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Microstructured boron foil scintillating G-GEM detector for neutron imaging

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ABSTRACT

In this study, a new simple neutron imaging gaseous detector was successfully developed by combining a micro-structured ^{10}B foil, a glass gas electron multiplier (G-GEM), and a mirror–lens–charge-coupled device (CCD)–camera system. The neutron imaging system consists of a chamber filled with Ar/CF$_4$ scintillating gas mixture. Inside this system, the G-GEM is mounted for gas multiplication. The neutron detection in this system is based on the reaction between ^{10}B and neutrons. A micro-structured ^{10}B is developed to overcome the issue of low detection efficiency. Secondary electrons excite Ar/CF$_4$ gas molecules, and high-yield visible photons are emitted from those excited gas molecules during the gas electron multiplication process in the G-GEM holes. These photons are easily detected by a mirror–lens–CCD–camera system. A neutron radiograph is then simply formed. We obtain the neutron images of different materials with a compact accelerator-driven neutron source. We confirm that the new scintillating G-GEM-based neutron imager works properly with low gamma ray sensitivity and exhibits a good performance as a new simple digital neutron imaging device.

1. Introduction

Radiography is a powerful tool for both science and engineering. Neutron imaging is a non-destructive technique, which uses neutrons to investigate the internal structure of objects. X-ray and neutron imaging are complementary techniques used to investigate the inside of materials. Neutron imaging is based on the universal law of attenuation of radiation passing through matter. Transmitted neutrons provide information about the material composition and structure because materials attenuate neutrons differently. Neutron imaging has been proven as a powerful tool and a promising method for material research. The technique has found many applications in the industry [1,2].

Different detector systems, such as films, scintillators, and imaging plates, are used in neutron imaging. A 2D position-sensitive detector is typically utilized for neutron imaging. Scintillation detectors are used most often and are optically coupled to a charge-coupled device (CCD) or electron multiplying charge-coupled device (EMCCD) camera. The detector is placed on one side of the object being investigated. The neutrons transmitted from the object are then recorded. The created shadow picture provides information about the internal structure of the object. However, the scintillator used in this detector type has a low brightness. Hence, a neutron image intensifier must be used to obtain a better image quality. A longer exposure time of the object is required in the absence of an image intensifier. In addition, the size of the image intensifier causes the limitation in the effective size of the detector [3].

A new detector material, called glass gas electron multiplier (G-GEM), was recently developed [4]. Compared with the conventional GEM, the G-GEM has the following advantages: self-supporting structure; easy handling and fabrication; absence of outgas material; resistance to neutron damage; and allows fabrication into a large area [5]. A microstructure boron neutron converter was developed together with the G-GEM [6]. This is a converter

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material with a higher neutron detection efficiency than normal flat neutron foil converters. By combining these two newly developed materials, we envisioned a neutron imaging detector that is cheap, insensitive to gamma radiation, easy to use, can be fabricated into a large imaging detector area, and is robust, such that it can be used for on-site measurements, such as security and cargo inspection in airports and sea ports [7].

We succeed in developing a gaseous-based neutron imaging detector, which is called the micro-structured boron foil-scintillating G-GEM. Neutron imaging is demonstrated at a compact accelerator-driven neutron source, which is the thermal neutron beam line of the RIKEN accelerator-driven neutron source (RANS) [8,19,20]. We present the preliminary experiment results in the following section.

2. Detector materials

We developed a neutron imaging detector with an effective sensitive area of $100 \times 100\ \mathrm{mm}^2$. The system consisted of two main detector components, namely, the micro-structured boron foil and the scintillation gas-filled G-GEM.

2.1. Micro-structured boron foil

Fig. 1 presents the scheme of the neutron detection with the boron foil and the secondary gas scintillation. The neutron detection herein was based on the following neutron reactions:

$$^{10}B + {}^{1}n \rightarrow {}^{7}Li* + {}^{4}He + 2.3\ \mathrm{MeV} \quad [93\%] \tag{1}$$

$$^{10}B + {}^{1}n \rightarrow {}^{7}Li* + {}^{4}He + 2.8\ \mathrm{MeV} \quad [7\%] \tag{2}$$

where, $^{7}\mathrm{Li}^{*}$ is an excited particle spontaneously emitting a 0.48 MeV gamma ray. The secondary particles produced after the nuclear reaction, which were either He- or Li-charged particles, came out from the boron foil and ionized the gas molecules in the gas chamber. In order to overcome low neutron detection efficiency of boron foiled gaseous detector, in this work micro-structured boron foil is used instead of conventional flat boron foil. The micro-structured boron foil converter's detection efficiency of neutron at 25.4 meV is approximately 17%, which is 3 times higher than conventional flat Boron foil detector reported by Oed as 5.5% [6,9].

