Development and performance evaluation of Thick-GEM

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Development and Performance Evaluation of Thick–GEM

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***Abstract*—A Gas Electron Multiplier with a thick insulator such as a 100 μm or 150 μm thick insulator (Thick–GEM) has been developed by dry etching successfully in Japan. The electric field inside a hole of the Thick–GEM was calculated and the basic properties of the Thick–GEM were measured. A much stronger electric field can be realized inside the hole of the Thick-GEM than that of a GEM with a 50 μm thick insulator (Standard–GEM). The Thick–GEM can attain much higher gain than the Standard–GEM and has a good gain stability within 1.0% for 9 hours. In this paper, the characteristics of the Thick–GEM are described compared with the Standard–GEM.**

***Index Terms*—Gas Electron Multiplier, dry etching, Thick–GEM.**

I. INTRODUCTION

THE Gas Electron Multiplier (GEM) [1], which was invented at CERN, is one of the the Micro Pattern Gas Detectors (MPGDs) having been developed significantly. A GEM generally consists of a 50 μm thick insulator coated with 5 μm thick metal layers at both sides. It has regularly aligned and densely packed holes with a typical hole diameter and pitch of 70 μm and 140 μm, respectively. Hereafter the GEM with a 50 μm thick insulator is referred as 'Standard–GEM' in this paper.

The mechanism of the signal amplification for the GEM is as follows. A strong electric field can be realize inside a GEM hole by applying a high voltage between GEM electrodes, and an electron avalanche is occurred when a drift electron passes through the GEM hole. Although some of the secondary electrons created inside the GEM hole are lost due to an absorption by the lower GEM electrode, the rest of the secondary electrons are detected as an electric signal. The gain of the single GEM can be defined as a following equation,

$$G = M \cdot \varepsilon_{trans}, \tag{1}$$

where M and ε_{trans} mean the multiplication factor and the transmission efficiency, respectively. The transmission efficiency is defined as a fraction of electrons which pass through a hole without an absorption by the GEM electrode to all secondary electrons. In general, the multiple Standard–GEM is used in order to achieve a high gain with a low applied voltage for each Standard–GEM.

In recent years a new type of the GEM is fabricated successfully using dry etching in cooperation with CNS, RIKEN and SciEnergy Co., Ltd in Japan (e-mail : info@scienergy.jp) [2], [3]. The main difference between the dry etched GEM and the wet etched GEM such as one made at CERN is the shape inside the GEM hole as shown in Fig. 1. On the one hand,

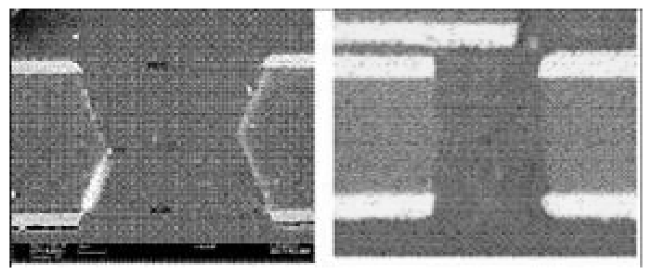

Fig. 1. The cross sections of the wet etched GEM (left panel) and the dry etched GEM (right panel).

the wet etched GEM has a bulge of the insulator inside a hole, this bi–conical hole shape is the characteristic of the wet etching. On the other hand, the dry etched GEM has no insulator bulge and its hole shape is cylindrical. Therefore, it is possible to make a GEM thicker using dry etching with a hole diameter and pitch of 70 μm and 140 μm. Finally, we have succeeded in fabricating a GEM with an insulator thickness of 100 μm or 150 μm. The GEMs with 100 μm and 150 μm thick insulators are referred as '100 μm–GEM' and '150 μm–GEM', respectively, and they are collectively called as 'Thick–GEM'.

II. THICK–GEM

It is feasible with the dry etching technique for piercing holes with a diameter and pitch of 70 μm and 140 μm in a 100–150 μm thick metalized polymer sheet. Liquid Crystal Polymer (LCP) is chosen as an insulator of the Thick–GEM since LCP can be pierced more easily than other polymer sheets. The Thick–GEM consists of a 100 μm or 150 μm thick LCP sheet coated with 8 μm thick copper layers. Its effective area is 10 cm$\times$10 cm in size. The geometry of each GEM is listed in Table I. The 100 μm–GEM and the 150 μm–GEM are comparable to the double and triple Standard–GEM with respect to the total length of the hole for electron multiplication. The left and right panels in Fig. 2 are photographs of the cross section of the 100 μm–GEM and the 150 μm–GEM, respectively.

