Journal of NUCLEAR SCIENCE and TECHNOLOGY, Supplement 4, p. 295–298 (March 2004)

Operational properties of the double Gas Electron Multiplier

Yong Kyun KIM*, Se Hwan PARK, Sang Hyo HAN, and Jang Ho HA

Korea Atomic Energy Research Institute, P. O. Box 105, Yuseong, Daejeon 305-600, Korea

The operation of a double GEM was examined in several gas mixtures, including Ar/Isobutane, Ar/CO_2, and Ar/N_2. In the double GEM detector, a large gain of about 5×10^4 was obtained for the Ar/Isobutane mixture. The ion feedback dependency of the double GEM was carefully measured according to the drift electric field, transfer field, the asymmetry of the GEM voltage, and the effective gain in various gas mixtures. The ion feedback depends significantly on the drift field and the effective gain, however it is almost independent of the gas mixture. A model of ion feedback in a double GEM structure was derived, and its prediction was compared with the experiment. The optimum value of the transfer field and the dependency of the collection current with respect to the drift, transfer, and collection field strengths for the GEM voltage sharing in the double GEM are also discussed.

KEY WORDS: Double Gas Electron Multiplier, gas mixtures, effective gains, transfer field, drift field, collection current, ion feedback measurement

I. Introduction

In modern high-energy physics experiments such as LHC at CERN, all single stage micro-pattern gas detectors suffer from discharge and fatal sparking damage as the result of the huge amount of primary electrons that are generated by the heavily ionizing particles passing the detector [1)]. To reduce the probability of a gas discharge in the presence of heavily ionizing radiation, the gas detectors should be operated only at a limited gain corresponding to the marginal detector operation. A new concept of a gas avalanche detector was introduced by Sauli[2)] with a Gas Electron Multiplier(GEM). Considerable progress has been made motivated by the growing interest in the application of GEM. GEM is superior to other gas detectors in the respect of a high counting rate, excellent spatial resolution, good imaging capability, operative in a magnetic field, large sensitive area, flexible geometry, and low cost[3)]. In Korea, GEM was operated coupled with MWPC and MSGC, and the charge sharing and electron transfer process were examined[4, 5)].

GEM end-cap detectors for the Time Projection Chamber (TPC) were investigated by several groups such as the TESLA collaboration[6)]. One of the important features in such an application is the strong suppression of the feedback of the positive ions, which are generated from an avalanche. The ion feedback in TPC can cause serious problems in high rate, and high multiplicity devices. Another interesting application of GEM is the GEM based photo multiplier. The broader use of a gas photon detector, especially in a commercial system, has been hindered by the necessity of permanent gas flushing. Sealed gas detectors usually age very fast in standard gas mixtures, and the operation in a noble gas can prevent the problem. However, the gain in a noble gas filled detector is usually very low due to the photon and ion mediated secondary process [7)]. Since the electron avalanche in GEM is confined to the hole, GEM has then advantage of being operated with a high gain in pure noble gas [8)].

The GEM photomultiplier has been investigated intensively at present [3)], however the ion feedback has to be reduced to prevent photocathode degradation from the ion impact. Ion feedback was measured previously in single and multiple GEM structures [9, 10)]. One of the interesting features in the previous studies was that the ion feedback ratio (the ratio of the cathode-to-anode current) was independent of the gas and pressure for a given gain even though the applied voltages across the GEM in the various gas conditions were not the same. It means that the charged particle diffusion, which is the function of pressure, gas, and electric field, does not affect the ion feedback. However, only a few kinds of gas mixtures were used in the previous experiment [9)], it is necessary to confirm the gas effect on the ion feedback. Also, it would be helpful to understand the ion feedback effect systematically for the gas detector development with GEM.

In our experiment, the ion feedback effect in a multi-GEM structure was studied extensively in various gas conditions using a double GEM structure. And the anode signal was recorded directly through the bottom of the second GEM. It helps to understand the ion feedback phenomena using a small number of parameters. An ion feedback model was made for our GEM structure. The effects of the drift field, the asymmetry of the applied voltage across the GEM, and the gain on the ion feedback can be explained with the charge transfer parameters of a single GEM.

