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Imaging Demonstration of a Glass Gas Electron Multiplier with Electronic Charge Readout

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Abstract. We have developed a glass gas electron multiplier (Glass GEM, G-GEM), which is composed of two copper electrodes separated by a photosensitive etchable glass substrate with holes arranged in a honeycomb pattern. In this paper we report the result of imaging with a G-GEM combined with 2D electronic charge readout. We used a crystallized photosensitive etchable glass (PEG3C) as the G-GEM substrate. A precise X-ray image of a small mammal was successfully obtained with position resolutions of approximately 110 to 140 micrometers in standard deviation.

1 Introduction

Gas electron multiplier is one of the most used MPGDs [1]. It has large-area imaging capability with high position resolution because of its numerous micro holes. Its high degree of freedom of detector design is also attractive; Since it only multiplies electrons, it can be combined with a variety of kinds of readout systems, or other types of MPGDs as their preamplifier.

Recently we have developed a new type of MPGD called glass gas electron multiplier (G-GEM) [2]. The G-GEM's substrate is composed of photosensitive etchable glass, PEG3 (HOYA Corporation, Japan). Holes of G-GEM are uniformly fabricated using photolithography technique over the entire sensitive area. The low volume resistivity of PEG3 (8.5×10^{12} Ω·cm) enables less charge-up detector in spite of the thick glass substrate to mechanically support itself. G-GEM is appropriate for sealed-type detectors since it is free of outgassing.

A portable gas-sealed type large-area imaging device will be attractive for many different fields. For example, it will be used for the imaging of heavy charged particles, which normally cause severe radiation damages to solid state detectors. The application of large-area neutron imaging is also expected. The imaging of low energy X-rays is another application field, because high signal to noise ratio can be obtained even with small energy deposit radiations since gas detectors have high gains. Because of G-GEM's non-outgassing property, it is a prospective detector for realizing this kind of portable gas-sealed type imaging device. Its high gain capability with single stage and self-supporting structure also make itself an attractive imaging device.

In this study, we demonstrated the imaging capability of G-GEM using two-dimensional electronic charge readout system. We report on the results, and discuss the position resolution obtained with the setup.

2 Experimental setup

We used a single G-GEM setup for the measurements. In this experiment, we used a G-GEM made of crystallized glass, which is a crystallized version of PEG3, called PEG3C (HOYA Corporation, Japan). Figure 1 shows photographs of a PEG3C G-GEM. PEG3C has higher resistivity (4.5×10^{14} Ω·cm) than that of PEG3 (8.5×10^{12} Ω·cm). On the other hand, the mechanical strength of PEG3C is improved compared with PEG3 glass, which means the PEG3C can be used with wider variety of designs such as thinner structure [3]. The sensitive area of the G-GEM is 100×100 mm^2. The thickness, hole pitch and hole diameter are 680 μm, 280 μm, and 170 μm respectively.

Figure 2 is the experimental setup. We installed a drift cathode 3 mm over and a readout 2 mm under the G-GEM. The G-GEM was powered with voltage divider, which is composed of high voltage resistors. The drift field was 1 kV/cm, and induction field was 3 kV/cm. A charge-sensitive preamplifier was connected to the bottom of G-GEM with an AC coupling capacitor, and the preamplifier output was connected to a shaping amplifier and an MCA for taking pulse height spectra. The detector was flushed with an Ar/CO_2 90/10 gas mixture at 6 L/h of flow rate.

The 2D readout anode consists of two planes of 256 parallel copper strips, with the upper one (x-axis) arranged

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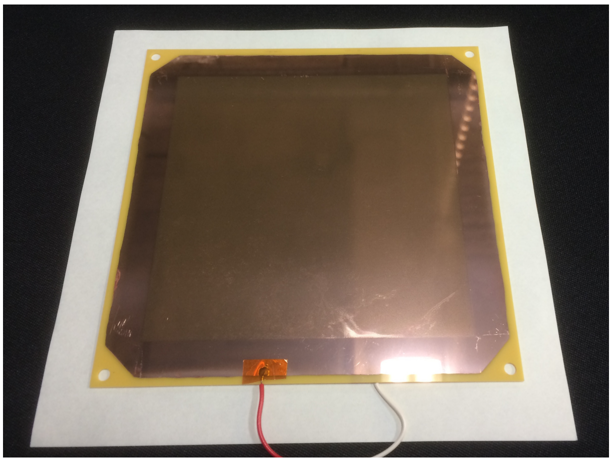