The Thick–GEM is expected to mainly have two advantages compared with the multiple Standard–GEM. The first one is that the Thick–GEM is expected to attain higher gain than the multiple Standard–GEM since the Thick–GEM has

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	Insulator Thickness [μm]	Diameter [μm]	Pitch [μm]	Cu Thickness [μm]
Standard–GEM	50	70	140	5
100 μm–GEM	100	70	140	8
150 μm–GEM	150	70	140	8

TABLE I

THE GEOMETRIES OF THE THICK–GEM AND THE STANDARD–GEM SUCH AS AN INSULATOR THICKNESS, A HOLE DIAMETER, A HOLE PITCH AND A THICKNESS OF COPPER LAYER.

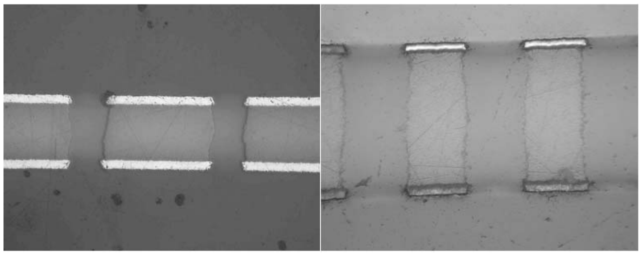

Fig. 2. The cross sections of the 100 μm–GEM (left panel) and the 150 μm–GEM (right panel).

a larger effective path length for multiplication and a higher transmission efficiency. In the case of the multiple Standard–GEM, the total transmission efficiency is the one for single Standard–GEM to the power of the number of layers. Thus the Thick–GEM will realize a much safer operation with a lower voltage per unit thickness. The second one is that the Thick–GEM is expected to have a smaller diffusion than the multiple Standard–GEM because of an avoidance of diffusion in a gap between the neighboring GEMs. Thus the Thick–GEM will have a higher spatial resolution compared with the multiple Standard–GEM.

III. ELECTRIC FIELD OF THICK–GEM

The electric fields in a hole of the Thick–GEM and the Standard–GEM are calculated using Maxwell 3D. The left and right panels in Fig. 3 show the calculation results of the electric field inside a hole along a hole center and a hole edge, respectively. The z position is defined as the direction perpendicular to the GEM and the top surface of the GEM locates at $z = 0$. The voltage difference per the Standard–GEM thickness (50 μm), which is denoted by $V_{\rm ref}$, is 250 V. In other words, the applied voltages are 250 V, 500 V and 750 V for the Standard–GEM, the 100 μm–GEM and the 150 μm–GEM, respectively. The solid, dash and dot lines represent the results of the 150 μm–GEM, the 100 μm–GEM and the Standard–GEM, respectively.

The electric field along a hole edge for each GEM is almost consistent with the maximum value which can be reached to, that is, 250 V/50 μm = $5{\times}10^4$ V/cm. Whereas there is remarkable difference in the electric field along a hole center. It is clearly seen that the electric field of the Thick–GEM is much stronger than that of the Standard–GEM. Especially, the 150 μm–GEM has a plateau for ~ 50 μm while the electric field of the Standard–GEM falls down before saturation.

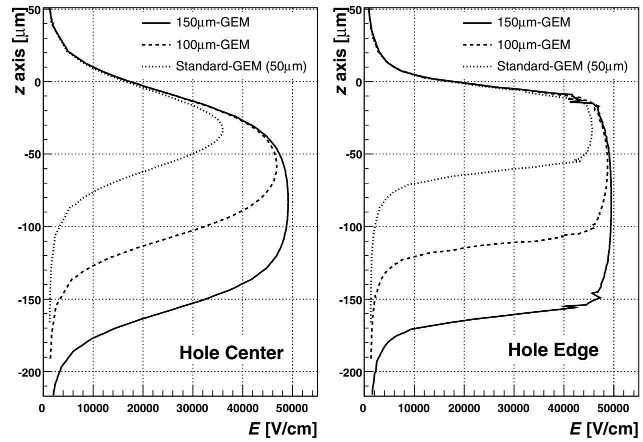

Fig. 3. Comparison of the electric field along a hole center (left) and a hole edge (right) for the Thick–GEM and the Standard–GEM at 250 V per the Standard–GEM thickness ($V_{\rm ref} = 250$ V).

