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An experimental study to understand the physics behind charging-up of Gas Electron Multiplier (GEM)

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Abstract. Charging-up is a phenomenon observed while working with gaseous ionization detector having dielectric. It is comprised of two processes: the polarization of dielectric due to exposure to high electric field and collection of charges on dielectric surface. Both these charging-up processes affect the gain of the detector as they change the local field configuration around the dielectric. Here, we have studied these effects using experimental techniques for a single GEM detector. It has been observed that due to polarization the gain has increased following a curve similar to charging-up of a capacitor. However, the radiation charging-up has reduced gain depending on radiation rate. Here, the radiation rate has been modified by using a) collimators, b) strong and weak sources. As the rate has been increased, the rate of collection of charges on GEM dielectric has accelerated. Its effects are important for experiments where beam current changes significantly with time and in TPC application which requires gain to be stable over time.

1. Introduction

The Gas Electron Multiplier (GEM) detector consists of GEM foil made up of polyimide sheet sandwiched between two metal sheets with biconical holes [1]. This GEM hole provides a very high field within a confined volume for multiplication, enhancing position resolution and making it ideal for an imaging application. GEM detectors are common nowadays and are either proposed or introduced in various beam-line experiments for triggering and tracking purposes [2]. Its use in various experiments makes it an important candidate to be tested for quality control, ageing effect, radiation damage, gain uniformity, charging-up, as well as environmental effects. In the current work, the charging-up effect and its impact on gain have been studied in detail.

In the charging-up process, the gain of the detector either increases or reduces due to modification of field around dielectric in amplification region. It occurs mainly due to two subprocesses: the polarization of dielectric due to a very high applied field (polarization charging-up) and accumulation of charge in dielectric from high-density electron-ion cloud around it (radiation charging-up).

2. Setup

A single GEM detector setup as shown in figure 1 has been studied by modifying electrode voltage and radiation rates. The detector configurations like induction gap, drift gap and gas mixture (Ar-CO_2 in ratio 76:24 by mass) have been kept fixed throughout the experiment except in section 5.1 where the gas mixture was 90:10. The radiation rate of (^{55}Fe) source has been modified with the help of collimator for measurements discussed in section 4, 5 and for that in section 5.1, two different sources have been used. The radiation rates mentioned is the total number of 5.9 keV x-ray radiation collected on the detector per unit time. The gain calibration has been done using the current measurement from the picoammeter and energy spectra from Multi-Channel Analyzer (MCA). More details about the experimental setup, radiation rate and gain measurement are mentioned in [3].

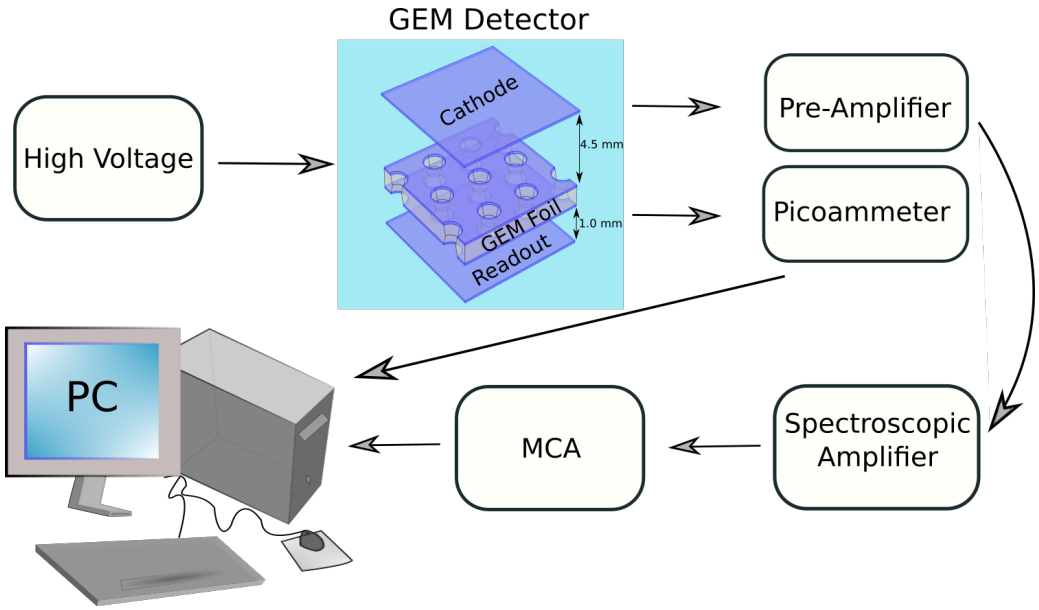

Figure 1. Schematic diagram of the experimental setup.

3. Gain variation due to environmental parameters

The environmental parameters, like temperature, pressure, humidity, etc. play an important role in the gain variation of the GEM detector [4]. Although the variation in temperature and pressure are not huge as shown in figure 2, however, the gain has varied substantially. T/P ratio has been used for correction of gain as shown in figure 3. It has been done to ensure that the gain variation studied in the subsequent sections is mainly due to charging-up.

4. Polarization charging-up

The polyimide in the GEM foil has been subjected to a very high field causing space charge polarization [5]. This polarization modifies the field around the polyimide. The field modification in the amplification region (GEM holes) changes the gain of the detector. To study the polarization charing-up we have measured the gain of the detector while it gets polarized as shown in figures 4 and 5. The detector has been kept unbiased and without radiation for days before performing these measurements. This has been done to ensure that the polyimide is free of any charge or polarization effect before the experiment.

