered by the elements is shown as a one-dimensional projection of the distribution of scattered neutrons in Fig. 4. The neutrons at position zero mainly arose from the irradiated neutrons, and the other neutrons resulted from scattering by the detector element. For comparison, the simulation result for a 100-μm-thick polyimide insulator, which is widely used in micropattern elements, was also plotted. The plot shows that neutrons are scattered by both the ceramic and polyimide. These neutrons were detected by adjacent pixels (relative to the incident position), and the counting ratio of pixels to the incident position was $10^{-5}$. Compared with the polymer-insulated element, the number of scattered neutrons for