Figure 1. Photograph of a PEG3C G-GEM

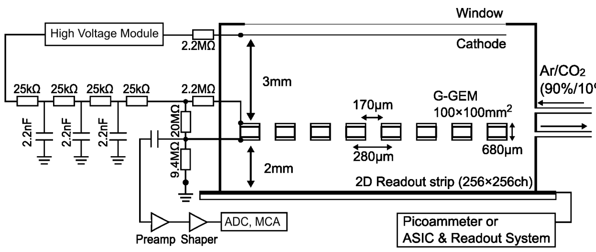

Figure 2. Setup of experiments

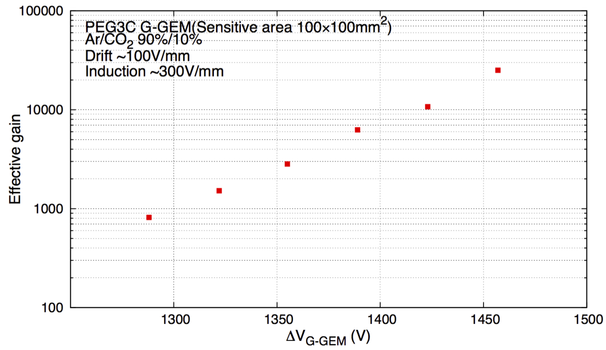

Figure 3. Gain curve of PEG3C G-GEM

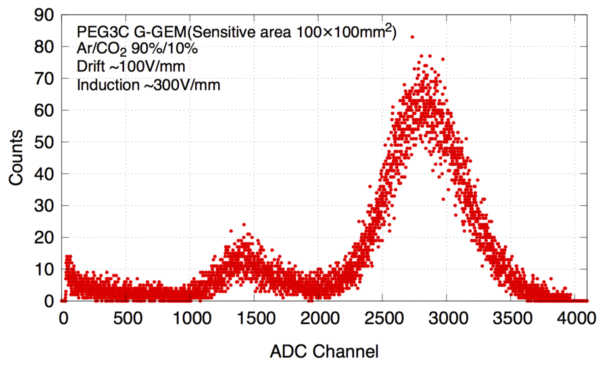

Figure 4. Pulse height spectrum obtained from the bottom of the G-GEM

perpendicular to and separated from the lower one (y-axis) by Kapton ridges of 50 μm thickness. The strips of both axes have a pitch of 400 μm, with a strip width of 80 μm and 340 μm for the x-axis and y-axis respectively, to allow equal charge sharing between both planes. For gain calibration, all the strips of the anode were shorted and read out with a Keithley 6487 picoammeter. For gain uniformity measurement and imaging demonstration, we installed four APV25s and a Scalable Readout System (SRS) to read analogue signals from every strips independently [4].

3 Gain and spectrum measurement

Effective gain of PEG3C G-GEM was calibrated with ^{55}Fe source. For gain measurement, a pico-ammeter was connected to the readout board. Effective gain G_{eff} was calibrated with the following equation.

$$I = n \cdot e \cdot f \cdot G_{eff} \tag{1}$$

Where I is readout current, e is elementary charge, f is interaction rate measured with MCA and also with the scaler which counted the rate of pulses from the bottom of G-GEM.

The maximum effective gain reached 2.5×10^4 (figure 3). High gain was obtained with a single PEG3C G-GEM. The pulse height spectrum was also measured with the signals from the bottom of G-GEM (figure 4). The energy resolution was 25.7 % at full-width half maximum (FWHM) of the gaussian fitted result at the gain of 1.07 $\times$ 10^4. We also observed a polarization effect after powering the G-GEM. It caused approximately 20 % of gain decrease in the timescale of 40 minutes, therefore the detector was kept powered on for more than several hours before the imaging demonstration in order to exclude polarization effect.

4 Gain uniormity

Before the imaging, the global gain uniformity was also measured for the PEG3C G-GEM. The global uniformity is important for imaging detector. If there are large differences of gains by point over the sensitive area, some parts of the sensitive area could not be biased sufficiently. In this case, signal-to-noise ratios become worse at the parts where the gains are not enough. In addition, in those parts signal levels might not be compatible to the following electronics.

For the uniformity measurement, the gain of G-GEM was set at 2500. First, we measured the total collected charges by ^{55}Fe irradiation over 100$\times$100 mm^2 sensitive area. We also measured the total hit counts at the same time. Then the charge map and hit count map were binned to 10 $\times$ 10 bins. And finally the charge map was divided by the hit count map, which provides information equivalent to gain map. Figure 5 shows the gain map, which was normalized at an arbitrary point.

