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Gain Characteristics of a 100 μm thick Gas Electron Multiplier (GEM)

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ABSTRACT: The standard Gas Electron Multiplier (GEM) invented by F. Sauli [1] consists of high density holes etched in 50 μm thick copper clad Kapton foil. This study, however, investigated the basic charge gain characteristics of a non-standard 100 μm thick Gas Electron Multiplier, fabricated using the same wet chemical etch process at CERN. It was possible to sustain charge gains of 3×10^3 and 1×10^4 using single and double stage configurations, respectively, operated in an Ar(70%)-CO_2(30%) gas mixture. These values are similar to those achieved with standard GEMs. Crucially, we found that the thicker GEM is more robust as it withstood sparking without catastrophic failure. We also measured the gain dependence on ambient variables such as pressure and temperature and found the gain sensitivity to be 4.0 K/mbar, compared with 1.55 K/mbar for the standard GEM.

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

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Contents

1 Introduction

Gaseous counters operate by amplifying the primary charge in an intense localised electric field region. The Gas Electron Multiplier (GEM) was invented at CERN [1] using wet etching to define holes in kapton foils. It consists of 50 μm thick kapton substrate which is metal clad (5 μm thick copper) on both sides. A standard GEM hole pattern consists of 50 μm holes arranged in a hexagonal pattern at 140 μm pitch. By applying a potential difference across the holes, high electric field is created within the holes which results in electron multiplication if the field strength exceeds approximately 20 kV/cm.

The industry standard thickness of 50 μm kapton used to fabricate the GEMs could be more prone to permanent damage during a spark than a thicker substrate. A number of other fabrication techniques have been devised over the past decade involving various substrates with thickness in the 100 μm to 1 mm range. These include mechanical drilling in PCB substrate to form a Thick-GEM [2], laser ablation [3–5] or a more recent technique using a photosensitive glass [6]. However, these techniques are either considerably expensive or more prone to non-uniformities in the manufacturing. In this work, we report on the performance of a 100 μm thick kapton GEM that has been fabricated at CERN using the wet chemical etch process with hole diameter and hole pitch set at 100 μm and 200 μm respectively. We demonstrate that it is possible to achieve charge gains comparable with standard GEMs when using these thicker GEMs, whilst avoiding the catastrophic failure that follows sparking.

2 Method

Figure 1 shows the experimental arrangement used in these studies. The X-ray sensitive area of the present detection system consisted on a stack of two 100 mm by 100 mm GEM supported on G-10 frames. The GEMs were fabricated by wet chemical etching at the CERN TS-DEM workshop and consisted of a 100 μm thick copper clad (5 microns) kapton foil with 100 μm holes patterned at 200 μm hole pitch. The drift electrode consisted of coarse mesh, made of 80 μm diameter stainless-steel wire with 900 μm spacing. The drift depth was set at 11 mm whilst the transfer and induction gaps were set at 2.8 mm and 2 mm, respectively. The readout electrode was also fabricated at CERN

2015 JINST 10 C12006

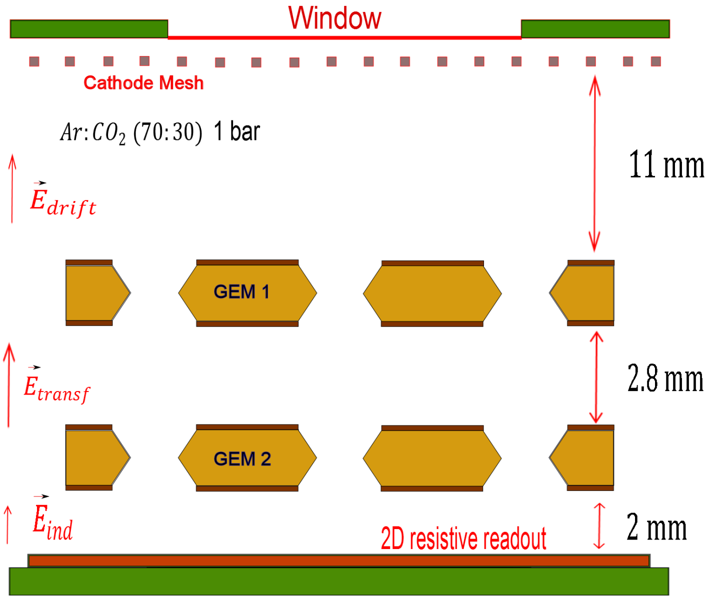

Figure 1. A schematic diagram of the GEM detector.

and consisted of two layers of orthogonal strips at 200 μm pitch with 50 μm and 200 μm width for top and bottom layers, respectively.

