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Electron transparency, ion transparency and ion feedback of a 3M GEM

P.S. Barbeau[a], J. Collar[a], J. Miyamoto[b,*], I. Shipsey[b]

[a] *Enrico Fermi Institute and Center for Cosmological Physics, University of Chicago, Chicago, IL 60637, USA*
[b] *Department of Physics, Purdue University, West Lafayette, IN 47907, USA*

Abstract

We report the first measurements of electron transparency, ion transparency and ion feedback of a mass produced 3M GEM. Our results indicate that a mass produced GEM and a CERN GEM have similar values of these three quantities.

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Keywords: GEM; Radiation detectors; Gas-filled detectors

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1. Introduction

The future Linear Collider (LC) creates challenging momentum resolution and multi-track separation requirements for a charged particle tracking detector. A Time Projection Chamber (TPC) may provide the best combination of detector segmentation and continuous track measurement [1]. However, the segmentation of current technology, TPCs, is insufficient for precison reconstruction of LC events.

A TPC readout based on a Micro Pattern Gas Detectors (MPGD) such as a GEM (Gas Electron Multiplier) [2] or MicroMEGAS [3] promises to provide improved segmentation and resolution. MPGDs employ micro-electronic fabrication techniques to define microstructures around which sizable gas amplification can be achieved. In a MPGD segmentation is improved due to reduced transverse signal size, and spatial resolution is improved both due to the reduced transverse signal size and the reduced $\mathbf{E} \times \mathbf{B}$ distortion of the drift path in the vicinity of the amplification. Operation in a high-rate environment is simplified because MPGDs naturally suppress ion feedback into the drift volume of the TPC.

In this paper we measure the ion feedback, ion transparency and electron transparency of a mass-produced GEM. A GEM is one of the most promising MPGDs: it consists of a 50 μm Kapton foil clad on each side with 5 μm of copper. A matrix of holes typically 70 μm diameter on a 140 μm pitch is chemically etched through the copper and Kapton layers. Application of a suitably large voltage difference between the metal layers of the GEM produces an electric field in the holes sufficient for gas amplification. The charge

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*Corresponding author.
E-mail address: miyamoto@ieee.org (J. Miyamoto).

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produced can be collected by the GEM or by a separate charge collection device. Large gas amplification can be obtained by operating GEMs in a cascade where the amplified charge produced in the first GEM is transferred to a second GEM where further amplification takes place [4].

Until now GEMs have been produced by a time consuming and complicated chemical etching procedure with little automation. However, the first mass production of GEMS was recently achieved [5,6]. The development of mass manufacturing techniques for GEMs is important because it may reduce cost and procurement time for large-scale implementations such as TPCs and hadron calorimeters, neutrino and other rare event detectors and in many other GEM applications, for a review see Ref. [7]. It is important, however, to establish if mass produced GEMs possess the same properties as individually produced GEMs. Preliminary studies of gas gain and energy resolution indicate that this is the case [6] but so far no measurements of transparency or feedback have been performed.

2. Experimental arrangement

Electron (ion) transparency is defined as the ratio of the number of electrons (ions) which enter a GEM hole to the number of electrons that exit a GEM hole and arrive at a charge collection plane. The measurement of transparency is subtle. Consider for example electron transparency. The transparency is never unity as some fraction of the electrons are lost before they reach the readout plane due to diffusion. If the GEM is operating with significant gas amplification there is also a cancellation effect between amplified electrons and positive ions drifting in opposite directions in the GEM holes [8].