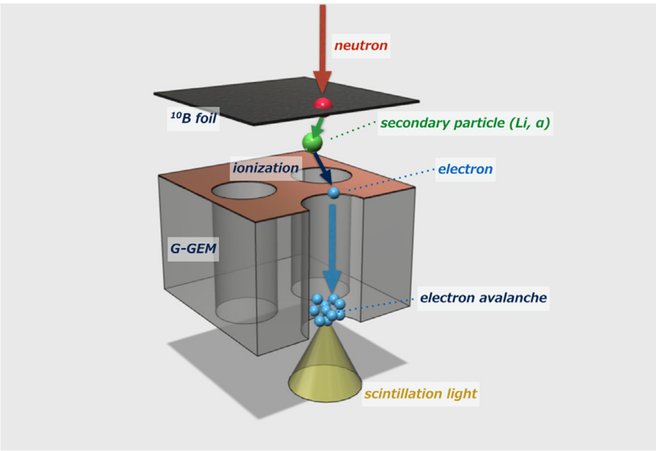

Fig. 1. Schematic of the neutron in the scintillation light converter.

2.2. Glass gas electron multiplier

Aside from the conventional foiled GEMS, the G-GEM was also used for the electron multiplier in this system. The G-GEM had high gas gain, which results in the high photon yield of gas scintillation during the avalanche process [21]. The fabrication details and basic performance can be found in Ref. [10]. The chamber gas was a mixture of Ar and CF_4 (90:10), which was allowed to flow continuously. The maximum effective gas gain in this process was approximately 1×10^3.

3. Neutron imaging process

The neutron detection herein was based on the reaction between ^{10}B and the neutrons. The secondary particle ionized the gas and created primary electrons during the reaction. The electrons created in the drift gap moved toward the G-GEM holes. The electron avalanche then occurred in the G-GEM holes. During which, the scintillation light was emitted by the electron-excited Ar/CF_4 molecules when they decayed to the ground state [11–15]. These secondary gas scintillation light can be easily detected using a mirror–lens–CCD–camera system [16]. A neutron radiograph can then be formed with this system.

4. Imaging system

Fig. 2 shows the schematic of our neutron imaging system, which consisted of a gas detector chamber, a reflecting mirror, and a cooled CCD camera. The detector operated in a gas flow mode at a pressure of 1 bar. The high voltage applied to the G-GEM was 1760 V. The gas gain with this applied voltage was approximately 1600. The optical camera used in this system was the commercially available cooled CCD camera (model: BITRAN BH-50L; lens: Fujinon CF25L [25 mm, F0.85]) with a resolution of 640 × 480 and 12 bits in each pixel. Cooling was achieved by using the Peltier element. A neutron radiograph was simply formed by taking a photograph from the backside of the scintillating G-GEM using an optical camera.

5. Experiment

5.1. Accelerator-based neutron source

The neutron imaging was demonstrated at the thermal neutron beam line of the RANS [8]. The thermal neutron flux was estimated

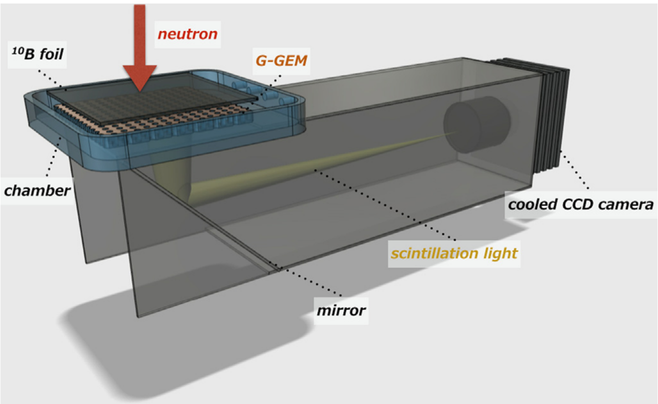

Fig. 2. Schematic representation of the boron foil, G-GEM, and optical readout using the mirror and the cooled CCD camera.