A study of gas electron multiplier

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Abstract A new kind of gas detector based on gas electron multiplier (GEM) is studied for X-ray imaging of high luminosity. A single-GEM device is designed to test the property of GEM foil .The effective gain and counting capability of a double-GEM detector are measured by an X-ray tube with Cu target. An initial X–ray imaging experiment is carried out using a triple-GEM detector and the position resolution of less than 0.1mm is achieved. The 3D distribution of electrostatic field of GEM mesh is also presented.

Keywords Gas electron multiplier, Effective gain, X-ray imaging

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1 Introduction

The gas electron multiplier (GEM) [1] is a two-side copper-coated Kapton foil and perforated with a high density of holes. It acts as preamplifier for electrons released by ionizing radiation in gas when suitable potentials are applied. The GEM holes are etched chemically in a photolithography process. Etching both sides simultaneously leads to the structure of double conical holes[2]. Fig.1 shows the microscopic view of GEM with double conical holes. The typical structure of GEM holes is shown in Fig.2.

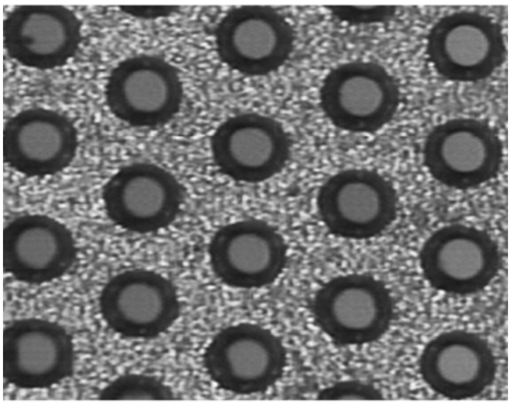

Fig.1 GEM microscopic view.

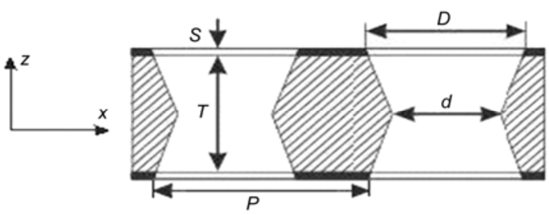

Fig.2 Double conical structure of GEM holes (S=5μm, T=50μm, D=70μm, d=60μm, P=140μm).

The distribution of electrostatic field of GEM with voltages applied is simulated by the 3Dmaxwell program based on the finite element method[3]. In the simulation program, we make the field intensity 2kV/cm for the upper gap, 6kV/cm for the lower gap, and GEM voltage 500V. The simulation result is shown in Fig.3~4. When electrons are produced and drifting along the fieldlines in the drift gap, a GEM will collect nearly all the electrons into its holes. The

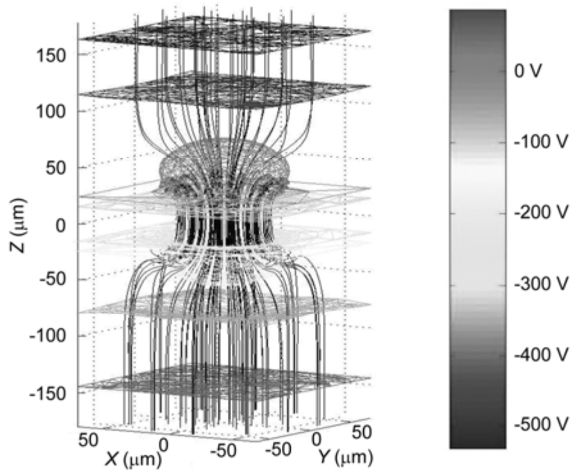

Fig.3 3D electric field lines distribution of GEM.

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fieldlines are strongly compressed up to larger than 5kV/cm[-1] (shown in Fig.4) and the resulting high electric field causes electron avalanche inside GEM holes.

