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Fabrication of GEM Detector and X-ray Image Acquisition Based upon its Scintillation Lights

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The gas electron multiplier (GEM), placed in the drift volume of a conventional gas detector, is a conceptually simple device for producing a large gas gain by concentrating the drift electric field over a very short distance to the point that electron avalanching occurs. This device consists of a thin insulating foil of several tens of μm in thickness, covered on each side with a thin metal layer, with tiny holes, usually 100 μm or less in diameter, and with a spacing of 100-200 μm through the entire foil, perforated by using chemical etching or high-powered laser beam technique. In this study, we have investigated its operating properties with various experimental conditions and demonstrated the possibility of using this device as a digital X-ray imaging sensor, by acquiring X-ray images based upon the scintillation lights of the GEM with a standard CCD camera.

KEYWORDS: Gas electron multiplier, X-ray image, gaseous detector, gas gain, scintillation

I. Introduction

The gas electron multiplier (GEM) is a newly-developed gas detector operating in the proportional avalanche mode [1)]. The GEM, placed in the drift volume of a conventional gas detector, creates a large gas gain by concentrating the drift electric field over a very short distance to the point that electron avalanching occurs (> 10^4 V/cm). This process improves the gain property of the detector and reduces its operating voltage; this avoids sparking damage, which now appears to be the most serious problem in this field [2)]. The GEM is comprised of a thin insulating foil (typically a 50 μm thick Kapton) with copper coating on each side and perforated by a high density of holes. Etched in the process of the printed circuit board (PCB), these holes are, typically, 40-80 μm in diameter and 100-200 μm in pitch. The geometric parameters of the GEM used in our studies are as follows: hole diameter = 40 μm, hole spacing = 100 μm, Kapton thickness = 50 μm, metal thickness = 5 μm, and active area = 100 x 100 mm^2 [3)].

In this study, we have investigated its operating properties with various experimental conditions and demonstrated the possibility of using this device as a digital X-ray imaging sensor, by acquiring X-ray images based on the scintillation lights of the GEM with a standard CCD camera [4,5)].

II. Experiment Result and Discussion

1. Effective Gas Gain

Figure 1 shows the effective gas gains measured with applied GEM voltages, V_{GEM} (= V_T-V_B), for a single GEM. Here, several different concentrations of an Ar/CO_2 gas mixture were used as a filling gas, and the intensities of the drift and collection fields were 2 kV/cm and 5 kV/cm, respectively. As shown in **Fig. 1**, the measured gas gains increased almost exponentially with V_{GEM}, indicating that the single GEM worked properly in the proportional avalanche mode. The maximum gas gain before breakdown was about 10^3 at a GEM voltage of 400 V in the Ar/CO_2 (90%/10%) gas mixture. For a 10% quenching gas concentration the operating voltage of the single GEM was about 300 - 400 V, while the operating voltage for a 30 % content was 350 - 500V. This result shows that the dynamic range of the GEM operating voltage becomes wide and high with the quenching gas content, but the maximum gas gains obtained before breakdown were not much different.

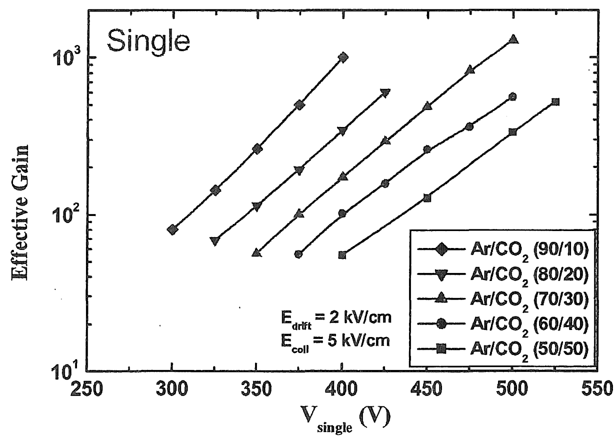

Fig. 1 Effective gas gains measured as a function of applied GEM voltages for a single GEM.

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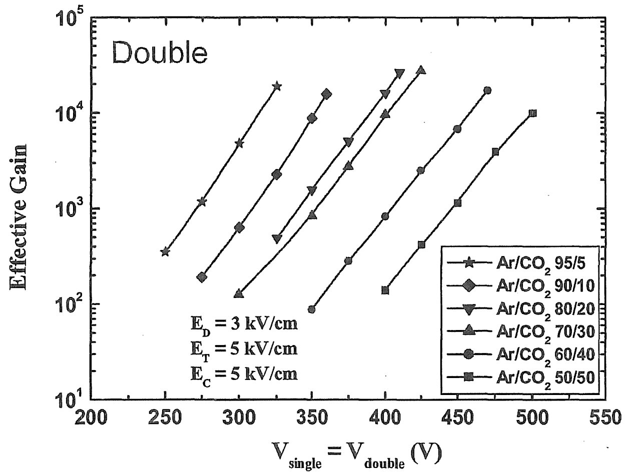


Fig. 2 Effective gas gains measured as a function of applied GEM voltages for a double-structured GEM.