IV. MEASUREMENT AND RESULTS

A. Setup

The measurement was carried out using the single Thick–GEM or the triple Standard–GEM. A schematic view of the setup for each GEM is shown in Fig. 4. A drift plane, which is made of a metallic mesh, is mounted 3 mm above the uppermost GEM and readout pads are placed 2 mm below the lowermost GEM in a chamber and the electric field in the drift region is 0.5 kV/cm except for the 100 μm–GEM measurement. Only in the 100 μm–GEM measurement, the gaps between the drift plane and the top surface of the GEM and between the readout pads and the bottom surface of the GEM are 5 mm and 1 mm, and the electric field in the drift region is 2.5 kV/cm. In the triple Standard–GEM measurement, the gap between neighboring GEMs is 2 mm. The high voltage to drift plane and each GEM electrode via a 10 MΩ resistor chain is supplied from a HV source individually. In all measurements, an ^{55}Fe X–ray source was used and the pressure and temperature in the chamber were monitored with precision of less than 0.05% to correct a gain variation due to a fluctuation of the temperature and pressure. A moisture percentage in the chamber was kept at less than 10 ppm during the measurement.

B. Voltage Dependence of Gain

In the measurement for the voltage dependence of the gain, the chamber was filled with Ar(70%)/CO_2(30%). Figure 5 shows the reduced gain of the Thick–GEM and the Standard–GEM as a function of $V_{\rm ref}$. The circle, triangle and box symbols represent the results of the 150 μm–GEM, the 100 μm–GEM and the Standard–GEM. respectively. Each solid line shows a fitted result with an exponential function to each data set. The measured results are scaled down to the single Standard–GEM thickness, i.e. the power of 1/3 for the 150 μm–GEM and the triple Standard–GEM and the power of 1/2 for the 100 μm–GEM.

In the case of the 150 μm–GEM, a continuous discharge started to occur at $V_{\rm ref} = 275$ V and the measurement could

