Electron transmission efficiency of gating-GEM foil for TPC*

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Abstract: In a TPC, ion feedback from the readout detector can cause a space-charge effect and distort the electrical field in the drift region. Gating is one of the effective methods to solve this problem, which can block ions at the expense of losing a certain amount of primary electrons. Compared with the traditional design with a wire structure, gating based on GEM foil is more attractive because of its simplicity. In this paper, the factors influencing the electron transmission efficiency are studied with simulations and experiments. After optimizing all these parameters, an electron transmission efficiency over 80% is obtained.

Key words: GEM, gating, electron transmission efficiency, TPC

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1 Introduction

A time projection chamber (TPC) is a gas-filled tracking detector invented by David Nygren [1]. It can provide 3D tracking of charged particles in the chamber. In recent years, the R&D of TPCs has mainly has focused on the readout methods based on a micro pattern gas detector (MPGD), among which the gas electron multiplier (GEM) is one of the most promising candidates. Compared with a multi-wire proportional counter (MWPC), using a GEM as the TPC readout detector has many advantages: excellent spatial resolution, negligible $\vec{E}\times\vec{B}$ track distortion effect and better ability to suppress ion feedback [2]. However, a certain amount of ions (about 0.2% [3]) still go through the holes of the GEM and reach the drift region of the TPC. These ions distort the local field and eventually deteriorate the TPC's performance. Fortunately, if the TPC runs in anon-continuous mode, like in the International Linear Collider (ILC), and a gate with a pulsed reversed voltage is placed close to the readout detector, the ions are further blocked by the gate [4]. Compared with the traditional design with a wire structure, gating based on GEM foil is more attractive because of its simplicity. ILC-TPC collaboration has proposed that GEM foil be used as one of the gating structure options, and an electron transmission efficiency of more than 70% is expected.

In this paper, the electron transmission efficiency ($\varepsilon_{\rm ET}$), which is defined as the ratio of the number of electrons that go through the gating-GEM to the number of those that are generated by primary ionization in the drift region before the gating-GEM, is factorized into two components: collection efficiency ($\varepsilon_{\rm C}$) that gives the fraction of electrons that are collected into the hole of the gating-GEM from the drift region without hitting the upper copper layer, and extraction efficiency ($\varepsilon_{\rm E}$), which gives the probability that an electron, once collected, successfully escapes from the hole and goes further to the readout GEM for amplification. In this sense, the electron transmission efficiency can be expressed as the product of the two terms $\varepsilon_{\rm ET}=\varepsilon_{\rm C}\times\varepsilon_{\rm E}$.

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2 Simulation study

Several parameters affect the electron transmission efficiency, including working gas, geometry of the gating-GEM and the electrical fields above and below the gating foil, which are referred to as the drift field and the transfer field respectively in this paper. Simulations on these parameters are carried out with Maxwell [5] and Garfield [6] under room temperature and atmospheric pressure.

