

Gas Electron Multiplier produced with the plasma etching method

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Abstract

We have produced Gas Electron Multiplier (GEM) using the plasma etching method. The new GEM has holes with a cylindrical shape and can hold up to 520 V in nitrogen. Amplification factor was measured as a function of the applied voltage. A gain of 10^4 was obtained in argon-mixture gases. The gain characteristics are very similar to those of the GEMs made at CERN.

Key words: GEM, plasma etching, cylindrical shape, GEM test setup, gain

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1 Introduction

Gas Electron Multiplier (GEM), which was initially invented by F.Sauli at CERN, is a metalized polymer foil with holes [1]. Metal layers play the role of electrodes and a few hundred volts are applied between them. When a drift electron passes through the holes of a GEM, strong electric field induces a cascade of electrons. This is the mechanism of the signal amplification by means of a GEM. As well as its low material budget, one of the advantages of GEM is that it can be operated in a multi-layer structure [2]. Gains of the order of 10^6 can be realized with triple-GEM configuration by applying relatively low voltage compared with typical wire chambers.

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Recent developments and applications of GEM to various detectors are reviewed in ref [3]. For example, in the COMPASS experiment at CERN, tracking detectors consisting of GEMs were installed and have been operated in a harsh radiation environment around the beam pipe [4]. It was also proposed that the GEM readout for Time Projection Chamber (TPC) would strongly reduce the positive ion feedback to the drift region; this technology is further investigated in the TESLA detector project [6]. It was demonstrated that a multi-layer GEMs together with CsI photocathode can be a UV photon detector [7]; this leads to an idea of the Hadron Blind Detector (HBD) for electron identification [8]. In astrophysics, the position sensitive detector composed of GEM and fine readout pads has been developed for the measurement of cosmic X-ray polarization [9]. Not only for the physics research, GEMs also could be powerful tools in the medical field, for example, two dimensional X-ray radiography [10] and radiation therapy beam monitoring [11].

Although the GEM has such a simple structure and a powerful potential as particle detectors, very few attempts have been made for producing GEMs except at CERN. We succeeded in producing GEM foils using the plasma etching method in Japan. This paper describes this new development and shows some of the characteristics of these new GEM foils.

2 Production of GEM

2.1 Production of GEM with the plasma etching method

The essential point of the production is the choice of technology for piercing metalized polymer foils. Candidate methods are wet etching, plasma etching and laser. Different methods result in producing different shapes of holes, and may affect the electron transparency [12].

The standard GEM produced at CERN consists of $50\,\mu\text{m}$ Kapton¹ coated on both sides with $5\,\mu\text{m}$ copper, with pitch and diameter of holes of $140\,\mu\text{m}$ and $70\,\mu\text{m}$, respectively [2]. The sensitive area is 10 cm by 10 cm. After making holes on copper layers by conventional photolithography, the foil is immersed in a specific solvent, which dissolves the Kapton layer. As a result, the GEM produced at CERN has holes with a double-conical shape as shown in the upper photograph in Fig. 1.

The plasma etching could be a better method for piercing the Kapton layer, because holes with a cylindrical shape might result in better electron trans-

¹ Tradename of Du Pont Co., Wilmington, DE, USA

parency and less probability of charging-up [12]. GEM foils were produced using the plasma etching method at Fuchigami Micro Co., Ltd.² Geometry of the foil, i.e. the thickness of the material, hole pitch and diameter are the same as those of the standard GEMs at CERN. The holes on the copper layers are made by photolithography. The plasma etching method to make holes on the Kapton layer is Reactive Ion Etching (RIE). The foil is settled as one of the electrodes in a chamber. The chamber is filled with oxide and fluoride gases, and the plasma is established between electrodes by applying high-frequency voltage. Kapton molecules are chemically destroyed by the radicals produced in the plasma, vaporized and exhausted from the chamber. As a result, the GEM produced at Fuchigami Micro Co., Ltd. has the holes with a cylindrical shape as shown in the lower photograph in Fig. 1. Note that the over-etching of the Kapton layer beneath the copper layers is unavoidable at the moment. This structure might cause higher discharge probability as discussed in Section 4.2.