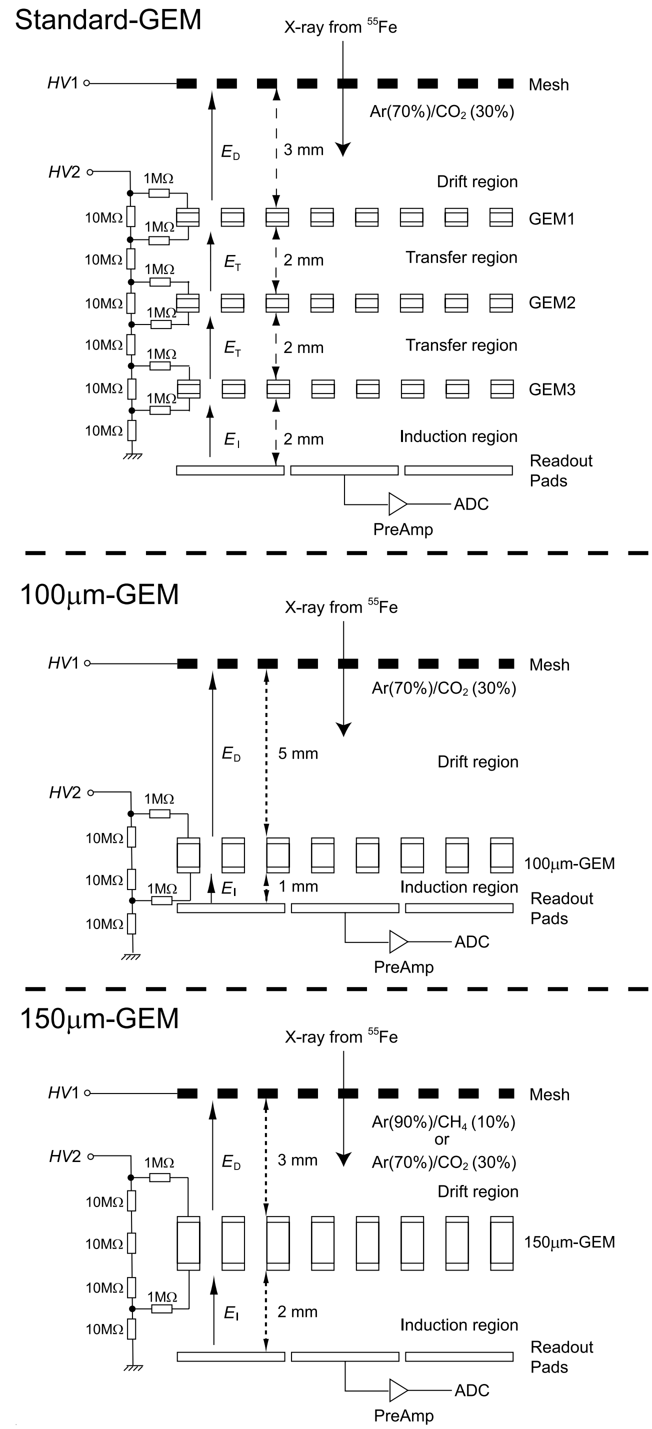

Fig. 4. A schematic view of the setup for each GEM.

not be conducted. Although the current 150 μm–GEM has a discharge problem at low $V_{\rm ref}$, it is clearly seen that the Thick–GEM can attain a much higher gain than the Standard–GEM at low $V_{\rm ref}$ as expected. In Table II, the gain of the Thick–GEM and the Standard–GEM at $V_{\rm ref}$ = 300 V, and the gain ratio to the Standard–GEM are listed. These values are obtained by extrapolating the fitted functions and indicated by the dot lines in Fig. 5.

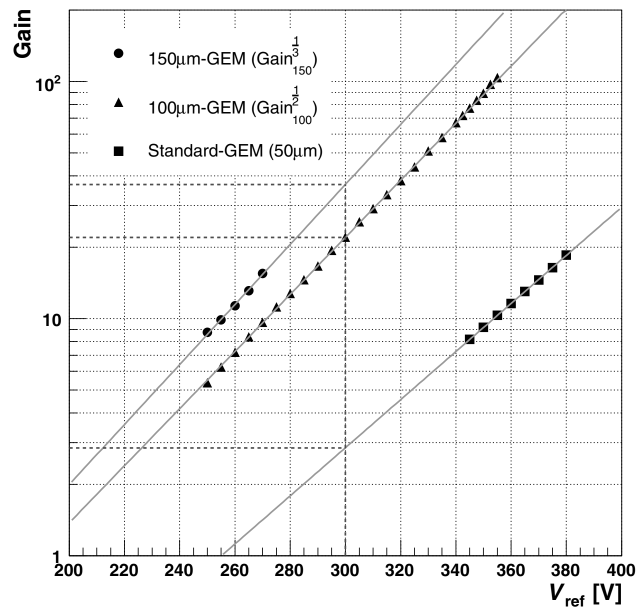

Fig. 5. The $V_{\rm ref}$ dependence of the gain of the Thick–GEM compared with the Standard–GEM in Ar(70%)/CO_2(30%).

	Reduced Gain at $V_{\rm ref} = 300$ V	Gain Ratio
150 μm–GEM	36.8	12.7
100 μm–GEM	22.0	7.6
Standard–GEM	2.9	1

TABLE II
THE COMPARISON OF THE THICK–GEMS WITH THE STANDARD–GEM IN A VALUE OF THE RESUCED GAIN AND A GAIN RATIO TO THE STANDARD–GEM AT $V_{\rm ref}$ = 300 V.

C. Multiplication Factor

The multiplication factor can be derived from the measured gain using Eq. 1.

$$G = M \cdot \varepsilon_{trans} \Leftrightarrow M = \frac{G}{\varepsilon_{trans}}. \qquad (2)$$

The transmission efficiency for each case is calculated using GARFIELD and is listed in Table III. Since the electric field in

	Standard–GEM	100 μm–GEM	150 μm–GEM
ε_{trans}	0.24	0.34	0.17

TABLE III
THE TRANSMISSION EFFICIENCY, ε_{trans} FOR EACH CASE.

the induction region of the 100 μm–GEM is twice as strong as those of the 150 μm–GEM and the Standard–GEM, the transmission efficiency of the 100 μm–GEM is higher.

