Study of Ion Back Flow suppression with thick COBRA GEM

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ABSTRACT: Ion Back Flow (IBF) suppression is essential to avoid a space-charge distortion of the electric field under a high rate condition in the Time Projection Chamber (TPC). A GEM technology is one possible solution to achieve a small IBF and to keep a good performance in terms of particle tracking and particle identification at high rates in TPC. We developed Thick COBRA GEMs to investigate the capability of further IBF suppression. It was found that the COBRA GEM can suppress IBF more effectively compared to a standard GEM. IBF reaches about 0.1–0.5% with a stack configuration consisting of one standard GEM facing to the drift field and two COBRA GEMs. In this paper, the current status of development of COBRA GEM is described.

KEYWORDS: Micropattern gaseous detectors (MSGC, GEM, THGEM, RETHGEM, MHSP, MICROPIC, MICROMEGAS, InGrid, etc); Electron multipliers (gas)

1For the ALICE TPC collaboration.
1 Introduction

ALICE [1] is the dedicated experiment to study the Quark Gluon Plasma (QGP), the hot and dense QCD medium, via heavy ion collisions at LHC. The ALICE Time Projection Chamber (ALICE TPC) [2], which is the main device in the central barrel for tracking and particle identification of charged particles, consists of a 90 m\(^3\) cylinder filled with Ne/CO\(_2\)/N\(_2\) (90/10/5). Multi Wire Proportional Chambers (MWPCs) are adopted with gating grids as readout chambers. The gating grid prevents ions from going back to the drift space (Ion Back Flow; IBF). Suppression of IBF is essential to avoid the worsening of the TPC performance, in particular under high rate and high multiplicity conditions.

A continuous readout of the ALICE TPC is planned with 50kHz Pb-Pb collisions after 2019. The current ALICE TPC has a limitation of the data taking with the maximum rate of 3.5kHz due to the gating grid operation. The required IBF is 0.5–1.0% at gain \(\sim 2000\) to achieve a continuous readout with the current TPC performance. One possible solution to fulfill the requirement is to replace the MWPCs with the Gas Electron Multipliers (GEMs) [3], which is a type of micro pattern gaseous detectors, because GEM has a good IBF blocking capability.

The structure of a standard GEM is a 50 \(\mu\)m-thick insulator sandwiched by 5 \(\mu\)m-thick copper foils with 70 \(\mu\)m\(\phi\) holes in 140 \(\mu\)m pitch. When high voltage is applied between GEM electrodes, an electron avalanche is induced by the high electric field inside holes. Ions going to the drift region can be blocked by the GEM electrodes. Furthermore, a stack configuration of GEMs can make the ion-blocking more efficient. The development of readout chambers with standard GEMs is therefore a main approach of the ALICE TPC upgrade. The performance evaluation of standard GEMs with triple and quadruple GEM stacks is being investigated. In addition, we are exploring the basic performance of the COBRA GEM [4] as another optional approach. The COBRA GEM is specially designed to achieve better IBF suppression compared to a standard GEM by a double electrode pattern on a surface. This characteristic electrode pattern enhances to make electric force lines converge.
Figure 1. A microphotograph of COBRA GEM surface (left). Cross-section drawing of COBRA GEM (right).

Table 1. The geometries of COBRA GEMs.

| Insulator thickness (µm) | Hole pitch (mm) | Hole Diameter (µm) | Rim width (µm) | Metal width (µm) |
|------------------------|----------------|-------------------|----------------|-----------------|
| 200                    | 0.5            | 150               | 50             | 50              |
| 400                    | 1.0            | 300               | 100            | 100             |

Its performance is being studied for application to the GEM-based TPC. In this article, we present the results of our recent studies of COBRA GEMs in Ne/CO₂ (90/10) and Ar/CO₂ (70/30) at atmospheric pressure.

2 Thick COBRA GEM

In collaboration with SciEnergy Co., Ltd. [6], we have developed two prototype COBRA GEMs; 200 and 400 µm-thick. Table 1 summarizes the geometry of these GEMs. The glass epoxy laminate (FR5) is employed as an insulator, and 6 µm-thick copper layers cover an active area of 3 × 3 cm². The holes were pierced by a drill. The patterns on the COBRA electrodes and the rims around the holes were produced by a wet etching technique. Our COBRA GEM is characterized by a double electrode pattern on both sides. A microphotograph of the COBRA GEM surface and a schematic view of a cross section are given in figure 1. By creating a voltage difference between these two COBRA electrodes, ∆Vₐc, ions can be efficiently absorbed. We define ∆Vₐc = Vᵢn − Vₒut, where Vᵢn,out are the voltages applied to inner and outer COBRA electrodes, respectively, as shown in figure 1. Illustrations of ion absorption at the COBRA electrodes calculated by Garfield [5] are given in figure 2. The left and right panels of figure 2 show the results for ∆Vₐc = 100 and 300 V at ∆Vₐm = 1200 V, where ∆Vₐm is the voltage difference between upper and lower electrodes. Most of ions are absorbed by the outer COBRA electrode at ∆Vₐc = 300 V, while a large number of ions still flow into the drift space at ∆Vₐc = 100 V.
3 Measurement setup

Figure 3 shows a schematic view of the measurement setup. The chamber is filled up with Ar/CO$_2$ (70/30) or Ne/CO$_2$ (90/10) at atmospheric pressure and the X-ray beam is injected perpendicular to the surface of the COBRA GEM. The distance between the readout pad ($3 \times 3$ cm$^2$) and the lower GEM electrode is 2 mm. The electric fields in the drift and induction regions, $E_{d,i}$, are 0.4 kV/cm and 3 kV/cm, respectively. In this measurement, the distance between the mesh plane and the upper GEM (=drift space) is 3 mm. The measurement with the stack configuration (figure 4) were also carried out. Two 200 µm-COBRA GEMs were placed below a standard GEM (50 µm thick; holes diameter: 70 µm; pitch: 140 µm). The electric field in the transfer region between the standard GEM and the upper COBRA GEM, $E_{t1}$ is 0.4 kV/cm, and that between the COBRA GEMs, $E_{t2}$ is 0.4 kV/cm.
Figure 4. A schematic view of the measurement setup in the stack configuration.

