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ARTICLE

Operation of Gas Electron Multipliers using Liquid Crystal Polymer as an Insulating Foil in Tissue Equivalent Gas

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Radiotherapy with high energy ion beams is a promising technology for tumor treatments and the microscopic information such as track structure is important to understand the physical process of radiation damage to tumor cells. In this report, the operational properties of newly developed gas electron multiplier (GEM) foils were investigated for the future application in ionization density study along the heavy ion tracks in human tissue. The new GEM uses liquid crystal polymer as an insulating foil and the test was performed at low pressures in Ar/CO$_2$ gas mixture and methane-based tissue equivalent gas. The effective gas gains from 10^2 to 10^3 were obtained for 50 and 100 μm thick GEMs in stable operations in Ar/CO$_2$ gas mixture at low pressures down to 200 hPa. The effective gas gains from 10^3 to 10^4 were obtained with 50 μm thick GEMs in stable condition in methane-based tissue equivalent gas.

KEYWORDS: gas electron multiplier, GEM, tissue equivalent gas

I Introduction

Radiotherapy with high energy heavy ion beams is a promising technology for the treatment of deep-seated tumors. For a precise treatment planning for heavy ion cancer therapy, the biological effect of heavy ions to a human body has to be evaluated in detail and thus microscopic information such as track structures is important to understand the physical process of radiation damages to cancer cells or normal tissue. However, it is impossible to directly measure ionizing density along the penetrating path of heavy ions in human tissue, so that the knowledge on the microscopic process largely depends on computational studies[1)].

In past experimental studies[2)], small tissue equivalent proportional counters have been used at low pressures to simulate the size of human cells by using the density ratio between human tissue and gas but the spatial resolutions are not enough to measure the ionization distribution of heavy ions. Meanwhile, micro pattern gaseous detectors with gas electron multiplier (GEM) foils have been developed and successfully used in high energy physics experiments and other application fields due to the good position resolution and high rate capability. A GEM detector with tissue equivalent gas at low pressures has a potential applicability for the measurement of spatial distributions of heavy ion ionizations. Attempts have been made to investigate the operational properties in tissue equivalent gas using conventional GEM foils.[3)]

Recently, a new type of GEM foils was developed.[4,5)] The new GEM foils were produced by laser etching method and used liquid crystal polymer (LCP) as an insulator. We made an attempt to utilize the new GEMs for the track structure measurement of heavy ions. As the first step of our research, the new GEMs were tested in Ar/CO$_2$ gas mixture and methane-based tissue equivalent gas at different pressures using 5.9 keV X-rays from ^{55}Fe and 5.48 MeV α-rays from ^{241}Am sources. The tests using Ar-CO$_2$ gas mixture were carried out as reference operational conditions because this mixture is the most widely used for proportional counters. In this report, the experimental results on effective gas gains and energy resolutions are presented.

II Experiments

The experimental set-up is shown in **Fig. 1**. A GEM foil consists of a LCP foil with 5 μm copper layer on both sides. LCP foils are more hydrophobic than Kapton foils which are used for conventional GEM foils. The thickness of LCP foils are 50 and 100 μm. The holes in a GEM foil are 70 μm in diameter and 140 μm in pitch, which is the same as conventional GEM foils. The sensitive area of the GEM foil is 10×10 cm^2. All LCP-GEMs used in the measurement were fabricated by Scienergy Co., Ltd.[6)]

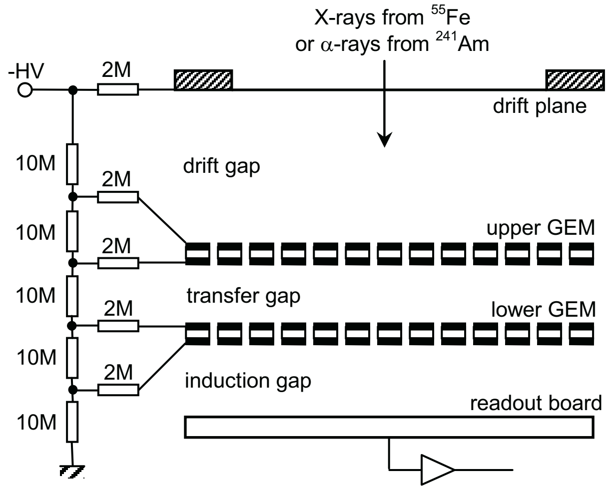

Fig. 1 A schematic view of the experimental setup (Double-GEM configuration).