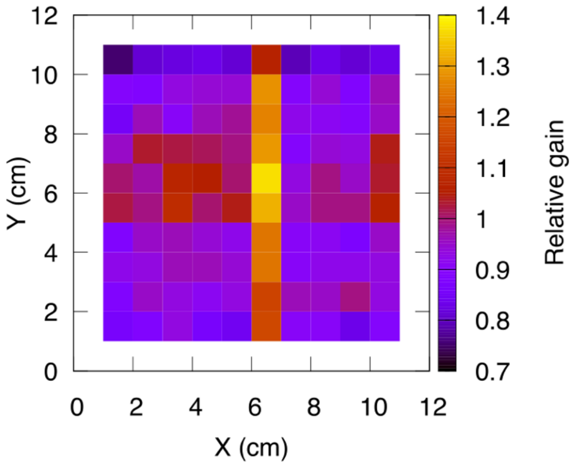

Figure 5. Normalized gain map of 100×100 mm^2 sensitive area. The high gain parts in the longitudinal bins of the middle are considered to be due to strip or channel defects.

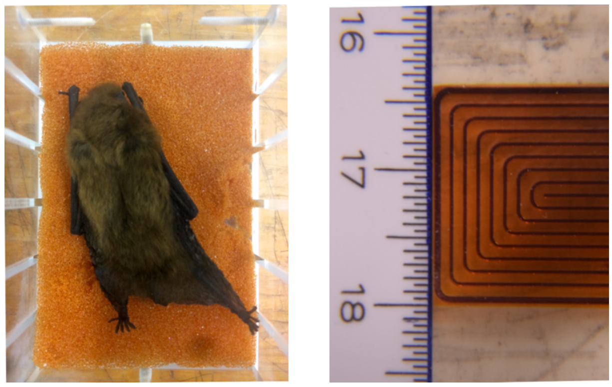

Figure 6. Photographs of the bat and kapton strip

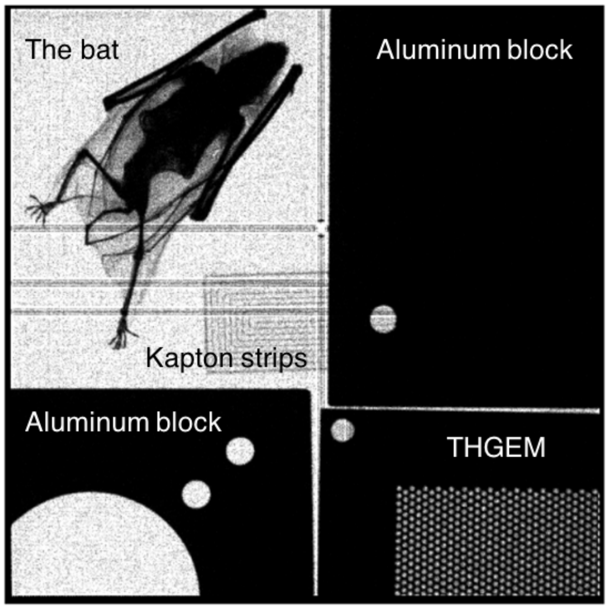

Figure 7. X-ray image of the whole sensitive area

For a uniformity evaluation, the edge 36 bins were also excluded because they are normally affected by field distortions. In addition, we had some strips which had abnormally less hit counts in the longitudinal direction of the middle of the sensitive area, thereby removing those areas from evaluation because they do not give enough statistical correctness compared with the other parts. The reason of less hit counts is considered as strip or channel defects in ASIC. As a result, the maximum normalized gain became 1.09, and the minimum became 0.87. The good uniformity over the sensitive area was obtained, which was sufficient level for the imaging applications.

5 X-ray imaging

We demonstrated imaging of a small mammal (bat) and evaluated the total position resolution. The bat was used for the imaging demonstration of the standard GEM in the past [5]. We took its X-ray image again with the G-GEM.

The bat was placed onto the detector window, together with an aluminum block and Kapton strips of 200 μm width and 1 mm pitch, with the last two being used for position resolution estimation. The ^{55}Fe source was placed approximately 60 cm over the detector to ensure sufficiently parallel beams. The gain was set to around 2500. Figure 6 is a photograph of the bat and the kapton strip before being placed on the detector. Figure 7 and 8 is the imaging result of 100×100 mm^2 area with four million hit events in total. We could clearly identify the skeletal structure, although a large number of the photons were stopped by the bones because of low energy source. Each of kapton 200 μm strips could also be clearly discriminated.