II. Ion Feedback Model for the Double GEM Structure

Fig. 1 shows the experimental setup of a double GEM detector. The physics of a multi GEM structure can be described with a few parameters [9]], which are from the charge transfer mechanism in single GEM. In a single GEM foil, collection efficiency, gain, and extraction efficiency

* Corresponding Author, Tel. +82-42-868-8723, Fax. +82-42-868-2897, E-Mail; ykkim4@kaeri.re.kr

can determine the charge transfer. Let's say electrons move from the upper region of GEM into the lower region of GEM. Then, the collection efficiency is the probability of a charged particle above GEM to be transferred into a GEM hole. The gain is the factor by which the number of electrons is multiplied by gas avalanche inside the GEM hole. The extraction efficiency is the fraction of charged particles to be extracted from the GEM holes into lower region of GEM.

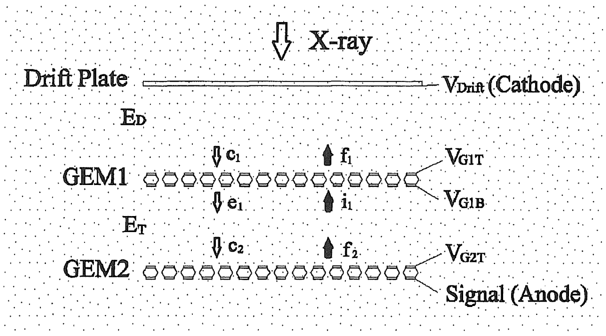

Fig. 1 Schematics of a double GEM detector. Collection efficiencies and extraction efficiencies of electrons (c_i and e_i) and ions (i_i and f_i) are also noted, which are for model calculations.

Previous measurements and numerical simulations on the charge transfer in the single GEM were performed to understand the charge transfer parameters [11)]. The gain is determined by the mean electric field inside the GEM hole, E_{hole}. That is, the E_{hole} of GEM1 in **Fig. 1** is a linear combination of E_D, E_T, and ΔV_{GEM}:

$$E_{hole} = a\,\Delta V_{GEM} + b(E_D+E_T), \qquad (1)$$

where a and b depend on the GEM geometry. The collection efficiency is a function of the field ratio E_D/E_{hole}. The collection efficiency decreases in a high drift field due to the defocusing of the field lines above the GEM. The collection efficiency of the electron and ion shows a sharp decrease when the E_D/E_{hole} approaches zero. It is due to the recombination of charge pairs at a very low drift velocity. The extraction efficiency is a function of E_T/E_{hole}. The extraction efficiency increases with E_T/E_{hole}, because more charged particles can be extracted from the lower side of the GEM foil in larger E_T/E_{hole}.

Our measurement of the ion feedback effect in the multi GEM can be explained from the charge transfer parameters in a single GEM. Let us say that the electron collection efficiency into the GEM hole c_i, the real gain of a GEM g_i, electron extraction efficiency from the GEM hole e_i. The ion extraction efficiency from the GEM hole is f_i, and the ion collection efficiency into the GEM hole is i_i. Each parameter is shown in **Fig. 1**.

Then the effective gain, G, in our double GEM structure is

$$G = c_1 g_1 e_1 c_2 g_2. \qquad (2)$$

The number of ion feedback for a single electron (I_D) is contributed from the ions generated in GEM1 to be extracted into the drift plate and the ions generated in GEM2 to arrive at the drift plate. It can be expressed as

$$I_D = c_1 g_1 f_1 + c_1 g_1 e_1 c_2 g_2 f_2 i_1 f_1. \qquad (3)$$

The first term is from the ions generated in GEM1, and the second term is the ions generated in GEM2. Then the ion feedback ratio(I_D/G) can be expressed as

$$I_D/G = f_1\,(i_1 f_2 + 1 / e_1 c_2 g_2) = f_1\,(i_1 f_2 + c_1 g_1 / G). \qquad (4)$$

III. Experimental Procedure

The experimental setup shown in **Fig. 1** was similar to that used in Refs. [4,5)]. Two GEM foils (Kapton thickness 50 μm, hole diameter 60μm the metal side, and hole pitch 100 μm) of a 10×10 cm^2 active area each, were mounted in a cascade inside a stainless-steel chamber. The GEM foils were made at CERN[12)]. The drift plate, which was made of aluminized Mylar, was placed above GEM1. The drift gap between the drift plate and GEM1, and the transfer gap between GEM1 and GEM2 were 3 mm and 2 mm, respectively. The 5.9 keV X-rays from ^{55}Fe were irradiated through a 0.5 mm thick Be window, and the anode signal was measured directly through the bottom electrode of GEM2. The anode and cathode signals were measured in a current mode. Each electrode (V_{G1T}, V_{G1B}, V_{G2T}, and V_{Drift}) was connected to an individual channel of a power supply, allowing the flexible setting of the electric fields in the two gaps and voltages across the GEM surfaces.