Hereafter, the GEMs produced at CERN and by us are referred to as ‘CERN-GEM’ and ‘CNS-GEM’, respectively.

2.2 Inspection of the foils

At CERN, insulation between copper electrodes is checked before application. They are required to hold 500 V in clean room conditions with a leakage current of less than 5 nA [13].

The resistance between copper electrodes of CNS-GEMs was only the order of 100 M Ω just after the fabrication. When 400 V was applied, lots of sparks were visible on its surface. The possible reason is that there still remained dusts or residual copper pieces in the holes after the plasma etching procedure, and they were the seeds of sparks. It took about ten minutes until the sparks become infrequent. Next, higher voltage was applied gradually in nitrogen; the CNS-GEMs could hold up to 520 V (CERN-GEMs can hold up to about 600 V.).

After these curing procedure, the characteristics of CNS-GEMs were investigated using a test setup described in the next section.

3 GEM test setup

Figure 2 shows the schematic view of the GEM test setup.

² Fuchigami Micro Co., Ltd.: 3-1 Nanei Kagoshima 891-0122, Japan.

In order to support GEM foils in the setup, G-10 frames were put on GEM foils according to the following procedure. At first, a GEM foil is put between plexiglass frames and fixed with screws as shown in Fig. 3 (a). The sensitive area is covered with acrylic plates for protection. In order to stretch the foil, it is put in an incubator, in which the temperature is 40°C, for one hour (See Fig. 3 (b)). Figure 3 (c) shows a G-10 frame (0.5 mm thickness). The frames are glued on both sides of the foil with epoxy (Araldite) and the assembly is put back in the incubator for five hours. Finally, the part of Kapton sticking out the G-10 frames are cut and the foil is ready for measurements (See Fig. 3 (d)).

Measurements were carried out with two or three GEM layers. The GEMs are separated by 1 mm spacers; the distance between neighboring GEMs is 2 mm. The high voltages to the GEM electrodes are supplied via a single input, shown as ‘*HV2*’ in Fig. 2. The *HV2* is equally divided using the chain of 1 M Ω resistors and the sub-divided voltages are provided to individual electrodes. A drift plane, which is a copper coated Kapton foil, is mounted 3 mm above the uppermost GEM. The high voltage ‘*HV1*’ is given to the drift plane. Typically, *HV1* is 600 V higher than *HV2* during our measurements. The electrons created inside the drift region between the drift plane and the uppermost GEM are transferred to the GEM layers. The cascade of the electrons induced in the GEM holes is collected by copper readout pads. The size of each pad is 1.5 cm by 1.5 cm, and the acceptance is 9.5 cm by 9.5 cm covered with 6 by 6 readout pads. The above components are mounted in a chamber made of aluminum.

The charge signals are fed to a charge-sensitive pre-amplifier, consisting of a 325 MHz amplifier³ with the feedback of 1 pF capacitor, and are recorded using a CAMAC ADC module⁴. The dynamic range of the ADC is 12 bits and the full scale corresponds to 1000 pC.

4 Measurements and Results

In our measurements, ⁵⁵Fe (X-ray, 5.9 keV) with intensity of 370 kBq was used. The gases examined are Ar(90%)-CH₄(10%) and Ar(70%)-CO₂(30%). The flow rate of the gas in the chamber was adjusted to about 50 cc/min at atmospheric pressure.

Figure 4 shows typical ADC spectra obtained from the setup including two layers of CNS-GEMs. For Fig. 4 (a) and (b), the chamber was filled with Ar(90%)-CH₄(10%) and Ar(70%)-CO₂(30%), respectively. In both cases, one can see a

³ AD8058: Low Cost, High Performance Feedback, 325 MHz Amplifiers, Data Sheet, Analog Devices, Inc., 1999.

⁴ PRC-022: 16CH Charge Sensitive ADC, REPIC Corporation.

sharp peak of 5.9 keV and a well-known escape peak characteristic of Ar gas.

4.1 Results of the gain measurements

In this section, the gain⁵ of CNS-GEMs is investigated as a function of V_{GEM} , which is the voltage applied to each GEM.