The experimental arrangement, shown in Fig. 1, consists of a single GEM and two metalized unsegmented G-10 boards that serve as the drift electrode and the charge collection plane, respectively. A beam of collimated X-ray photons from an X-ray generator enter the detector between, and parallel to, the drift plane and GEM upper surface. This arrangement, which is similar to that used in Ref. [9], ensures that primary ions are produced entirely above the GEM. (If the photons entered though a window in the drift electrode they may convert in the GEM holes or after the lower GEM electrode, thereby complicating the measurement of transparency.) To avoid charge amplification, a high-intensity photon beam is used so that a large amount of charge is liberated in the gas and consequently large readily measurable currents are produced on the electrodes. Currents on each of four electrodes, drift, GEM upper, GEM lower and readout plane, are measured either by a picoammeter or, for electrodes at HV, by a voltage drop on a 10 MΩ resistor. The same experimental arrangement is also used to study ion transparency and ion feedback.

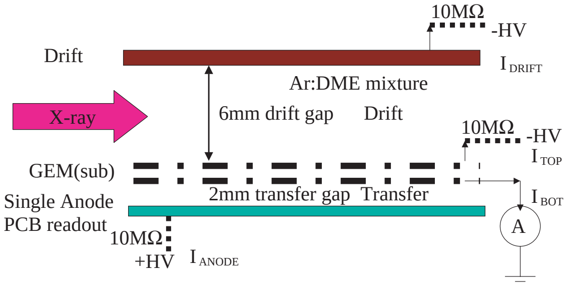

Fig. 1. The experimental apparatus. In this figure the four currents; drift, GEM upper, GEM lower and readout are denoted by I_{DRIFT}, I_{TOP}, I_{BOT}, and I_{ANODE}, respectively.

3. Electron transparency

Electron transparency is measured by computing the ratio of the current on the readout electrode to the total electron current (sum of GEM upper, GEM lower and readout plane electrode). Results are shown in Figs. 2 and 3 for a weak (50 V/cm) and a stronger (150 V/cm) drift field in Ar-DME(9:1) gas. In a weak drift field the electron transparency is larger as fewer electric field lines terminate on the GEM upper electrode. Even in the stronger drift field an electron transparency as high as 50% is obtained. Electron transparency for a reduced argon ratio (Ar:DME 7:3), for pure argon, and for pure DME is

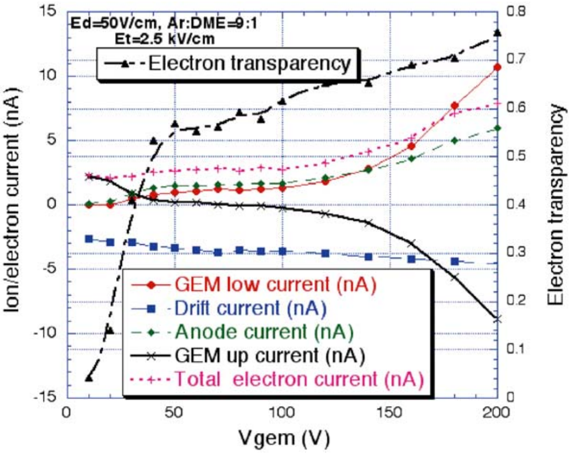

Fig. 2. The four electrode currents, the total electron current and the electron transparency as a function of potential difference across the GEM in Ar:DME 9:1. The drift field is 50 V/cm and the transfer field is 2.5 kV/cm.

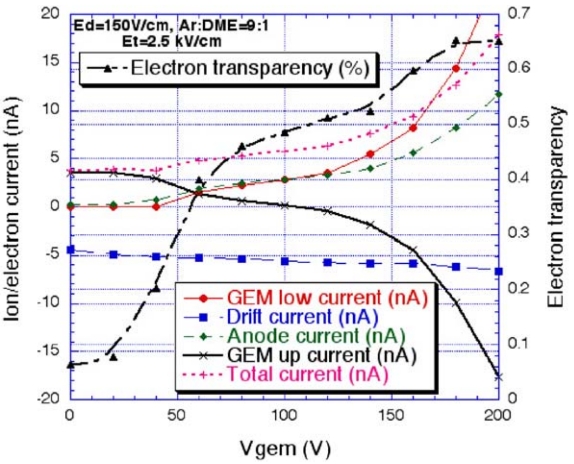

Fig. 3. The four electrode currents, the total electron current and the electron transparency as a function of potential difference across the GEM in Ar:DME 9:1. The drift field is 150 V/cm and the transfer field is 2.5 kV/cm.