Effective gain of the detector was defined as the anode current divided by the primary ionization current, which was measured through the top of GEM1 with the high voltage bias only between the drift plate and GEM1. The ion feedback ratio was defined as the cathode current divided by the anode current. Highly pure (99.999%) gases were used in our measurement. The gas mixture of $Ar+CO_2$ or $Ar+N_2$ flew through the chamber, and the gas mixing ratio was changed to get the influence of gas on the ion feedback. The voltage-effective gain characteristics in various gas mixtures were shown in **Fig. 2**, where the lines are the exponential function of the voltage across the GEM (ΔV_{GEM}). Each current was measured ten times and the error was estimated from the standard deviation. E_D and E_T were fixed at 2kV/cm and 3kV/cm, respectively. We biased the same ΔV_{GEM}'s in GEM1 and GEM2. The effective gain follows the exponential behavior up to a high ΔV_{GEM}.

The effects of the effective gain and gas mixing ratio of the various gases on the ion feedback ratio are shown in **Fig. 3**. The large error bars in some data points were from the noise increase due to spark between electrodes during the measurement. The ion feedback ratio for a given effective gain was measured with the various gas mixtures of Ar/CO_2 or Ar/N_2. The ion feedback ratio decreased with the effective gain, and it was almost independent of the gas mixing ratio, which was consistent with the previous result

[9]. It means the diffusion of charged particles does not affect the ion feedback.

Fig. 4 shows the effect of E_D on the ion feedback. The same voltages were biased across GEM1 and GEM2. $E_T = 3$ kV/cm and ΔV_{GEM} in each gas mixture was kept constant to make the effective gain 10^3. The ion feedback ratio increased almost linearly with E_D. But the effective gain was not so sensitive to E_D.

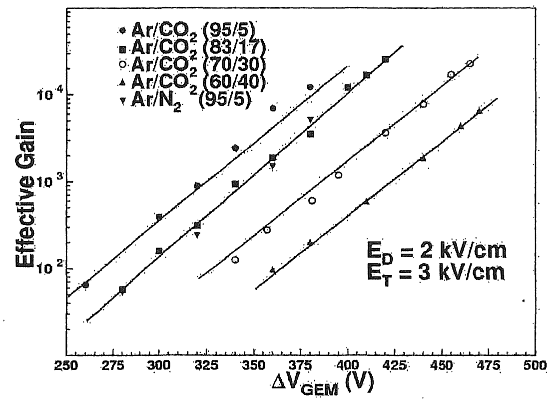

Fig. 2 Effective gain as a function of voltage across the GEM. E_D was kept constant.

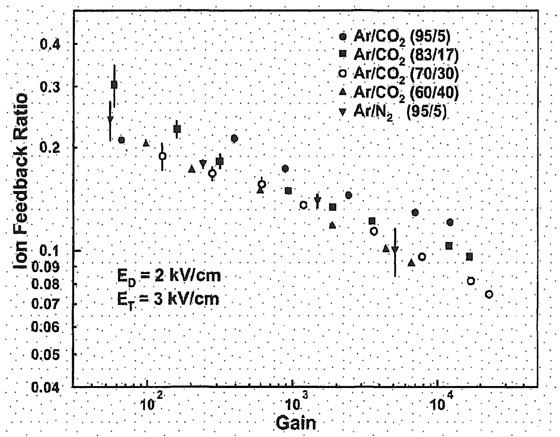

Fig. 3 Ion feedback ratio as a function of effective gain. E_D and E_T were kept constant.

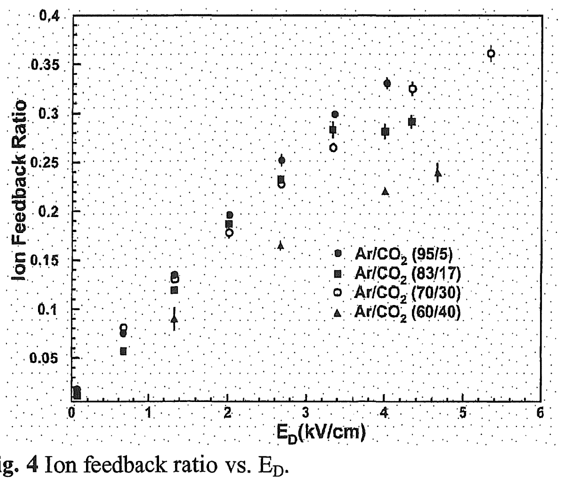

Fig. 4 Ion feedback ratio vs. E_D.