The ADC spectra around the 5.9 keV peak are fitted to Gaussian. From the mean value (S_{mean}), the gain (G) is calculated as:

$$G = \frac{S_{mean}}{C} \cdot \frac{1}{q_e n_e}, \quad (1)$$

where q_e is the electron charge and n_e is the number of electron-ion pairs created by the absorption of 5.9 keV X-ray: 225 and 212 for Ar(90%)-CH₄(10%) and Ar(70%)-CO₂(30%), respectively [14]. The coefficient, C , was determined to be 6.63 fC⁻¹ from the calibration of the pre-amplifier and ADC.

Figure 5 (a) and (b) show the measured gain as a function of V_{GEM} for Ar(90%)-CH₄(10%) and Ar(70%)-CO₂(30%), respectively. The closed circles show the results obtained with the double-GEM configuration; both GEMs are CNS-GEMs. The closed squares show the ones obtained with the triple-GEM configuration: two CNS-GEMs on one CERN-GEM. The open symbols are obtained from CERN-GEMs for comparison. The gains measured using CNS-GEMs are consistent with those using CERN-GEMs. In addition, the absolute values for Ar(70%)-CO₂(30%) from the double-GEM configurations are comparable to the ones seen in ref [2] if the difference of experimental conditions is taken into account.

With the double-GEM configuration, a gain of about 7000 is reached when the V_{GEM} is raised to 400 and 450 V for Ar(90%)-CH₄(10%) and Ar(70%)-CO₂(30%), respectively. With the triple-GEM configuration, the exponential slopes become steeper. In addition, compared with the double-GEM configuration, higher gain can be achieved with lower V_{GEM} ; a gain of about 10⁴ is reached when the V_{GEM} is raised to 350 and 380 V for Ar(90%)-CH₄(10%) and Ar(70%)-CO₂(30%), respectively. The data points obtained using CNS-GEMs are fitted to an exponential function:

$$G = \exp(p_1 + p_2 \cdot V_{GEM}), \quad (2)$$

⁵ The gain is measured from the amount of charge collected by the readout pads. Taking into account charge losses during the electron transfer process in gas, it may be more appropriate to call “effective” gain [2].

where p_1 and p_2 are free parameters. The results of the fits are shown as solid lines in Fig. 5. The gain of one GEM layer is expected to be obtained by $(G_{2-GEM})^{1/2}$ and $(G_{3-GEM})^{1/3}$; both of them show a good agreement within the current accuracy of the measurement.

4.2 Discharge problem

Measurements were also carried out with CF_4 . Signals could be observed with three layers of CERN-GEMs. The gain was obtained to be about 5000 at $V_{GEM} = 530$ V. However, in the case of the triple-GEM configuration including two CNS-GEMs, sparks started to occur when V_{GEM} was increased to 520 V, and safe operations seemed to be impossible.

This difference would be ascribed to the overetching of Kapton foil in the case of CNS-GEMs, as is shown in the lower photograph in Fig. 1. In the next fabrication, we plan to improve the plasma etching procedure in order to remove the overhang.

5 Summary

Gas Electron Multiplier, GEM, was produced using the plasma etching method. It has holes with a cylindrical shape and can hold up to 520 V in nitrogen without being damaged by electric discharge.

The measured gain was investigated as functions of the applied voltage, gas and the number of GEM layers. In the gases of $\text{Ar}(90\%)\text{-CH}_4(10\%)$ and $\text{Ar}(70\%)\text{-CO}_2(30\%)$, the results obtained from CNS-GEMs are consistent with those from CERN-GEMs.

In the next production, we plan to improve the plasma etching process to overcome the discharge problem experienced at high voltage.