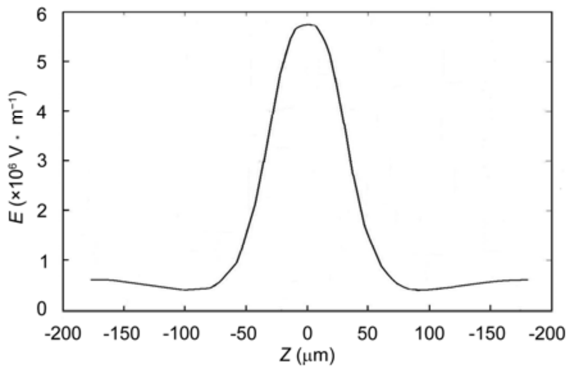

Fig.4 Field intensity in holes of GEM.

2 Effective gain of single-gem

The resistance of a manufactured GEM foil should be more than 500GΩ. All GEMs are tested in a nitrogen-filled box before used. A single GEM device with a cathode, a piece of GEM foil and a Print Circuit Board (PCB), is designed to test the quality of GEM foils and to measure its effective gain. The schematic view is shown in Fig.5. The test beam of X-rays is generated from an X-ray tube with Cu target. With different negative voltages applied to the drift cathode, GEM top layer and GEM bottom layer, the currents of I_b and I_s are measured by ampere-meter as shown in Fig.5, where I_b is the leak current on the bottom layer of GEM, I_s is the signal current collected on the PCB readout, E_{drift} is the field intensity of the 5mm drift gap, and $E_{transfer}$ is the field intensity of the 2mm transfer gap. Because a part of fieldlines end to the bottom electrode of GEM, the number of electrons collected on the PCB is reduced. The real gain of single GEM is defined as $M' = (I_b+I_s)/(enR)$, where e and n are the electron charge and the number of ion pairs per conversion, R is the counting rate of X-ray. The effective gain is given by $M=I_s/(enR)$. The test results show (see Fig.6) that the real gain of single-GEM can up to 10^3. The effective gain is about 1/3 of the real when the transfer field is 3kV. [4]

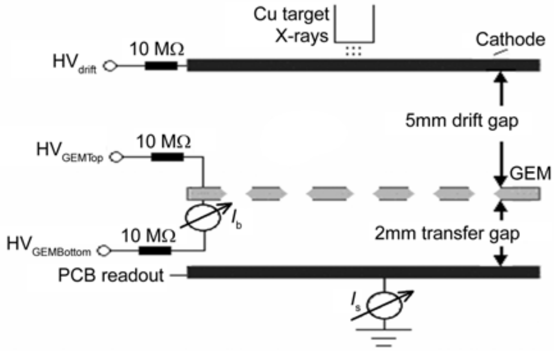

Fig.5 Schematic view of single GEM device.

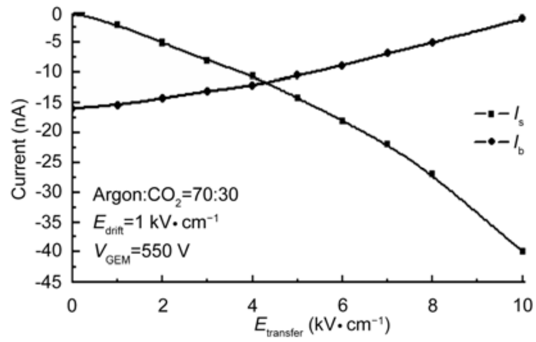

Fig.6 Dependence of I_b and I_s on transfer field.

3 Double-gem detectors

The Multi-GEM detector is a parallel plate device with one or more GEM foils. We design a double-GEM detector to acquire a large enough gain in order to detect the small number of photoelectrons. Fig.7 shows the schematic of a double-GEM detector.