The test chamber consisted of a drift plane, GEM foils and a readout print circuit board. The drift plane is a thin Al-Mylar film with active area of 10×10 cm^2. The readout board has 3×3 pads and only the central pad was read out and the others were connected to the ground. The charge produced on the readout pad was fed into a preamplifier (ORTEC 142PC) and then amplified and shaped with a main amplifier (ORTEC 572). The pulses were send to a MCA (Amptek MCA8000A) controlled with a PC. The relationship between ADC channel and input charge was calibrated by feeding known voltage pulses into the test input of the preamplifier through a capacitor.

The high voltage was supplied via a chain of 10 MΩresisters, and a 2 MΩ resister was connected as a protection resister in series with each electrode.

Two kinds of gas mixtures, Ar-CO$_2$ (70/30) and methane based tissue equivalent gas (CH$_4$ 64.4%, CO$_2$ 32.5% and N$_2$ 3.1%), were used in the measurement.

A typical pulse height spectrum obtained by our GEM detector is shown in **Fig. 2**. The peak corresponds to the 5.9 keV X-rays from ^{55}Fe source.

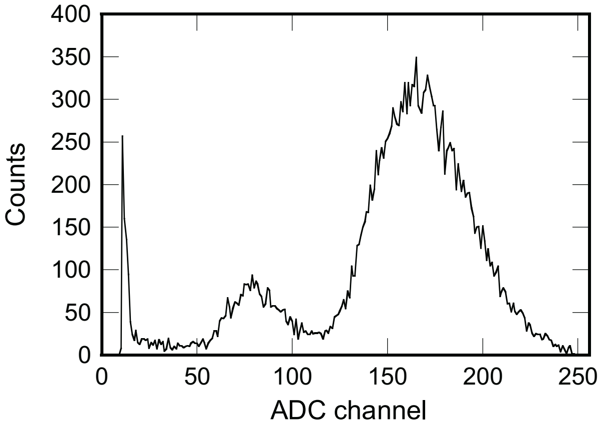

Fig. 2 The pulse height spectrum of X-rays from ^{55}Fe source measured with Double-GEM (50 μm thick) configuration in Ar/CO$_2$ (70/30) gas mixture. The typical energy resolution was about 25% FWHM. The lower peak in the spectrum is the argon escape peak.

III Results and Discussion

1 Basic Property of LCP-GEM

The effective gas gains for 50 and 100 μm thick LCP-GEMs were measured at the different pressures in Ar-CO$_2$ (70/30) gas mixture. Two GEMs were used in cascade in each measurement (Double-GEM configuration). The drift gap was set at 3 and 6 mm for 50 μm thick and 100 μm thick GEM, respectively. The transfer and induction gaps were set at 3 and 2 mm for both 50 and 100 μm thick GEMs. The X-rays from ^{55}Fe source were used and the peak in the spectrum was fitted to a Gaussian to obtain the mean value and the FWHM of the peak.

The effective gas gain (G$_{\mathrm{eff}}$) was obtained by using the following equation.

$$G_{\mathrm{eff}} = C \times \frac{M}{en}, \qquad (1)$$

where C is a constant, M is the mean value of the peak, e is the electron charge and n is the number of electron-ion pairs produced by 5.9 keV X-rays. The mean value of n is 212 for Ar-CO$_2$ (70/30) gas mixture[7].

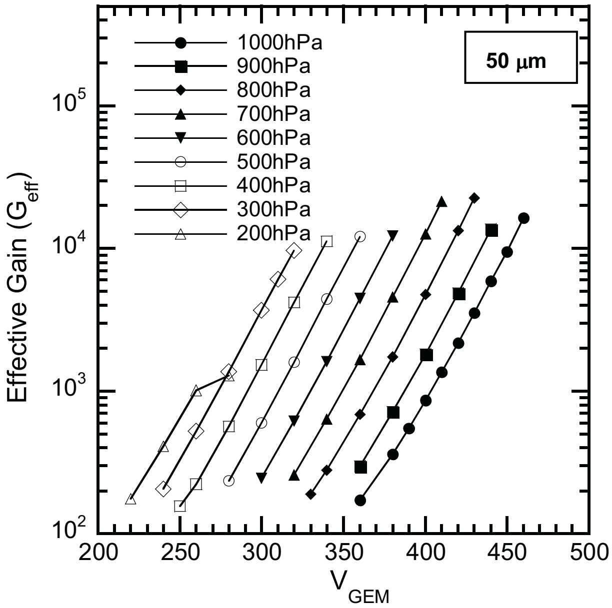

Fig. 3 The effective gas gains for the 50 μm thick GEM at different gas pressures in Ar/CO$_2$ (70/30) gas mixture.