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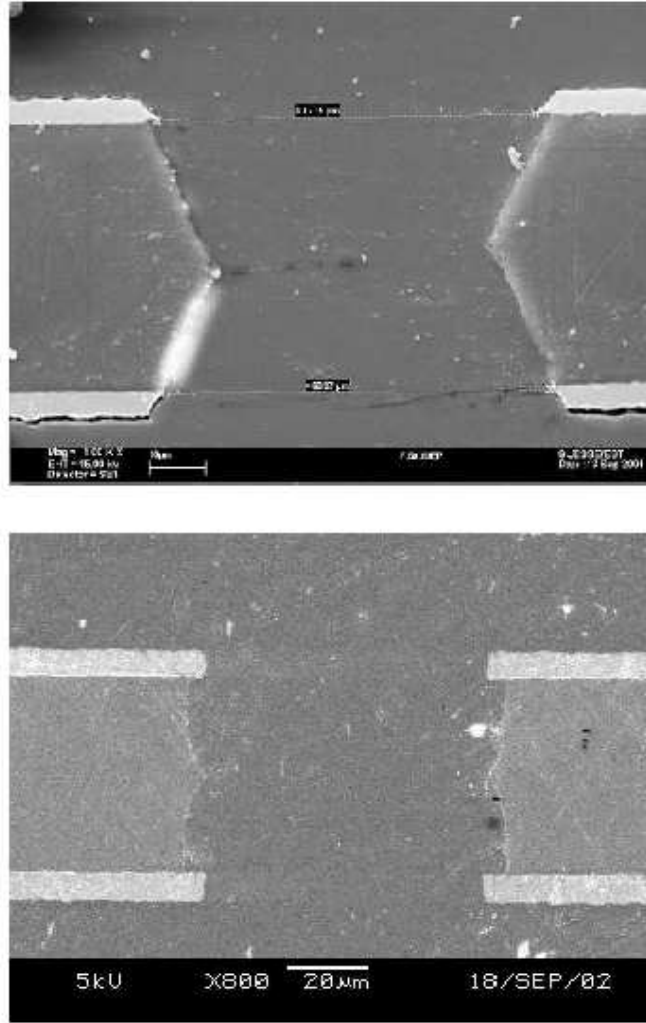


Fig. 1. The upper photograph shows a hole of GEM produced at CERN [12]. On the other hand, the lower photograph shows the one produced at Fuchigami Micro Co., Ltd. using the plasma etching method.

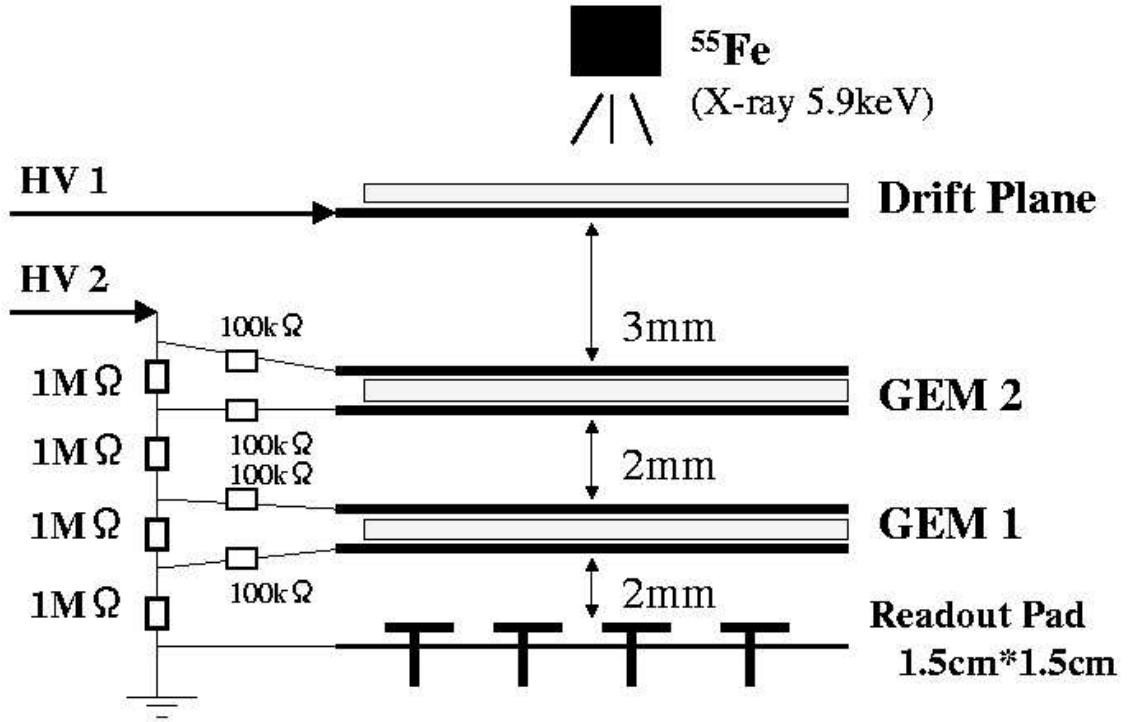


Fig. 2. A schematic view of the GEM test setup.