In order to estimate the position resolutions in detail, the edge profiles (arrays of hit count bins) were extracted for both X and Y directions from the edges of aluminum blocks. The edge profiles were then fitted with the error function as shown below.

$$f(x) = a \cdot erf\left(\frac{x-\mu}{\sqrt{2}\sigma}\right) \tag{2}$$

where x is position, μ is expectation of edge position, σ is standard deviation, a is scaling factor and c is offset. Figure 9 and 10 show edge profiles and fitted curves. The position resolutions were σ=137 μm in X direction, and 114 μm in Y direction.

6 Conclusion

In this study, the imaging demonstration of a G-GEM with electronic charge readout was successfully conducted. We used a G-GEM made of crystalized photosensitive etchable glass, PEG3C. The G-GEM showed high gain of 25000 at maximum with single stage. The global gain uniformity was approximately within ±10 % over the sensitive area. We obtained a precise X-ray image of a small mammal with the G-GEM combined with the electronic charge readout system. The high position resolutions of σ=137 μm in X direction and σ=114 μm in Y direction were obtained. The future development of sealed-type imaging device is expected.

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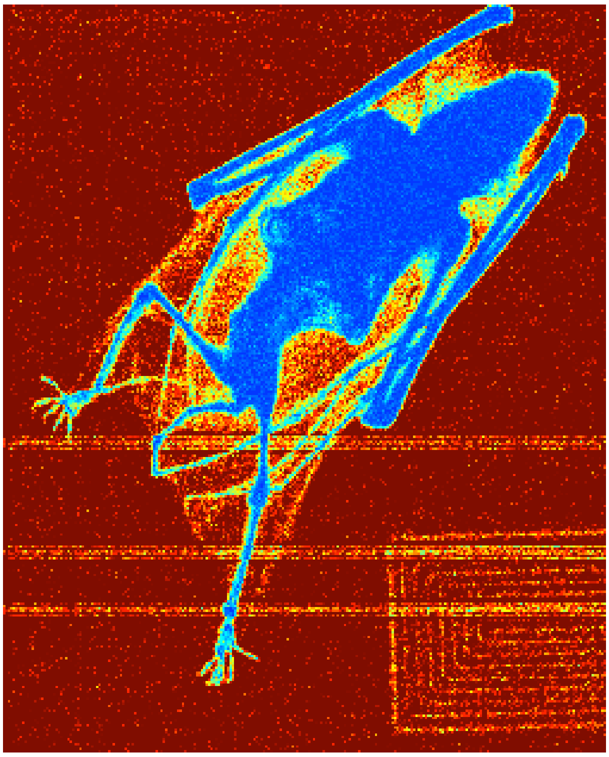

Figure 8. X-ray image of the bat

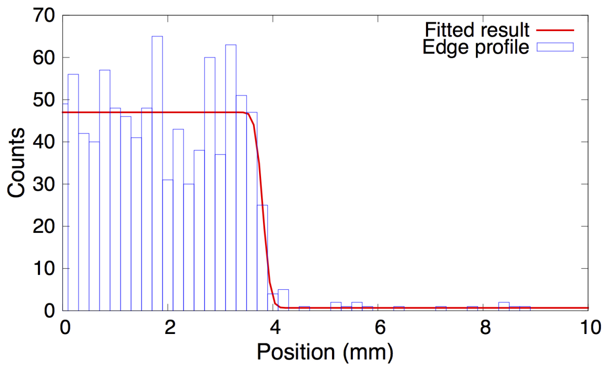

Figure 9. Fitted result of an edge in X direction using error function

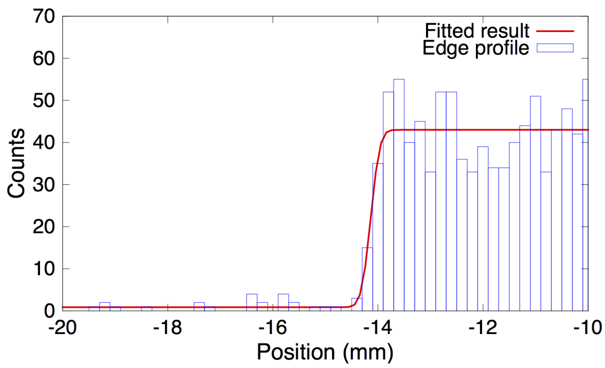

Figure 10. Fitted result of an edge in Y direction using error function