Figure 5. The gain as a function of $\Delta V_{\text{GEM}}$ for the 200 $\mu$m-thick and 400 $\mu$m-thick COBRA GEMs with Ar/CO$_2$ (70/30) and Ne/CO$_2$ (90/10).

4 Results

Figure 5 shows the gain with the single COBRA configuration as a function of $\Delta V_{\text{GEM}}$. We calculate the gain as $I_a/(I_c^0/2)$, where $I_a$ and $I_c^0$ are the current at the pad plane and the mesh current without electron multiplication, respectively. The factor 2 in the expression of the gain comes from the fact that only half mesh current contributes to electron multiplication because the attenuation coefficient for the X-ray energy we used in this measurement is longer than 3 cm and the
Figure 6. The gain and IBF as a function of \( \Delta V_{AC} \) with the single 200\( \mu \)m-thick COBRA configuration in Ne/CO\(_2\) (90/10).

number of seed electrons in mesh-shield and shield-COBRA is almost the same. Open and closed squares represent the results of the gain for the 200\( \mu \)m-thick COBRA GEM in Ne/CO\(_2\) (90/10) and Ar/CO\(_2\) (70/30), respectively. Closed circles show the gain for the 400\( \mu \)m-thick COBRA GEM in Ar/CO\(_2\) (70/30). The gain of single COBRA GEM increases exponentially as \( \Delta V_{GEM} \) increases. It can reach more than \( 10^3 \) as expected from the result for a 400\( \mu \)m-thick GEM [7].

Figure 6 shows the gain and IBF with the single 200\( \mu \)m-thick COBRA configuration in Ne/CO\(_2\) (90/10) as a function of \( \Delta V_{AC} \). We define (IBF) = \( (I_c - I_0^c)/I_u \), where \( I_c \) is the current at the mesh plane. \( \Delta V_{GEM} \) of the COBRA GEM is 550V. The X-ray rate is tuned to match the current density at the readout pad to the expected one in 50kHz Pb-Pb collisions. A better IBF is achieved at a higher \( \Delta V_{AC} \) since the ion absorption at the COBRA electrodes is improved. A higher \( \Delta V_{AC} \) also brings a higher gain because of a better collection of the electrons and a higher electric field in the hole. The gain is decreasing above \( \Delta V_{AC} \sim 240 \text{V} \) because the field switched to the reverse direction and seed electrons cannot reach the GEM.

Figure 7 shows the gain and IBF with the stack configuration in Ne/CO\(_2\) (90/10) as a function of \( \Delta V_{AC} \), where \( \Delta V_{AC} \) is applied simultaneously on both 200\( \mu \)m-thick COBRA GEMs. \( \Delta V_{GEM} \) of the standard GEM is kept at 200V during this measurement. We changed \( \Delta V_{GEM} \) of each COBRA GEM; \( \Delta V_{GEM,2,3} = 430, 430 \text{V} \) (black square), 390,470 V (blue cross), 350,510 V (green triangle), 310,550 V (yellow plus), and 260,590 V (red circle). IBF can be more suppressed with higher \( \Delta V_{AC} \). IBF achieved 0.1-0.5% at \( \Delta V_{AC} = 250 \text{V} \) at gain \( \sim 1000 \). A clear difference among different settings of \( \Delta V_{GEM,2,3} \) is seen at \( \Delta V_{AC} = 250 \text{V} \). To better understand the \( \Delta V_{AC} \) dependence of the gain and IBF, further measurements with different \( \Delta V_{GEM,2,3}, \Delta V_{AC}, \) and \( E_{it,2} \) are needed.

5 Summary and outlooks

We have developed COBRA GEMs with two different geometries. The gain that a COBRA GEM can reach is larger than \( 10^3 \). The COBRA GEM achieves 0.1-0.5% IBF at a gain around 1000
Figure 7. The gain and IBF in Ne/CO$_2$ (90/10) as a function of $\Delta$V$_{AC}$, where $\Delta$V$_{AC}$ is applied simultaneously on both 200 $\mu$m-thick COBRA-GEMs. $\Delta$V$_{GEM2,3} = 430, 430$ V (black square), 390, 470 V (blue cross), 350, 510 V (green triangle), 310, 550 V (yellow plus), and 260, 590 V (red circle).

with the stack configuration. Further IBF suppression is possible by optimizing the $\Delta$V$_{GEM}$, $\Delta$V$_{AC}$, and $E_{t1,2}$. We are going to evaluate the gain stability, energy resolution and efficiency through both measurement and simulation. In addition, we are developing a 100 $\mu$m-thick COBRA GEM without rim to reduce the influence of charging-up of the insulator.

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