Fig. 5 shows the effect of E_T in various gas mixtures. The voltage across GEM1 was also equal to the voltage across GEM2. The data was obtained with a fixed E_D (2 kV/cm) and ΔV_{GEM}. Effective gain increased with E_T, and the ion feedback ratio decreased slowly with E_T in the high E_T region. **Fig. 6** shows the effect of E_T in various gas mixtures. The voltage across GEM1 was also equal to the voltage across GEM2. The data was obtained with a fixed E_D (2 kV/cm) and ΔV_{GEM}. Effective gain increased with E_T, and the ion feedback ratio decreased slowly in the high E_T region.

The effect of the asymmetry of ΔV_{GEM}'s on the ion feedback ratio was also measured, which is shown in **Fig. 6**. Only the voltages across GEM1 and GEM2 were changed. We increased ΔV_{GEM} of GEM1 and ΔV_{GEM} of GEM2 was decreased to keep the same effective gain of 10^3. As the voltage across GEM1 became higher, the ion feedback ratio increased.

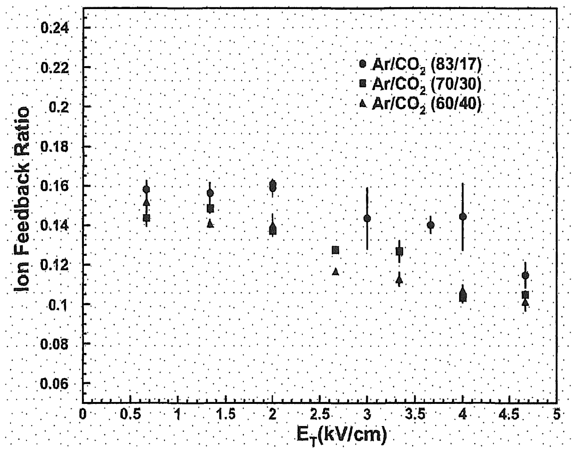

Fig. 5 Ion feedback ratio vs. E_T.

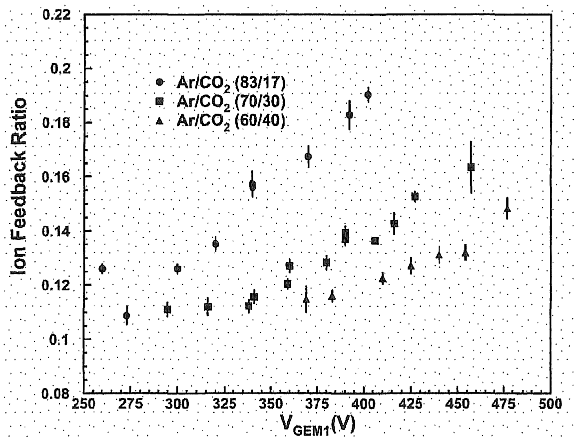

Fig. 6 Effect of asymmetry of ΔV_{GEM} on the ion feedback ratio. Effective gain was set constant at 10^3 during the measurement. ΔV_{GEM1} means the voltage across GEM1.

IV. Discussion

Since G was not changed with E_D in our measurement, it is assumed that b of Eq. 1 can be negligible. Then E_D and E_T do not affect g_i. The effect of E_D on the ion feedback ratio can be understood from Eq. 4. E_D can affect f_1, and f_1 increases with E_D [11], which is consistent with **Fig. 4**.

The effect of the asymmetry in ΔV_{GEM}'s on the ion feedback ratio follows from the model. Eq. 4 predicts that if the effective gain (G) remains the same, the ion feedback ratio will increase with g_1, which is consistent with **Fig. 6**. The discrepancies of the ion feedback ratio with respect to the gas mixture in **Fig. 6** comes from the fact that g_1's are different in various gas mixtures even if the same ΔV_{GEM} is applied, which is shown in **Fig. 2**.