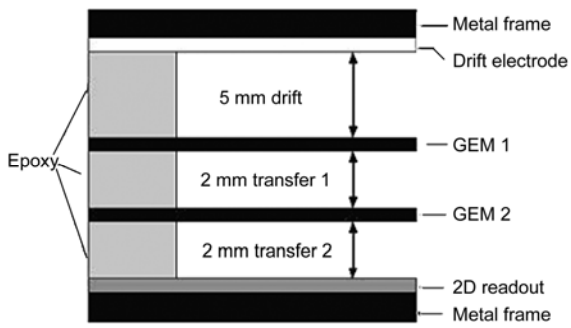

Fig.7 Schematic view of a double-GEM detector.

The PCB readout with orthogonal strips in x, y dimensions on both sides is used for particle localization (see Fig.8). The strips pitch on both sides is 0.8mm. The width of the strips is 0.35mm on the upper layer and 0.65mm on the bottom layer to get the same exposed area on both sides.

The system supplying voltages to the double-GEM detector is similar to Fig.5. The changes of effective gains in different gas mixtures and in the same gas mixture with different GEM voltages are measured[5] (see Figs.9, 10) by using 5.9keV X-rays of

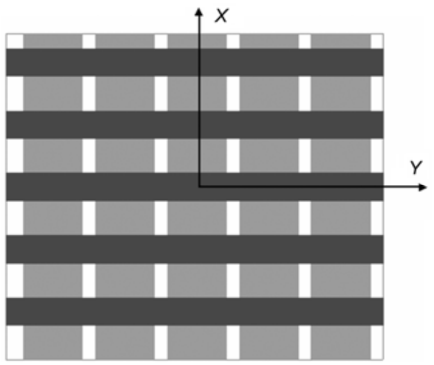

Fig.8 PCB readout (thickness of 0.3mm).

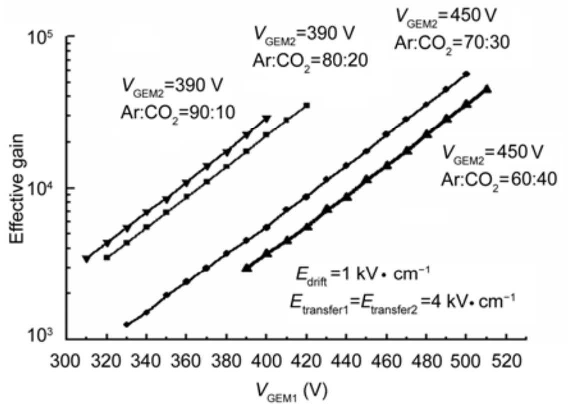

Fig.9 Comparison of effective gains for different gas compositions.

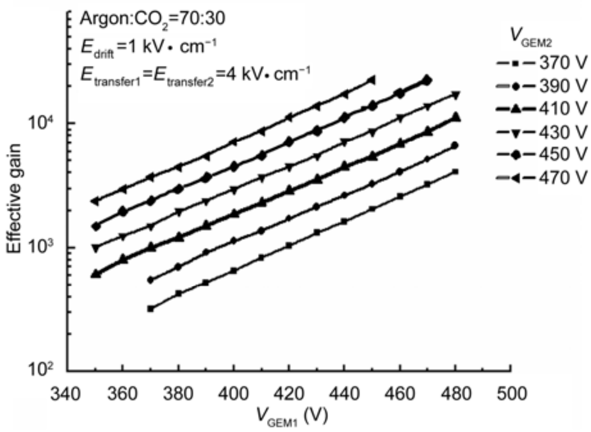

Fig.10 Dependence of effective gains on GEM voltages.

^{55}Fe. The detector can get a larger gain and work with lower voltages in a gas mixture (Ar:CO_2=70:30) especially. But the phenomenon of discharge is detected occasionally when both V_{GEM1} and V_{GEM2} are more than 480V. The effective gain dependence on the gap field is also measured. With E_{drift} and $E_{transfer1}$ increasing, the electron transparency of GEM mesh is almost constant, while it changes linearily with $E_{transfer2}$ (see Fig.11). From the results, a better working condition is selected: E_{drift} =1 kV•cm^{-1}, $E_{transfer1,2}$ = 4 kV•cm^{-1}, and $V_{GEM1,2}$= 450V. Thus the effective gain will be 1.4×10^4.