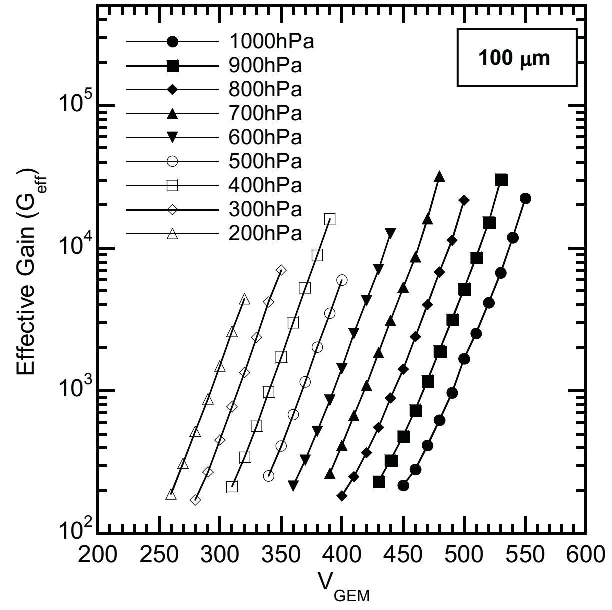

Fig. 4 The effective gas gains for the 100 μm thick GEM at different gas pressures in Ar/CO$_2$ (70/30) gas mixture.

Figures 3 and **4** show the effective gas gain as a function of the voltage supplied between the two surfaces of the GEM foil (V$_{\mathrm{GEM}}$). The maximum value of G$_{\mathrm{eff}}$ at each pressure does not necessarily correspond to the maximum safe gain because we stopped measurements after a few discharges were observed to prevent GEMs from being damaged by destructive discharges. One can see that the gain-voltage relationship is exponential for both types of GEMs.

In **Fig. 3**, the gas gains from 10^2 to 10^4 were obtained in stable condition at pressures from 300 to 1000 hPa. At 200 hPa, several spurious pulses that followed the first signal pulse were observed at the V_{GEM} greater than 260 V. These spurious pulses become larger and clearer at lower pressures. The spurious pulses overlapped with the first signal and that made the measurements of gains difficult at pressures lower than 100 hPa. These spurious pulses are expected to be produced due to ion-backflow because the time difference between pulses approximately corresponded to the drift time of positive ions, which was calculated from the mobility of positive ions. However, the further analysis is needed to identify the reason for this phenomenon.

In **Fig. 4**, the gas gains from 10^2 to 10^4 were obtained in stable condition at pressures from 200 to 1000 hPa. The values of V_{GEM} for 100 μm thick GEMs are roughly 1.2 times greater than that for 50 μm GEMs to obtain the same effective gas gains. The maximum gas gains were higher than those for 50 μm thick GEMs at the pressures greater than 700 hPa. We didn't investigate higher maximum gas gains to avoid electric breakdown of GEM foils but there is a possibility that thick GEMs have higher safe gains at higher V_{GEM}. At pressures lower than 100 hPa, spurious pulses are observed again in the same way as with 50 μm thick GEMs.

The energy resolutions were also measured at different pressures for both 50 and 100 μm thick GEMs. Energy resolutions at normal pressure were about 25% FWHM for both GEMs and got better at lower pressures. The best energy resolutions of about 17% were observed at 200 hPa for both GEMs.

The effective gas gains were measured by using three 50 μm thick GEMs (Triple-GEM configuration) for comparison with Double-GEM configuration. **Figure 5** shows the effective gas gains for Triple-GEM configuration. It has already been well known that Triple-GEM configuration gives higher gas gains than Double-GEM configuration at the same V_{GEM} for conventional GEMs. The gain-voltage relationship is well expressed with an exponential function for both configurations. The gas gain greater than 10^4 was obtained in the stable operation for Triple-GEM configuration at lower V_{GEM} than that for Double-GEM configuration.

2 Effective Gas Gain in Methane-based Tissue Equivalent Gas

The effective gas gains for 50 μm thick GEMs were measured at the different pressures in methane-based tissue equivalent gas. The Double-GEM configuration was used and the drift gap, transfer gap and induction gap were set at 6, 3 and 2 mm, respectively.

The effective gas gain for 5.9 keV X-rays from ^{55}Fe was obtained in the same way as the previous measurement. The number of primary electron-ion pairs in methane-based tissue equivalent gas for 5.9 keV X-rays is 189.