In the experimental studies described in the following sections, a Mn-Kα X-ray (5.89 keV) beam illuminated the detector drift space perpendicular to the detector plane. In this study, the detection chamber was operated at a constant gas flow of an Ar(70%)-CO_2(30%) gas mixture. The drift electrode and the GEM mesh were operated with negative voltage with respect to the 2D readout board that was held close to earth. The 2D readout was electrically connected to an Ortec preamplifier (model 142PC). The preamplifier output was then fed into a Tennelec shaping amplifier (model TC 243) with shaping time constants adjusted to 0.5μs. The output of the shaping amplifier was in turn fed into an Ortec multi-channel analyser. The effective gain and the X-ray energy resolution were examined as a function of the voltage differences applied across the GEM holes, ΔVGEM, by comparing the pulse height with that of a known charge pulse from a calibrated capacitor. The drift field, E_{drift}, was maintained at approximately 1.4 kV/cm throughout these studies. In order to protect the GEM elements, we limited our currents to 5 μA beyond which the high voltage power supplies were automatically turned off.

For gaseous detectors operating in gas flow mode, the charge gain observed for given conditions is sensitive to ambient variable q (= P/T) [7] where P is the gas pressure in mbar and T the absolute temperature in K. Over two weeks, the centroid channel on the pulse-height analyser corresponding to the Mn-K X-rays signal was tracked and the local temperature T and pressure P values recorded using an automated system. The temperature, pressure and discharges data logging were acquired in synchronous mode with the pulse amplitude DAQ. For that a dedicated sensor board was built and controlled in parallel with the DAQ. The communication between the computer and sensors was ensured through an Arduino Uno board which served as an interface with an ATmega328P microcontroller and also biased the sensors. The board houses a LM35 temperature sensor and two MPX4115A pressure sensors, measuring the pressure inside the detector and the atmospheric pressure. Through Python scripts it is possible to start and stop the pulse amplitude DAQ, while measuring the temperature and pressure. The discharge logger was constantly monitored by outputting and inverting the high voltage supply alarm signal to the microcontroller ADC which recorded the time of each single discharge.

3 Results and discussion

Figure 2 shows the charge gain characteristics of the 100 μm thick GEM in single and double mode, using the Ar (70%)-CO_2 (30%) gas mixture. In order to compare the gain response with 50 μm GEM, data from elsewhere [8] is included for comparison. As expected, the gain characteristics of the thicker GEM are shifted towards higher voltages. However, the uppermost charge gains of approximately 3000 and 10,000 for the single and double configuration, respectively, before the onset of electrical instabilities are approximately the same. This implies that the limiting factor with respect to highest gain in both devices is not their geometry but most likely the counter gas or the electrical breakdown strength of kapton.

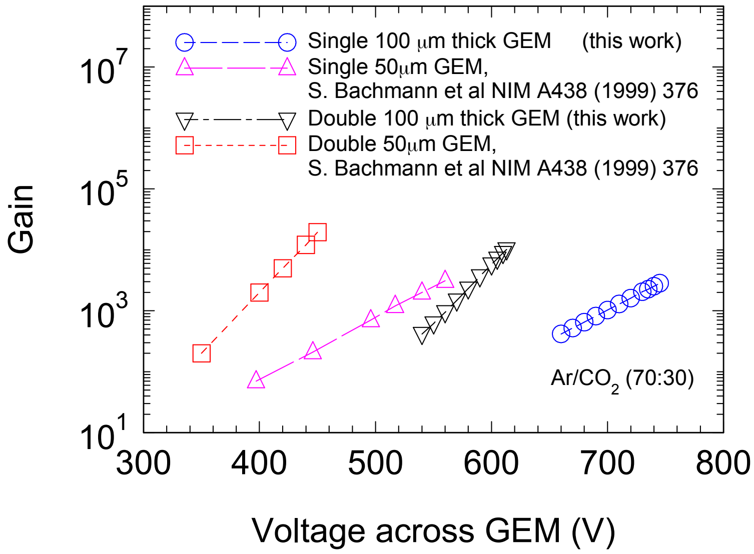

Figure 2. Variation of charge gain of a single and double GEMs as a function of the voltage applied across the GEM holes, ΔVGEM, using Ar(70%)-CO_2(30%). For the single GEM case, the induction field E_{ind} was set at 5 kV/cm and drift field E_{drift} at 1.4 kV/cm. For the double configuration, the transfer field E_{transf} and E_{ind} were set at 3.6 kV/cm and 2.5 kV/cm, respectively, whilst E_{drift} was at 1.4 kV/cm.

Figure 3 shows the effective gain of a 100 micron GEM foil over 2 weeks, plotted as a function of P/T. During the course of these measurements, we observed 290 sparks where the gain collapsed. This implies a spark probability per event of approximately 9.2×10^{-7} given the count rate was 260 Hz during the data acquisition period. We adopted a measurement methodology of rejecting data for any measurements taken after 5 minutes of a spark event to enable gain recovery. Remarkably, the gain recovered to its original value as illustrated by this figure.