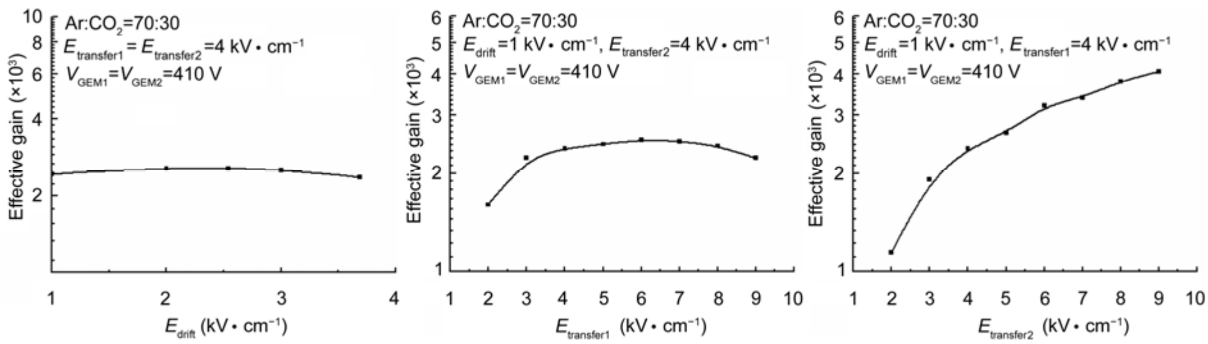

Fig.11 Effect of gap fields on effective gain.

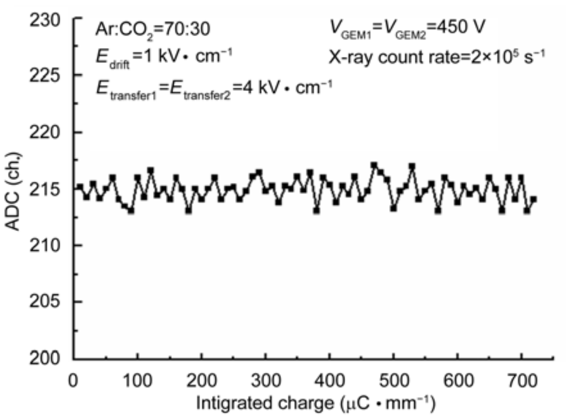

Fig.12 Stability of the double-GEM detector.

The counting capability is measured using X-ray tube under the same condition shown in Fig.12. The integrated charge is defined as $Q = I_s t = MneRt/S$, where e and n are the electron charge and number of ion pairs per conversion, t is the time of irradiation, the beam intensity R is 5×10^5Hz and the irradiated spot S is 0.5mm^2, and M is the effective gain. When the integrated charge is up to 700μC · mm^{-2}, the change of pulse height (ADC) is less than 1%.

4 X-ray imaging

A third GEM foil is inserted between the GEM2 and the PCB readout for reducing the discharge probability and getting a stable gain to realize the X-ray imaging. The gaps of GEM2 to GEM3 (transfer2 gap) and GEM3 to PCB (transfer3 gap) are both 2mm. With $E_{\rm drift}$=1kV · cm^{-1}, $E_{\rm transfer1,2,3}$=4kV · cm^{-1}, $V_{\rm GEM1}$=370V, and $V_{\rm GEM2,3}$=450V, the effective gain will be 4.5×10^5 when operated with X-ray of 8.9keV in the same gas mixture.