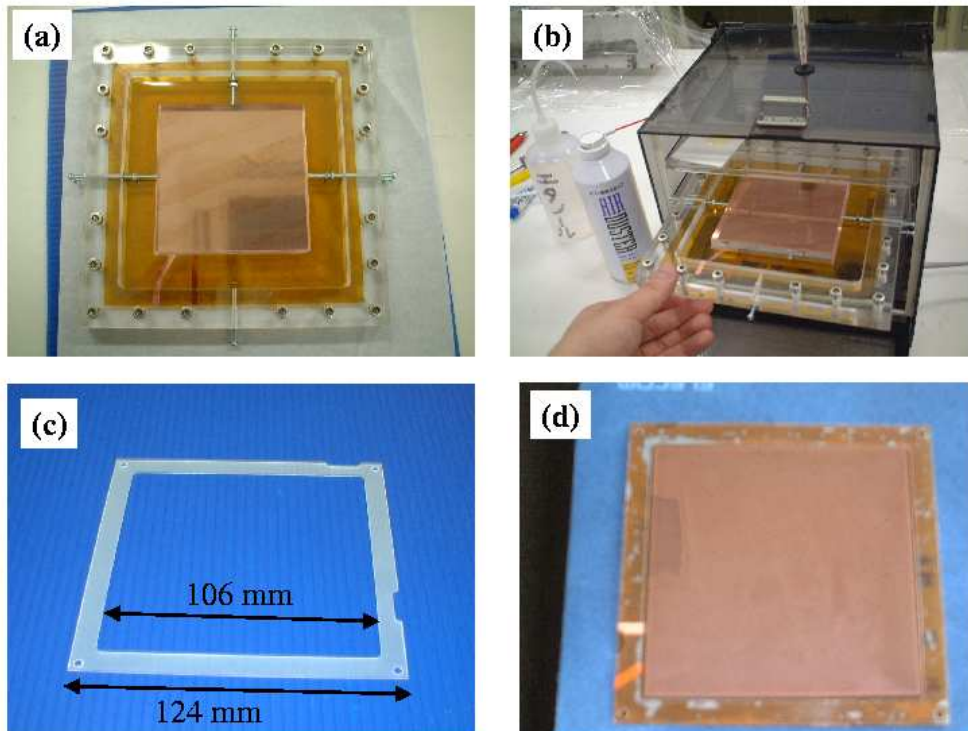


Fig. 3. The procedure to put G-10 frames on GEM foils.

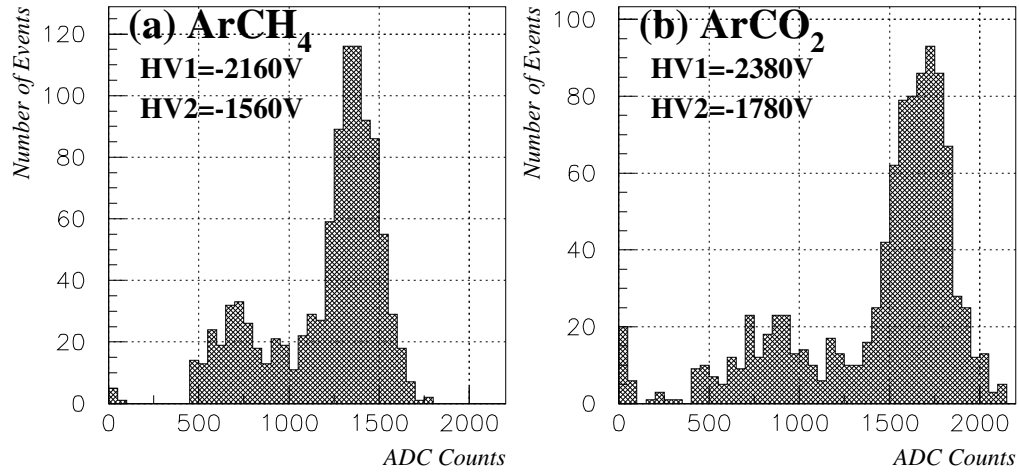


Fig. 4. Typical ADC spectra obtained from (a)Ar(90%)-CH₄(10%) and (b)Ar(70%)-CO₂(30%) with double-GEM configuration.