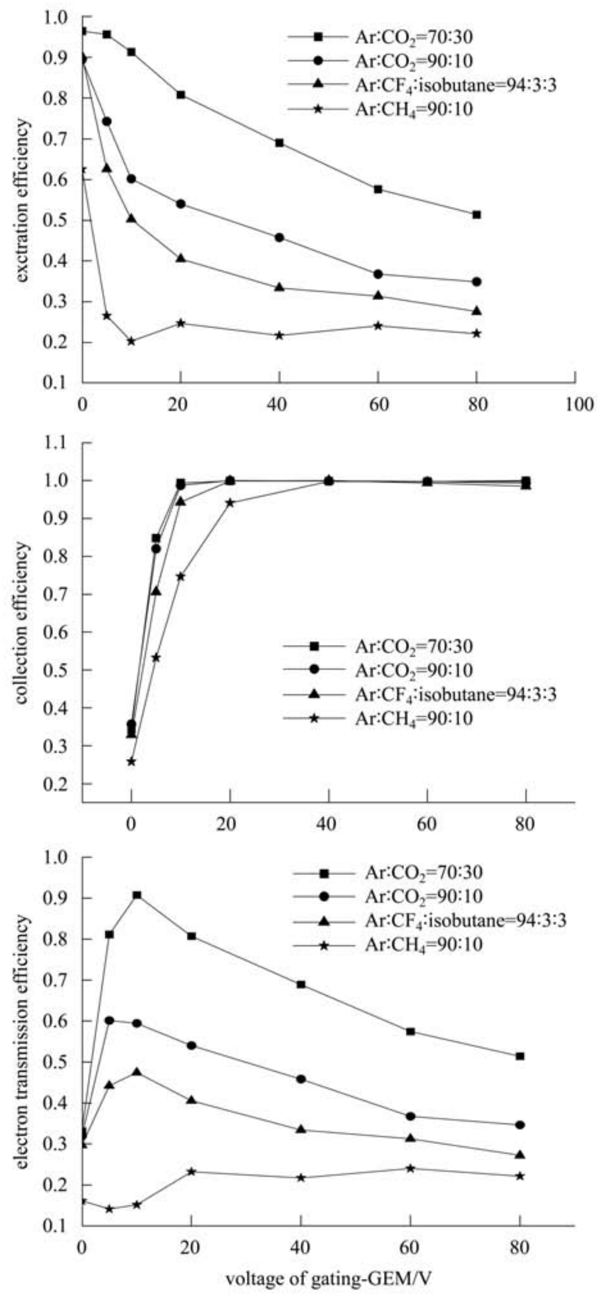

Fig. 1. Simulation results of ε_C, ε_E and ε_{ET} versus gating-GEM voltages in different working gases.

2.1 Working gas

The transport of electrons relies on the components of the gas mixture. A mixture of Ar and CO_2 is usually used in GEM detector, while a mixture of Ar, CH_4 and so on is used in TPC. Simulations of mixtures that contain CO_2 and CH_4 respectively are performed and shown in Fig. 1. From them one can see that when the gating-GEM is working at a low voltage around 10 V, the mixture of Ar-CO_2 (70-30) has the best electron transmission efficiency, and the content of CO_2 is critical in increasing the extraction efficiency. When GEM is working as a gating foil, the electric field in its holes is less than 10 kV/cm, and electron avalanche will not occur in its holes. The lateral diffusion of electrons in the gas is the major factor influencing the extraction efficiency, which will be reduced with the increasing of lateral diffusion, and the smallest lateral diffusion appears in an Ar and CO_2 mixture with a ratio of 70:30, as shown in Fig. 2.

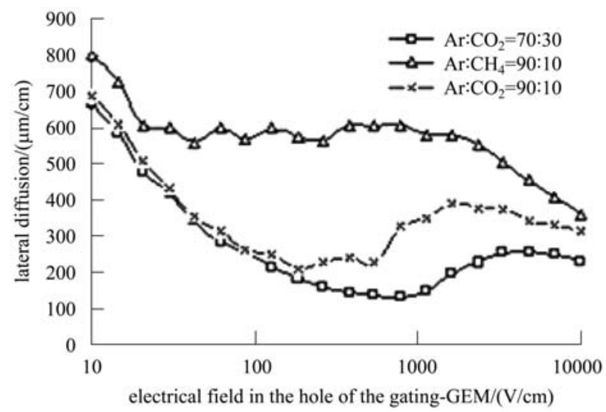

Fig. 2. The electron lateral diffusion in different gases.

2.2 Structure of the gating-GEM

The main parameters of the gating-GEM foils considered here are the diameter of the holes and the thickness of the Kapton. Three different dimensions are studied and shown in Fig. 3. From it, one can see that with the increase of the aperture, the collection efficiency is improved. When the thickness of Kapton decreases, the probability of electrons hitting the Kapton also reduces, which gives a higher extraction efficiency.

In the same gas mixture, the electron transmission efficiency against the voltage of the gating-GEM increases at first and then decreases slowly. And the maximum value of about 80.4% can be achieved with a GEM of voltage of about 10 V; this is a very attractive advantage of using GEM gating.