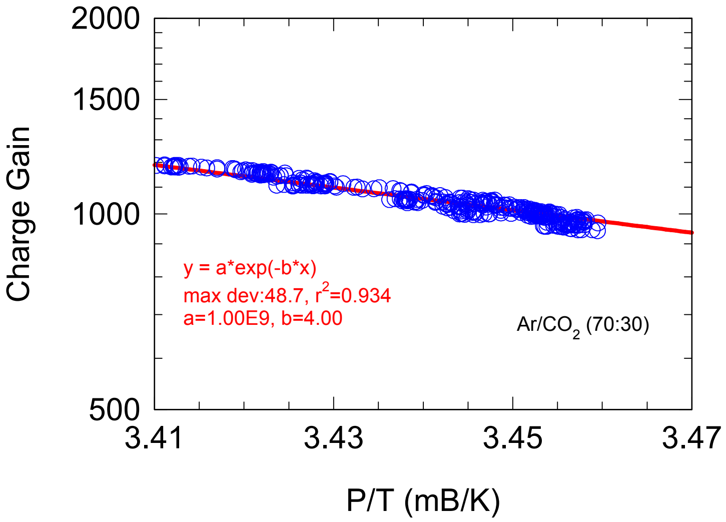

Figure 3. The effective gain measured over a period of two weeks using Ar (70%)-CO_2 (30%) as a function of the ambient parameter P/T at a constant ΔV_{GEM} and E_{ind}. The experimental data was fitted with $y = a \cdot \exp(-bx)$ where the gain sensitivity with respect to P/T was found to be 4.0 K/mB.

Figure 4 shows a typical pulse height spectrum for the 5.89 keV X-rays showing an energy resolution of 25% FWHM, with the gain set at 1025. Given that the present GEMs have been in intermittent laboratory operation for over a year, this resolution is well within the acceptance limits.

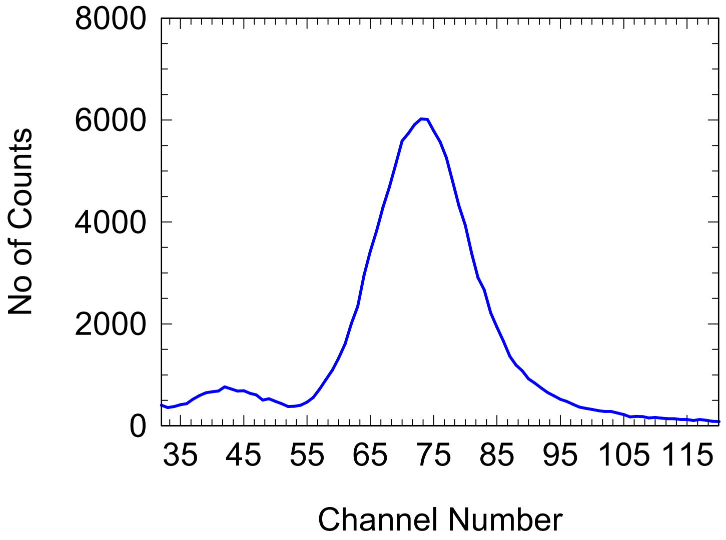

Figure 4. A pulse height spectrum for 5.89 keV X-rays using single GEM configuration within the same gas and gain regime as shown in figure 3, at a gain of 1025. The energy resolution under these conditions was found to be approximately 25% FWHM.

Fitting an exponential curve to the figure 3 gives the effective gain sensitivity of the detector to changes in the ambient conditions. In the present case, this evaluates to 4.0 K/mB as shown in figure 3. Assuming that P is roughly constant at around 1000 mB and allowing for maximum temperature excursion of ±5°C from 20°C would result in a maximum gain increase of 22.9%.

In comparison, the charge gain sensitivity for the standard GEM was found to be 1.55 K/mB [9] where the lower sensitivity of charge gain to P/T variations is attributed to more intense and localized electric fields with smaller mean free paths in the electron avalanche processes. This trend is consistent with other gaseous detectors such as least sensitive MSGCs (0.28 K/mB) [10] or the most sensitive parallel plate proportional counter (8.4 K/mB) [11].

4 Conclusions

We investigated charge gain and gain stability of a 100 μm thick GEM, that was fabricated using the same chemical etching as for the standard 50 μm thick GEM. Charge gains obtained were comparable to those obtained with the 50 μm thick GEM in both single and double configurations. However, we found the 100 μm thick GEM to be much more resilient to sparking, showing full gain recovery within a period of 5 minutes after a spark. In order to further improve the charge gain, the electric field strength within the 100 μm GEM must be increased by decreasing the hole diameter. By doing so, we will also achieve a lower gain sensitivity to ambient variables.

Acknowledgments

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2015 JINST 10 C12006