measured and displayed in Fig. 4 along with the previous measurements from Figs. 2 and 3 for comparison. In gas mixtures with a higher ratio of argon, or pure argon, electron transverse diffusion is large and therefore electrons become neutralised on the GEM lower electrode. In consequence, the electron transparency becomes small. Conversely in pure DME, where electron diffusion is negligible, approximately 90% of electrons reach the readout plane. This value is comparable to that found with a CERN GEM [9].

4. Ion transparency

Until now ions have rarely been used as drifting charge carriers in gas detectors; however, the recent introduction of the negative ion TPC [10] makes a measurement of the GEM ion transparency of interest. To measure ion transparency we reverse the polarity of all electrodes (i.e. positive to negative and negative to positive) to reverse the electric field vector in the detector. In this modified arrangement, ions created in the drift volume drift towards the GEM, pass through it and reach the readout electrode. Ion transparency is measured by computing the ratio of the (ion) current on the readout electrode to the total ion current (sum of GEM upper, GEM lower[1] and readout electrode) in both pure Ar and Ar:DME 7:3 and the results are displayed in Fig. 5. As expected, there is very little difference in the ion transparency in the two gases because the heavy negative ion paths in the gas are determined mostly by the electric field lines with transverse diffusion playing a negligible role. The ion transparency reported here is somewhat better than that for a CERN GEM [9]. However, we speculate that this difference is unlikely to be real, and may be due to a different anode and drift electrode geometry between this work and [9].

5. Ion feedback

Once gas amplification begins in the GEM, ions created in the GEM holes are collected either by the GEM upper electrode (desirable) or follow the electric field lines into the drift volume before being neutralised by the drift electrode. Therefore, ion feedback is very sensitive to the strength of the drift field. Ion feedback is measured by computing the ratio of the drift current (ions) to the readout plane current (electrons). The experimental

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[1] The GEM lower current is not measurably different from zero in this configuration.

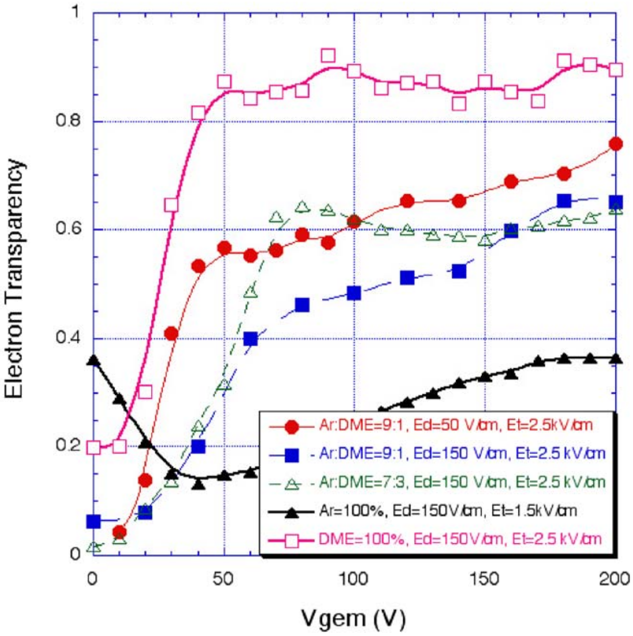

Fig. 4. The electron transparency as a function of potential difference across the GEM in a variety of gases. The drift field is 150 V/cm and the transfer field is 2.5 kV/cm.