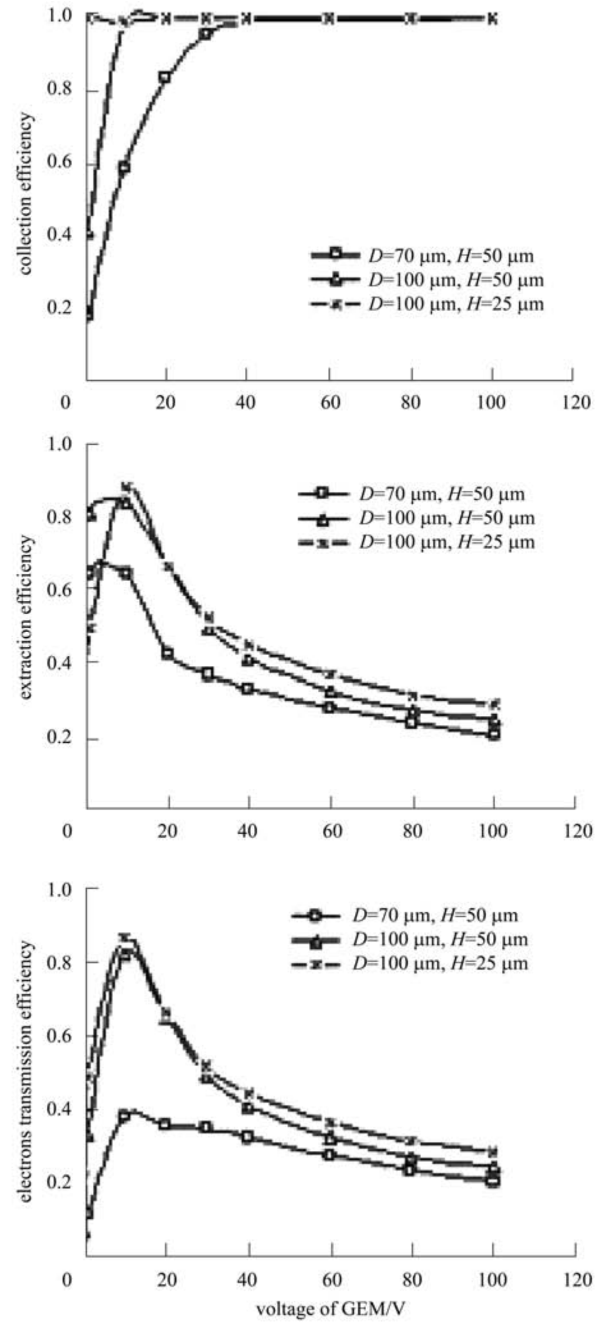

Fig. 3. Simulation results of ε_C, ε_E and ε_{ET} against GEM voltages in different dimensions. Here, D is the diameter of GEM holes. H is the thickness of GEM Kapton.

2.3 Electric field in the drift region and the transport region

Simulations are performed for different drift fields and transfer fields separately, as shown in Fig. 4. The curves show that ε_C is mainly affected by the drift field while ε_E is affected by the transfer field. When the drift filed strength is increased and the voltage of gating-GEM is kept constant, the converging effect on the electrical field lines by the holes on gating-GEM is weakened, and the possibility of electrons moving along the electrical field to the upper electrode of gating-GEM is increased, leading to a poor collection. An increase of the transfer field leads to a smaller probability of electrons reaching the lower electrode of the gating-GEM, and thus a greater probability of electrons being drawn from the holes. An electron transmission efficiency of about 95% can be achieved when E_d and E_t are set to 150 V/cm and 900 V/cm accordingly.

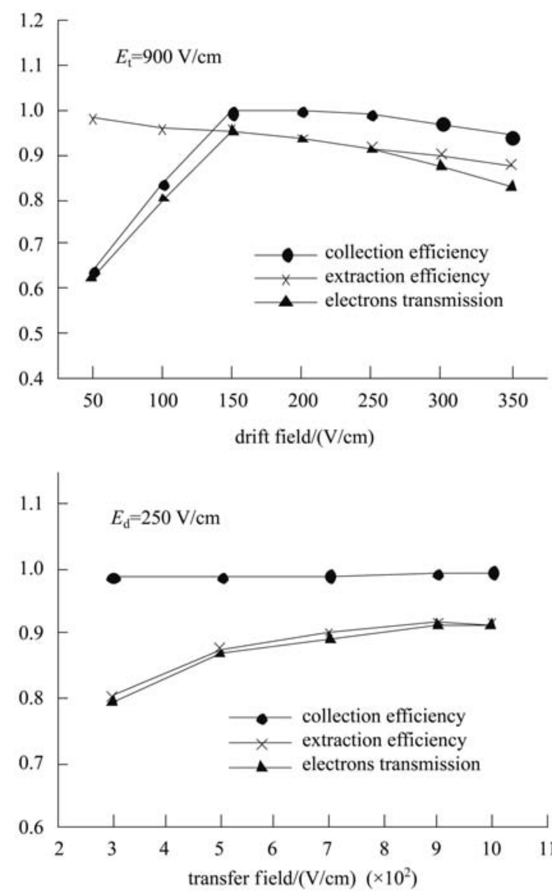

Fig. 4. Simulation results of ε_C, ε_E and ε_{ET} as a function of the drift field (upper) and the transfer field (lower).