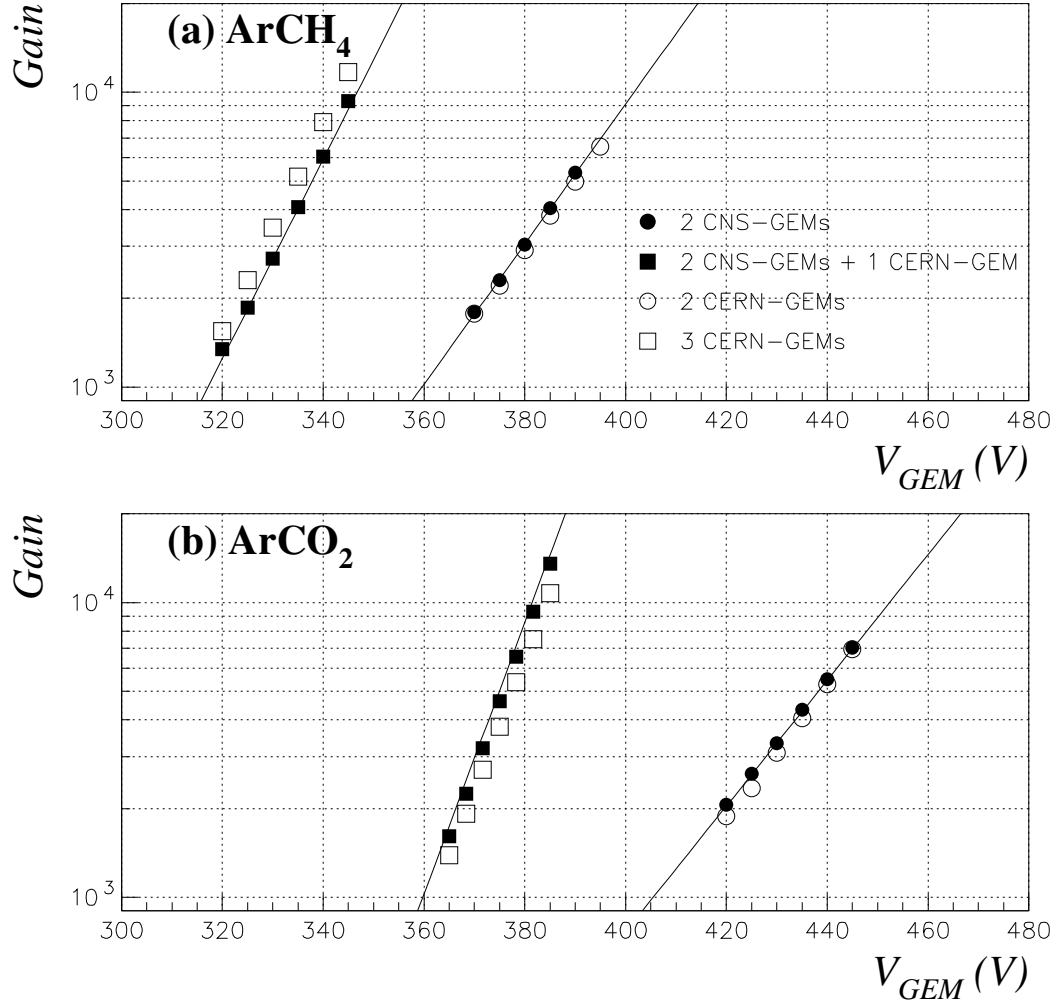


Fig. 5. The measured gain as a function of V_{GEM} obtained with (a)Ar(90%)-CH₄(10%) and (b)Ar(70%)-CO₂(30%).