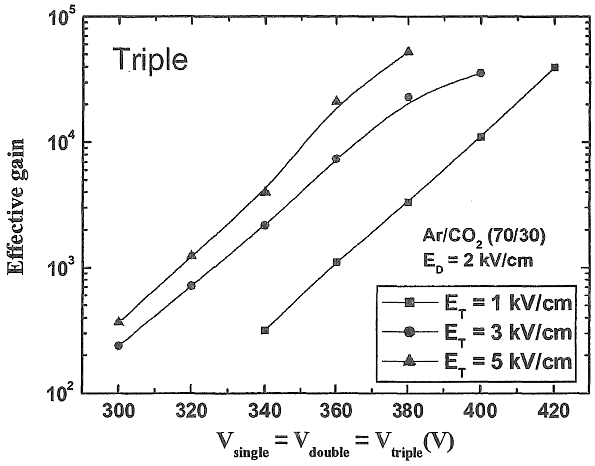


Fig. 3 Effective gas gains measured as a function of applied GEM voltages for a triple-structured GEM.

Typically, the GEM gain improves as the GEM voltage increases, the hole diameter decreases, the insulator thickness increases, or the gas mixture is optimized. But the simplest method is to use several GEMs at the same time.

Figure 2 is the measured gas gains of a double-structured GEM, an assembly in cascade of two GEMs at a close distance. In the case of the single GEM the gas volume is divided into the drift and the collection regions, and for the double-structured GEM the transfer region is added between the upper GEM and the lower GEM. In **Figure 2**, the voltages applied to each GEM were kept equal, and electric field intensities of the drift, the transfer, and the collection regions were 3, 5, and 5 kV/cm, respectively. The increase of the gas gains for the double-structured GEM was similar for the single GEM, but the maximum gas gain for the former was about 10^4, about ten times higher than for the latter. **Figure 3** is the measured gas gains of a triple-structured GEM and the maximum gas gain was about 5×10^4.

For many detector applications of a larger active area,

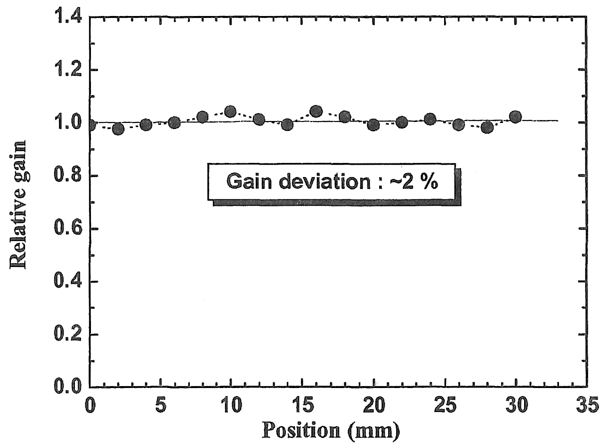


Fig. 4 Gas gain uniformity of a single-structured GEM.

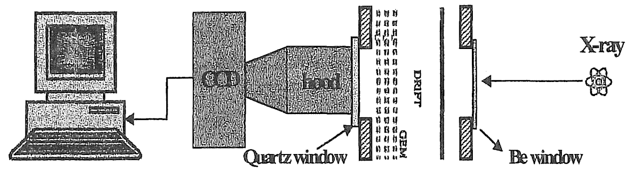


Fig. 5 X-ray imaging acquisition system based on the GEM coupled with a standard CCD camera.

signal uniformity over the whole detector surface is often important. **Figure 4** shows the relative gas gains measured by moving an ^{55}Fe source with a 2 mm interval. The uniformity of gas gains was estimated with about 2% deviation.

2. Scintillation Light Emission

For electron avalanching in the gas detector, the primary electrons accelerated by the applied potential difference collide with filling gas molecules and cause the gas excitation and ionization. The excited gas returns preferentially to the lowest possible energy state in a few nsec. For example, Ar emits UV lights (spectrum peak : 1250 Å) when it returns from an excited state to a ground state [4]. Recently, F. Fraga in Coimbra University tried to detect the scintillation lights emitted by electron avalanching in the GEM. According to his study, scintillation lights which cover a wide band from visible to infrared wave length were generated in an Ar/CF_4 gas mixture, and it was also proven that an X-ray image could be acquired with a standard CCD camera, as shown in **Fig. 5**. In this paper, we established an image acquisition system to detect the position of X-rays which pass the drift window, and acquired an X-ray image by using a standard CCD camera, instead of the method to directly detect avalanche electrons.