3 Experiments

3.1 Experimental setup

Figure 5 presents the experimental setup, with three CERN-made standard-size GEMs (1, 2 and 3) as the amplification stage. A gating-GEM foil from SciEnergy Co. Japan, with a Kapton thickness of 25 μm and hole diameter of 100 μm was used. Tests were carried out under different working gases, different gating voltages and electric fields.

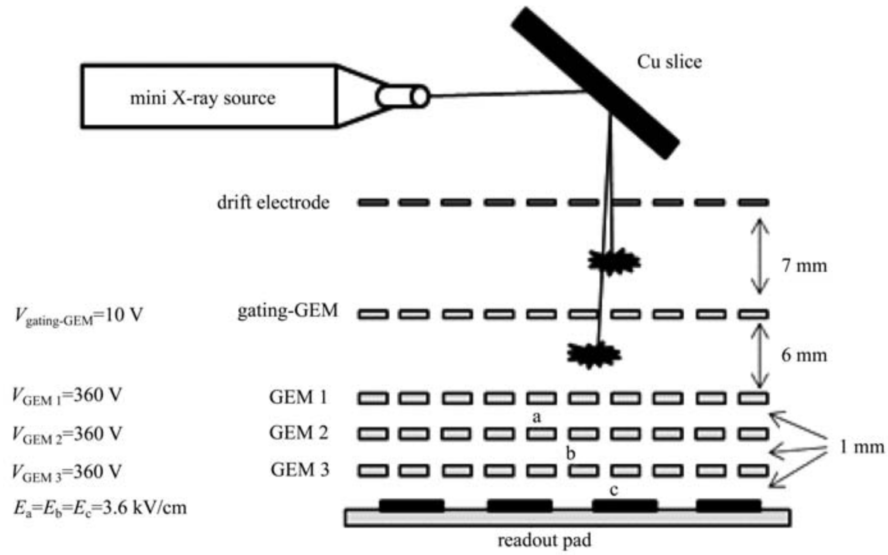

Fig. 5. Schematic diagram of the experimental setup.

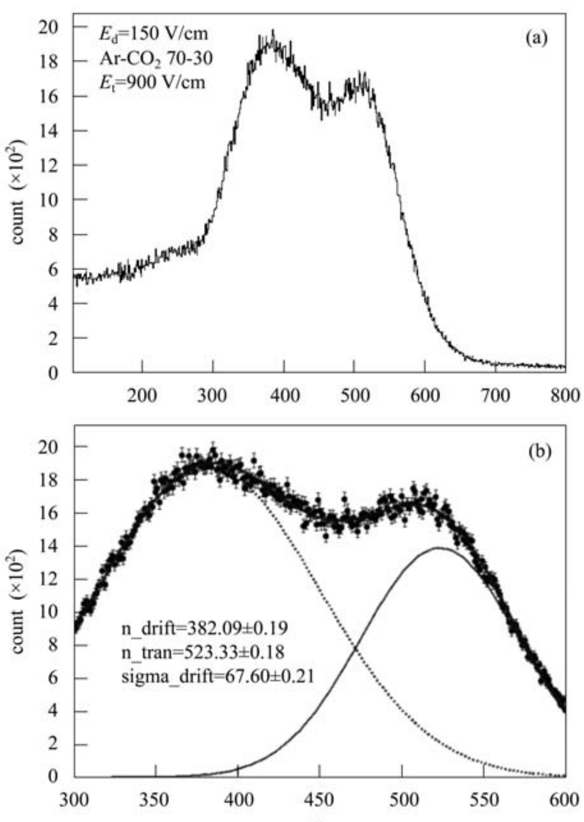

Fig. 6. (a) Pulse height spectra recorded in the experiment, where two peaks can be seen clearly. (b) Resolving and fitting of (a), including photo-peaks originating in the drift region (dashed line) and the transfer field (full line).

3.2 Data analysis

Due to the existence of the gating-GEM foil, the energy spectrum of Cu characteristic X-ray (8 keV) has two peaks (Fig. 6(a)), and the right one originates from the energy deposition in the transport region and the left one from that in the drift region. So the electron transmission efficiency equals the ratio of the two peak positions. RooFit [7] is used to resolve the spectra, as shown in Fig. 6(b). During the fitting process, the contribution of the transfer region is fitted based on the spectrum measured in the same conditions but a zero electric field in the drift region.