The effective gain dependency on the ion feedback ratio is also from Eq. 4. ΔV_{GEM} can affect all the parameters in Eq. 4. However, the effect of ΔV_{GEM} on g_i is much larger than the effect on the other parameters. Therefore, one can assume all the parameters are constant except g_i if only ΔV_{GEM} is varied. Since g_1 is equal to g_2 in our measurement, one can get

$$I_D / G = a + b / G^{1/2}, \qquad (5)$$

where a is $f_1 i_1 f_2$, and b is $f_1(c_1/e_1 c_2)^{1/2}$.

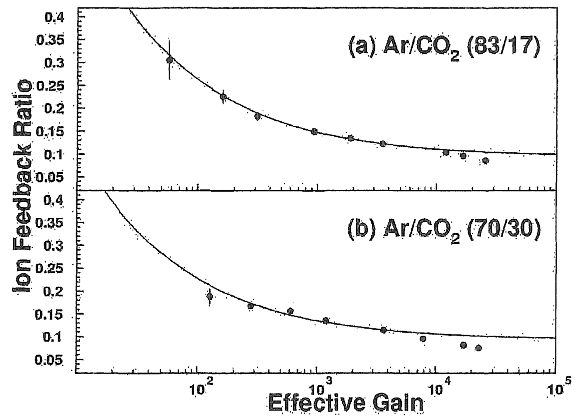

Fig. 7 The phenomenological formula about the effective gain dependency on the ion feedback was fitted to the measurement. The lines are the fitting result, and the circles are the data.

We can make a fit to the measurement using Eq. 5. The parameters of a and b were varied to give the minimum of reduced chi-square. The lines in **Fig. 7** are from the fitting, and the circles are from the measurement. The model can explain the effective gain dependency of the ion feedback ratio except in the higher gain region. That is, the measured data is smaller than the model prediction. As pointed out by Bondar [9], it could be related to the avalanche extension effect in the GEM. Since the positive ions are produced outside the GEM hole in a higher gain, it has more chance to drift to the bottom of the GEM rather than entering the hole.

We made a model prediction for our measurement, and the ion feedback ratio can be explained by the collection efficiency, gain, and extraction efficiency in a single GEM. The effective gain dependency was well reproduced by the model prediction except in a higher gain, which could be understood by the avalanche extension. Also the model can explain the ion feedback effect of the asymmetry of ΔV_{GEM}. With our study, one can predict the ion feedback effect in a multi GEM structure from the charge transfer parameters in a single GEM, which could be helpful for further research on a GEM photomultiplier and TPC.

Acknowledgement

This work has been carried out under the Nuclear R&D program by the Ministry of Science and Technology of Korea. The authors also wish to acknowledge the partial support from KOSEF Engineering Research Center program of Innovative Technology Center for Radiation Safety (iTRS) at Hanyang University, Seoul, Korea..

References

1) B. Schmidt, Nucl. Instr. Meth. A **419**, 230 (1998).
2) F. Sauli, Nucl. Instr. Meth. A **386**, 531 (1997).
3) A. Buzulutskov, Nucl. Instr. Meth. A **494**, 148 (2002).
4) S. Han, H. Kang, Y. Kim, B. Moon, C. Chung, H. Cho, and S. Kang, J. Kor. Phy. Soci. **40**, 820 (2002).
5) S. Han, H. Kang, Y. Kim, B. Moon, C. Chung, H. Cho, and S. Kang, J. Kor. Phy. Soci. **41**, 674 (2002).
6) TESLA Technical design report, Part IV, A Detector for TESLA, March 2001.
7) A. Buzulutskov, A. Breskin, R. Chechik, G. Garty, F. Sauli, and L. Shekhtman, Nucl. Instr. Meth. A **443**, 164 (2000).
8) A. Buzulutskov, L. Shekhtman, A. Bressan, A. Di Mauro, L. Ropelewski, F. Sauli, and S. Biagi, Nucl. Instr. Meth. A **433**, 471 (1999).
9) A. Bondar, A. Buzulutskov, L. Shekhtman, A. Vasiljev, Nucl. Instr. Meth., A, **496**, 325 (2003).
10) S. Bachmann, A. Bressan, L. Ropelewski, F. Sauli, A. Sharma, D. Mohrmann, Nucl. Instr. Meth. A **438**, 376 (1999).
11) M. Killenberg, S. Lotze, J. Mnich, S. Roth, S. Schulte, B. Sobloher, W. Struczinski, and M. Tonitti, Nucl. Instr. Meth., A **498**, 369 (2003).
12) The Printed Circuits Workshop, CERN