3. Image Acquisition System

An ^{55}Fe radioactive isotope (5.9 keV, 7.4×10^8 Bq) was used as an X-ray source and irradiated GEMs from a collimator of 5 mm in diameter and 10 cm away from the Be window. The drift electrode, which was made of an aluminized mylar sheet stretched on an insulating frame, was mounted 3 mm above the GEM. Three GEMs were used to acquire an X-ray image, and each gas region was separated with 2 mm thick insulating spacers. A gas mixture of Ar/CF_4 was used to generate scintillation lights of high intensity. The scintillation lights were fed into a standard CCD camera through a quartz window of the test chamber and its lens. In **Fig. 6**, a black hood of 20 cm length between the test chamber and the camera lens blocks ambient lights and provides a proper focal distance. A quartz window combined the hood passes visible and UV lights emitted in the GEM hole. A MegaPlus 1.4i camera was used to read out the light signals. We used a CCD sensor from Kodak (KAF1400) with 1317 × 1035 pixels having a size of 6.8 × 6.8 μm^2, and their spectral response went from 400 to 1000 nm. The X-ray image data were recorded to the CCD camera, then transferred to a computer through a PIXCI image board, and analyzed using an XCAPTM (EPIX Inc.) image software.

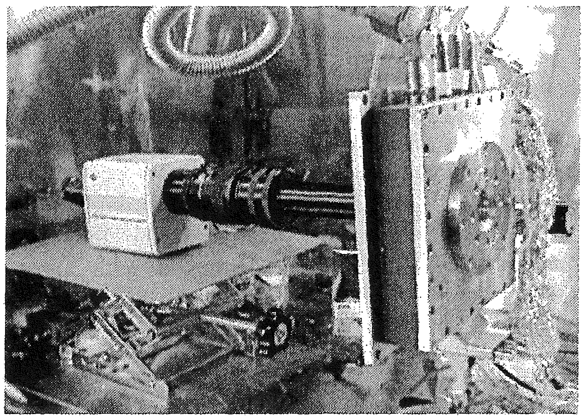


Fig. 6 Photograph of an X-ray imaging acquisition system that we established.

4. X-ray Image Acquisition Experiment

Figure 7 is an image of scintillation lights produced by the GEM holes. The image was acquired by the CCD camera when the whole area of the GEM was irradiated with the X-ray beam. The gas mixture used for the X-ray image acquisition was Ar/CF_4 (95%/5%), and the applied GEM voltage was 300 V. As the GEM voltage increased, the brightness of the scintillation lights increased. As shown in **Fig. 7**, we saw the GEM holes very clear. **Figure 8** shows the distribution of the scintillation lights collected at each pixel of the CCD camera when the GEM was uniformly irradiated to the X-rays. The light distribution was estimated with about 10%. **Figure 9** is the image of a H-shaped plastic phantom. **Figure 10** shows **(a)** the light intensity measured along the path lines of (a) and (b) in **Fig. 9**, and **(b)** the 3D image of the H-shaped phantom reconstructed using the XCAPTM analysis software, showing the clear image.

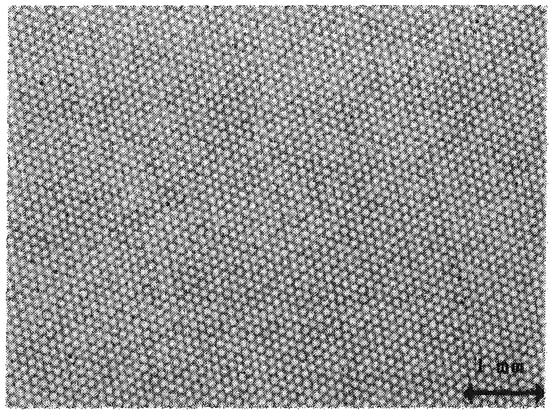


Fig. 7 Image of scintillation lights produced by the GEM holes.