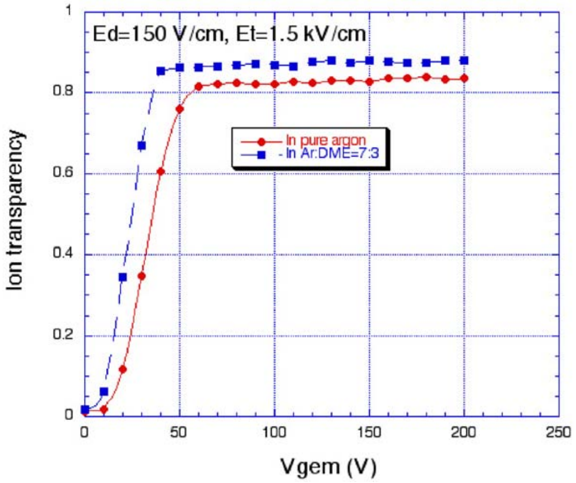

Fig. 5. The ion transparency as a function of potential difference across the GEM in pure argon and in Ar:DME 7:3. The drift field is 150 V/cm, and the transfer field is 1.5 kV/cm.

arrangement was identical to that used for the measurement of electron transparency. The result is displayed in Fig. 6 as a function of the effective gas gain. (The effective gas gain is the product of the real GEM gain and the electron transparency.) The gas mixture is Ar:DME 9:1 and the transfer field is 2.5 kV/cm. Three values of the drift field have been studied; 150, 1.0 and 2.5 kV/cm. In a weak drift field the ion feedback is small and sharply declines as the effective gain of the GEM increase. Extrapolating our measurement we estimate that the ion feedback is a few per cent at a gain of 1000. This is a similar value to that found for a single CERN GEM in Ref. [9]. As the drift field strength increases the ion feedback grows for a given gas gain. Therefore, the inherent ion suppression provided by a GEM is only effective in a weak drift field. However, multiple GEM structures have been shown to provide large additional ion suppression when the electric fields are judiciously chosen [11].

6. Summary

Using a simple experimental apparatus consisting of a single GEM with drift and readout planes

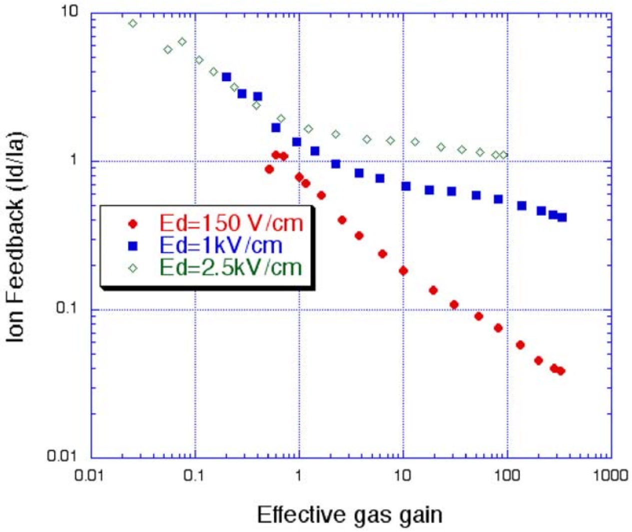

Fig. 6. The ion feedback as a function of effective gas gain for three values of the drift field. The gas mixture is Ar:DME 9:1 and the transfer field is 2.5 kV/cm.

irradiated above the GEM parallel to the GEM surface, we have measured electron and ion transparency of a mass-produced GEM in various gas mixtures and drift field. In gases with small transverse diffusion (higher DME content or pure DME), the electron transparency is 60–90% dependent on the gas mixture. The electron transparency is reduced in mixtures with a higher argon content due to increased transverse diffusion. Ion transparency is measured to be 90% and is independent of gas mixture since the role of diffusion is negligible. The 3M GEM is an efficient suppressor of ion feedback in a weak drift field where only a few per cent of ions return to the drift volume at high effective gas gain. At larger drift fields the suppression of ion feedback becomes less effective. Combining a GEM with a MicroMEGAS or using a multiple GEM structure is an effective way to achieve strong ion feedback suppression at high gas gain.

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