A three-slit image is shown in Fig.13 using the centre-of-gravity readout method. The slit perpendicular to X-axis is 0.5mm. The two slits perpendicular to Y-axis are both 0.3mm with a 2mm distance. The position projection of the slits on X-axis and Y-axis are shown in Fig.14 (a), (b) respectively. The average measured spacial resolution σ_x is 180.0μm, and σ_y is 137.6μm. Deducting the effect of slits width which is 153.6μm for the slit of 0.5mm and 92.2μm for the slit of 0.3mm based on the trapezium distribution method,[6] the real spacial resolution of the detector is 94μm in X direction and 102μm in Y direction.

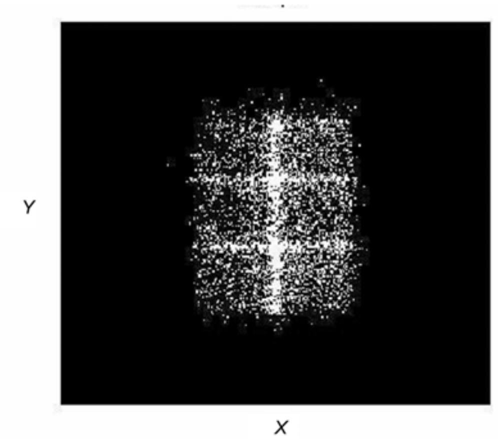

Fig.13 Slits imaged by the triple-GEM.

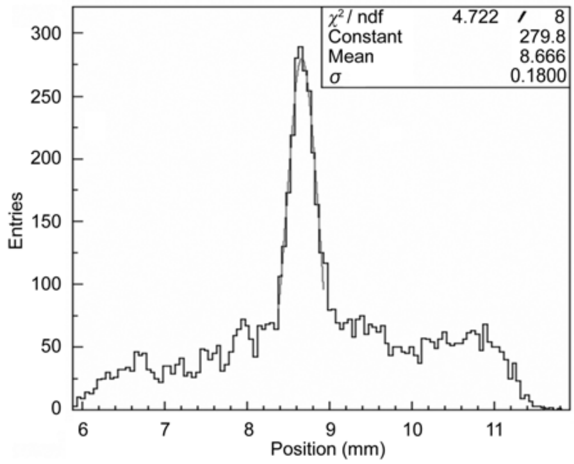

Fig.14(a) Position distribution on X-direction.

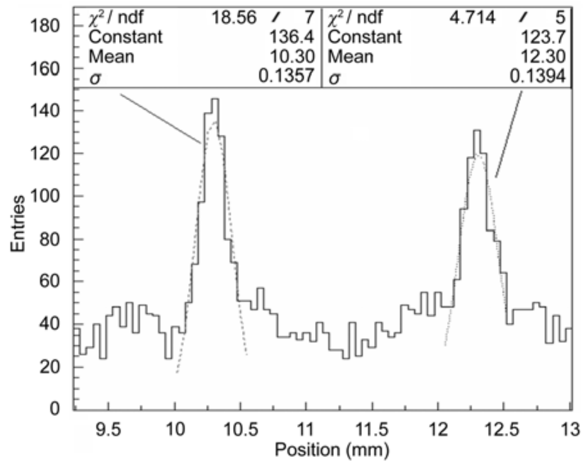

Fig.14(b) Position distribution on Y-direction.

5 Conclusion

The performance of GEM devices is measured in detail. The effective gain of double-GEM can be up to 1.4×10^4 with each GEM voltage of 450V and suitable gap fields operated in the gas mixture of Ar:CO_2=70:30. The multiplication and electrons collection of the GEM detector are two separate processes which reduces the spacial charge effect. The detector can work stably under X-rays with a high rate of 10^5Hz · mm^{-2}.

The effective gain of triple-GEM detector can reach 5×10^5. Using the centre-of-gravity readout method with 2D PCB, it can work well in X-ray imaging, with a good spatial resolution better than 0.1mm after the electronic fluctuation be subtracted.

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