Figure 6 shows the derived multiplication factor from the measured gain for each GEM as a function of $V_{\rm ref}$. The circle, triangle and box symbols represent the results of the 150 μm–GEM, the 100 μm–GEM and the Standard–GEM, respectively. Here the results of the Thick–GEM is also scaled down as described in the above section. As expected from the calculation results of the electric field inside a GEM hole, the

Thick–GEM has a much larger multiplication factor compared the Standard–GEM.

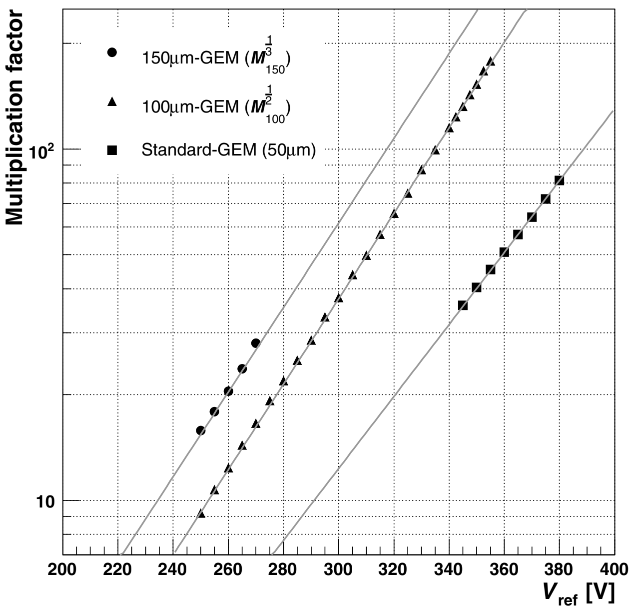

Fig. 6. The V_{ref} dependence of the multiplication factor of the Thick–GEM compared with the Standard–GEM in Ar(70%)/CO_2(30%).

D. Short–Term Gain Stability

A short–term gain stability of the 150 μm–GEM was measured using Ar(90%)/CH_4(10%). During this measurement, V_{ref} was kept at 230 V and the rate of a signal was about 2.5 Hz in a readout pad.

Figure 7 shows the short–term gain stability of the 150 μm–GEM with the low rate of a signal. The result is normalized to the STP condition by a relation between the gain and P/T, where the STP condition means the Standard Temperature and Pressure condition as $P = 760$ Torr, $T = 300$ K, i.e. $P/T \simeq 2.53$ Torr/K. The gain of the 150 μm–GEM is very stable within 1.0% for 9 hours.

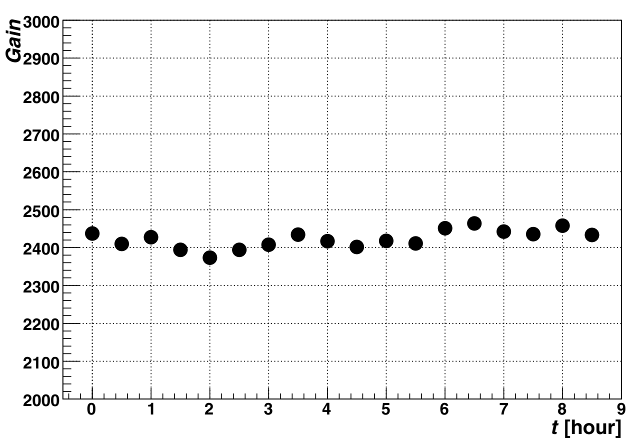

Fig. 7. The short–term gain stability of the 150μm–GEM in Ar(90%)/CH_4(10%).

V. Summary and Outlook

The Thick–GEM has been successfully fabricated using a dry etching technique in Japan. The electric fields of the Thick–GEM and the Standard–GEM were calculated and the basic properties of the Thick–GEM were measured. The electric field of the Thick–GEM is much stronger than that of the Standard–GEM, especially the 150 μm–GEM has a plateau for ~ 50 μm even along a hole center while the electric field of the Standard–GEM falls down before saturation. The Thick–GEM can attain a much higher gain at low V_{ref} compared with the Standard–GEM as expected and the multiplication factor for each GEM are derived from the measured gain with the calculation results of the transmission efficiency using GARFIELD. However, the current 150 μm–GEM has a discharge problem at low V_{ref}. The investigation for the cause of discharge and improvement of the 150 μm–GEM are now in progress. The Thick–GEM also has a good short–term gain stability with a very low rate of a signal. More information is needed such as whether the Thick–GEM has a good gain stability at a high rate of a signal and for long–term or not.

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