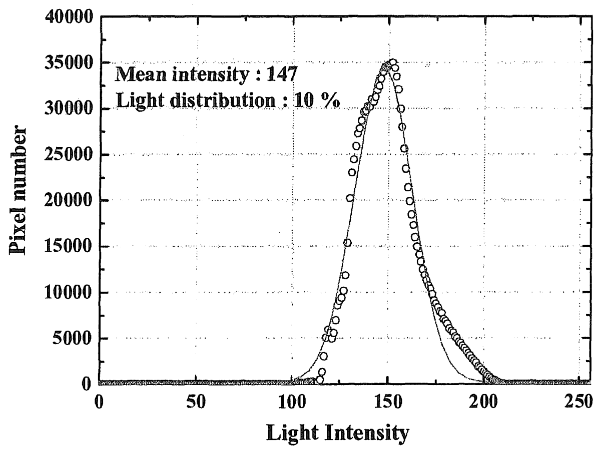


Fig. 8 Distribution of the scintillation lights collected on the pixels of the CCD camera when the GEM was uniformly irradiated to X-rays.

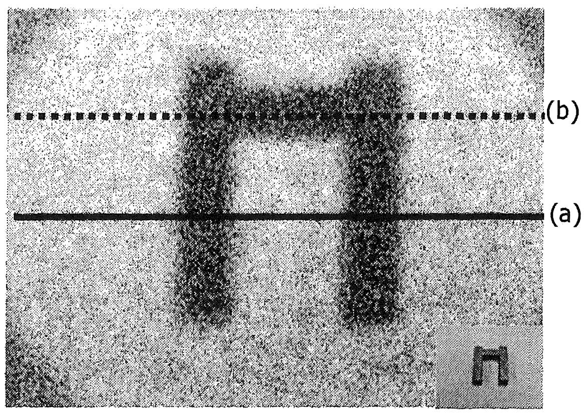
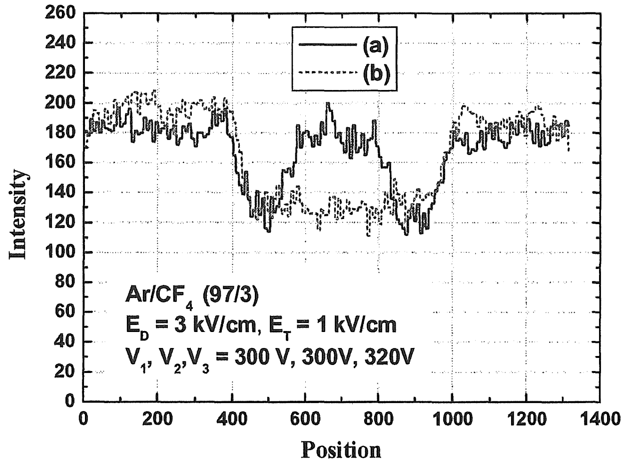
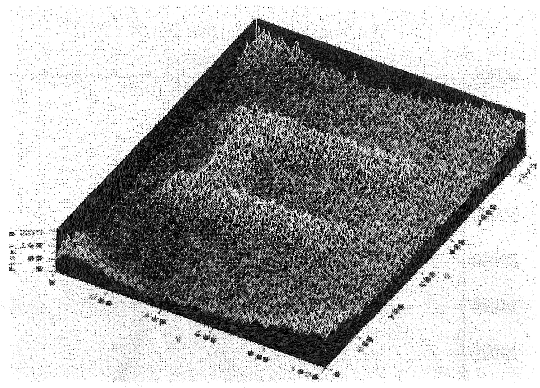


Fig. 9 Radiography of a H-shaped plastic phantom taken by the GEM coupled with a standard CCD camera.



(a)



(b)

Fig. 10 The light intensity measured along the path lines of (a) and (b) in Fig. 9, and (b) the 3D image of the H-shaped plastic phantom reconstructed using the XCAPTM analysis software.

III. Conclusion

The gas electron multiplier (GEM), placed in the drift volume of a conventional gas detector, is a conceptually simple device for producing a large gas gain by concentrating the drift electric field over a very short distance to the point that electron avalanching occurs. In this study, we have investigated its operating properties with various experimental conditions, and demonstrated the possibility of using this device as a digital X-ray imaging sensor, by acquiring X-ray images based on the scintillation lights from the GEM with a standard CCD camera. The effective gas gain, defined as the ratio of total electrons reaching the collection electrode divided by the primary electrons, was improved efficiently by increasing the applied GEM voltage or by using multi-GEMs. Larger gas gains of the GEM result in a higher signal-to-noise ratio (SNR) and thus higher image contrast. We obtained a radiography of a H-shaped plastic phantom using scintillation lights of the GEM and an analyzed acquisition image using the XCAPTM image software. We demonstrated the possibility of using this device as a digital X-ray imaging sensor with a standard CCD camera.

Acknowledgement

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