3.3 Test results

3.3.1 Different working gases at different gating voltages

Table 1 contains the experiment results of the electron transmission efficiency in different gases with E_d and E_t set to 250 V/cm and 900 V/cm accordingly, which match the simulation results in general. The ε_{ET} in Ar:CO$_2$ (70:30) is much larger than in Ar:CH$_4$(90:10), and the largest value could reach about 80%.

Table 1. The ε_{ET} of the gating-GEM in different gases under different gating-voltages.

gating voltage/V	ε_{ET} in Ar/CO$_2$=70/30	ε_{ET} in Ar/CH$_4$=90/10
0	39.80%	24.87%
5	77.35%	34.98%
10	79.86%	33.11%
20	75.48%	30.66%
40	59.94%	28.59%
60	50.79%	28.01%
80	43.56%	28.47%

3.3.2 Electric fields

As shown in Fig. 7, the measured $\varepsilon_{\rm ET}$ increases with the drift field at first, and reaches the maximum value at about 250 V/cm, followed by a slow decrease. Meanwhile, when the transfer field increases the $\varepsilon_{\rm ET}$ increases until it reaches saturation.

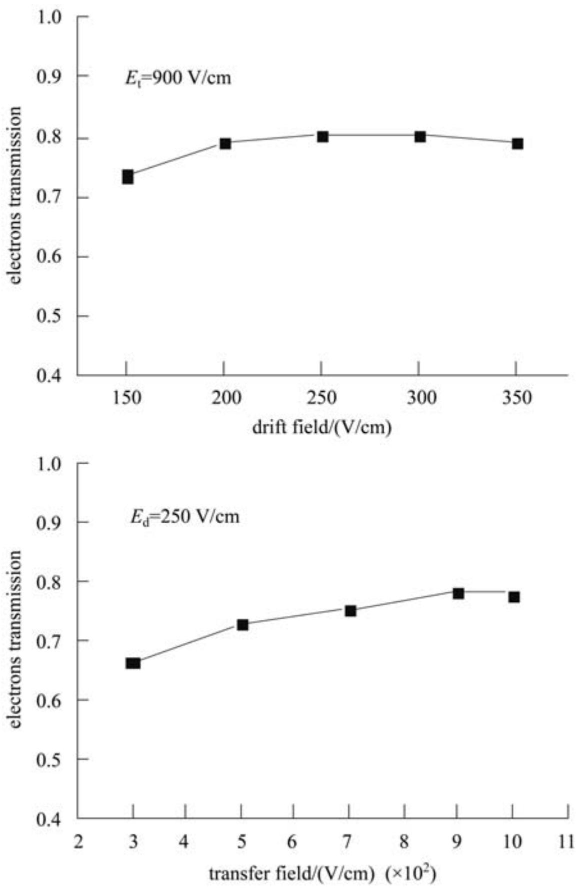

Fig. 7. The changes of $\varepsilon_{\rm ET}$ against the drift field (upper) and the transfer field (lower) in the experiment.

However, the transfer region here is also the drift region of the amplification GEM-GEM1, so the transfer field should not be too large. The recommended value is 900 V/cm. Comparing the results of the experiment and the simulation, namely Fig. 7 and Fig. 4, one can find a small difference in the relations between $\varepsilon_{\rm ET}$ and the drift field and a good correlation of $\varepsilon_{\rm ET}$ and the transfer field. This probably derives from the impact of the diffusion of electrons in the gas in different fields. Meanwhile the gas used in the experiment may be not exactly the same as the one used in the simulation. Moreover, the environment plays an important role in the experiment, and the temperature of our laboratory was not kept exactly at 25 ℃.

4 Conclusion

Optimizing the parameters of a gating-GEM to improve electron transmission is the principal objective of this study. To achieve this goal, simulations of gas, structure of gating-device and electrical fields are carried out and a special detector is constructed to confirm the simulation results. In a detector using a gating-GEM with an inverted voltage of about 10 V, 25 μm-thick Kapton and holes of 100 μm in diameter, an electron transmission efficiency of 80% could be obtained under a drift field of 250 V/cm and a transfer field of 900 V/cm. The introduction of a gating-GEM in a TPC surely improves the field of its cylindrical drift region, but the electron transmission of this gating-device cannot reach 100%, which means the primary ionization electrons (carrying energy and the location information of the ionizing particles) cannot be collected completely by the endplate detector and this leads to worse energy resolution, detection efficiency and particle identification of the TPC [8]. When the gating-GEM is used as an ion filter in a TPC in practical application, adjustment of the gain on the endplate should be taken into account, in addition to trying to obtain higher electron transmission. The magnetic field is not considered here, which needs to be studied further.

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