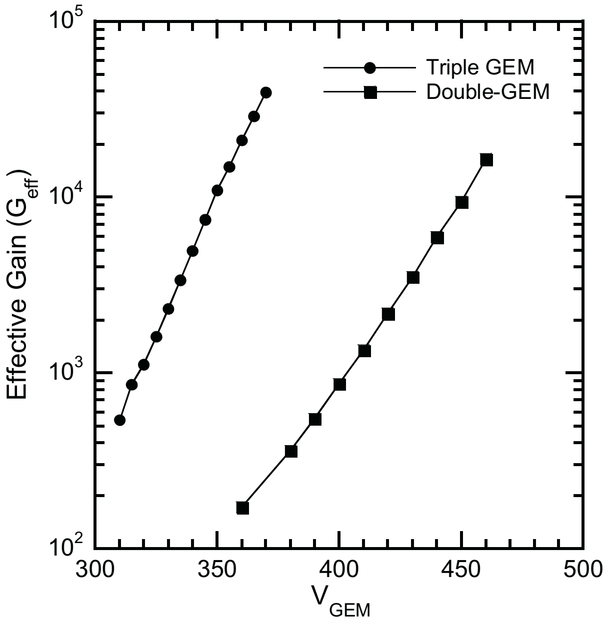

Fig. 5 The effective gas gains for Double- and Triple-GEM configuration as a function of the voltage supplied between the two surfaces of the GEM foil (V_{GEM}).

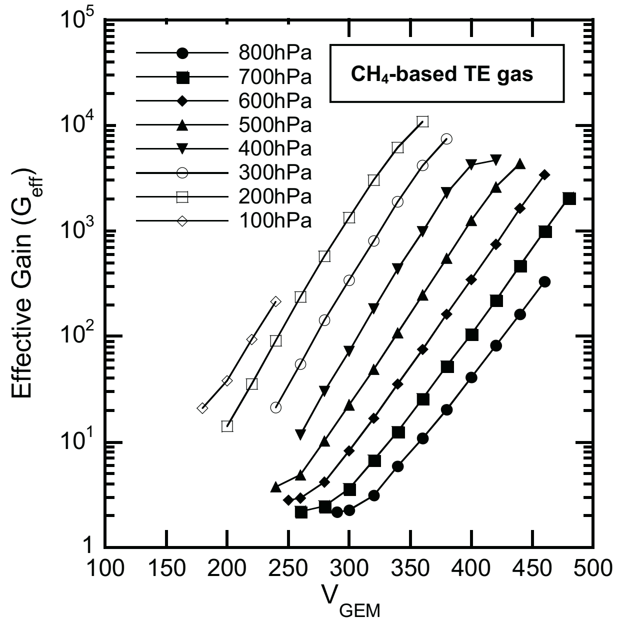

Fig. 6 The effective gas gains at different gas pressures in methane-based tissue equivalent gas as a function of the voltage supplied between the two surfaces of the GEM foil (V_{GEM}).

In addition to the measurements with ^{55}Fe source, α-rays from ^{241}Am source were used. In the measurement with ^{55}Fe, only a few points were obtained for each pressure because the signals were too small to obtain effective gas gains. The more primary electron-ion pairs are produced by α-rays so the effective gains are obtained by using larger signals. However, the number of primary electron-ion pairs produced by the α-rays is difficult to be estimated because it mainly depends on the range of the penetrating α-rays in the drift gap region. In our measurement, the α-rays are roughly collimated with a 2 mm thick Al plate with a ϕ2 mm hole and Landau-like distribution was obtained as an energy spectrum. We used the peak channel of the distribution as a position index and the effective gas gains were calculated by comparing the peak channel in α-ray spectrum and that in ^{55}Fe X-ray spectrum under the same measurement conditions. **Figure 6** shows the effective gains as a function of V_{GEM}. The gain-voltage relationship is well expressed with an exponential function. The gas gains were lower than those in Ar/CO_2 gas mixture as a whole and the operations were stable at pressures from 200 to 800 hPa. The maximum gas gains from 10^3 to 10^4 were obtained in stable condition. However, spurious pulses were observed again at the pressures below 100 hPa so we could not continue the measurement at lower pressures.

IV Summary

The basic properties of newly developed LCP-GEMs were investigated in Ar/CO_2 (70/30) gas mixture and methane-based tissue equivalent gas. The gas gains for 50 and 100 μm thick GEMs were measured in Ar/CO_2 gas mixture and stable operations were obtained at low pressures. In methane-based tissue equivalent gas, the gas gains from 10^3 to 10^4 were obtained with 50 μm thick GEMs in stable condition. Spurious pulses were observed at 100 hPa or less in both gas mixtures. This phenomenon is considered to be due to ion-backflow, but additional tests and more detailed analysis are needed. As the next step of our study, we will develop a time projection chamber in tissue equivalent gas using LCP-GEMs and try to measure the three dimensional position of ionization distribution along the penetrating path of an energetic heavy ion.

Acknowledgment

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