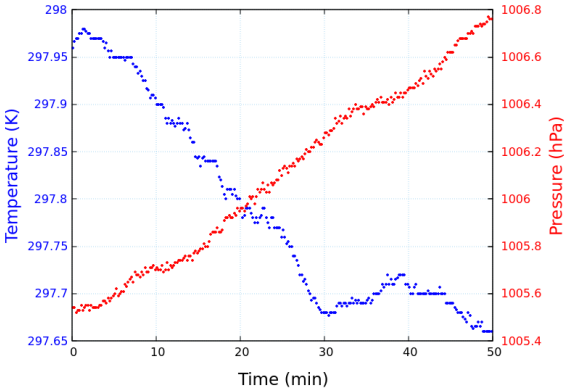

Figure 2. Temperature and pressure variation with time.

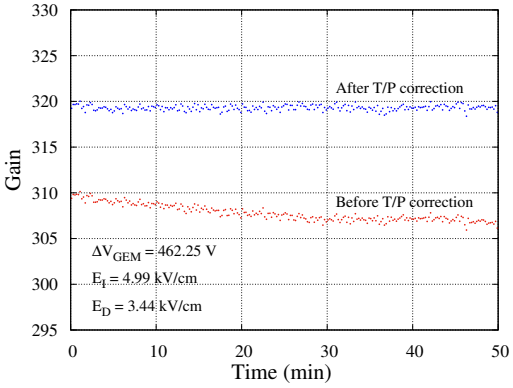

Figure 3. Gain correction taking into account T/P ratio.

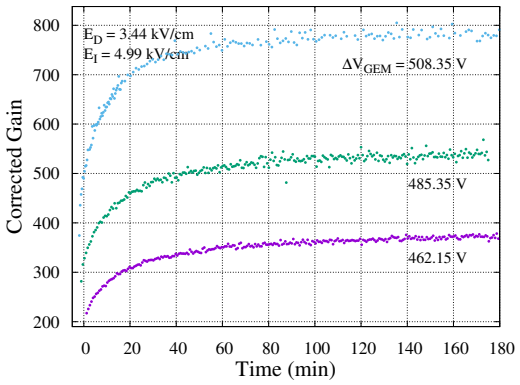

Figure 4. Polarization charging-up at diffrent GEM voltages using 0.12 kHz radiation rate.

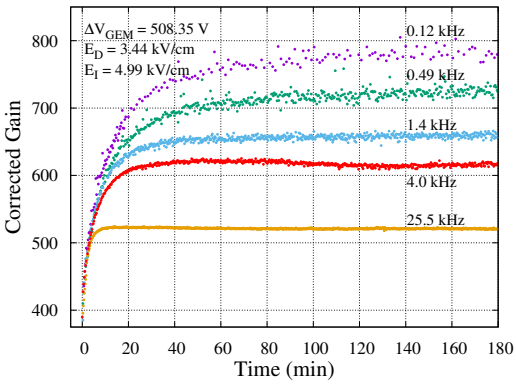

Figure 5. Effect of rate on polarization charging-up.

At t=0 sec, the respective potential has been achieved and from here on, the increase in gain is due to charging-up effects. To maximize the effect of polarization charging-up with respect to radiation charging-up, a low-rate source has been used for the gain measurement. On increasing the potential across GEM foil, while keeping all other parameters the same, it has been observed that the jump in gain due to polarization charging-up increases as shown in figure 4. On the other hand, if the potential is fixed and the rate is increased then the jump in gain reduces and a steady state is reached at a lower gain value as shown in figure 5. This is due to the combined effect of polarization and radiation charging-up (discussed in section 5) since at a higher rate the effect of radiation charging-up starts increasing.

5. Radiation charging-up/down

Radiation charging-up occurs due to the accumulation of charges on the polyimide surface during multiplication inside the GEM hole [6]. The charges collected at the surface modifies the local field causing gain reduction. To study its effect the detector has been kept at the respective potential for days before irradiation. This makes sure that the GEM foils are polarized and the modification in gain so observed is mostly due to radiation charging-up. As seen in figure 6, the gain reduces and after a while saturates depending upon the rate of radiation. To measure the

radiation charging-down gain the high-rate source used for charging-up has been replaced by a test probe (weak source) after charging-up gain saturation and the results are as observed has been shown in figure 7. The gain starts increasing once again till a saturation level is achieved.

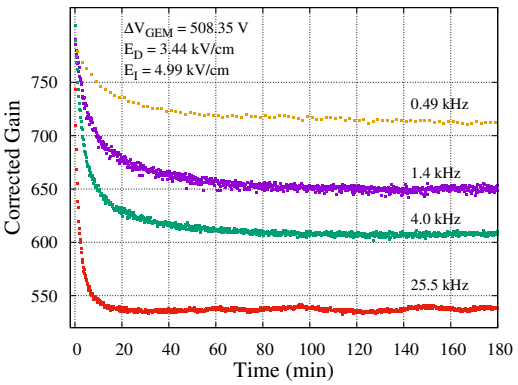

Figure 6. Radiation charging-up with various radiation rates.

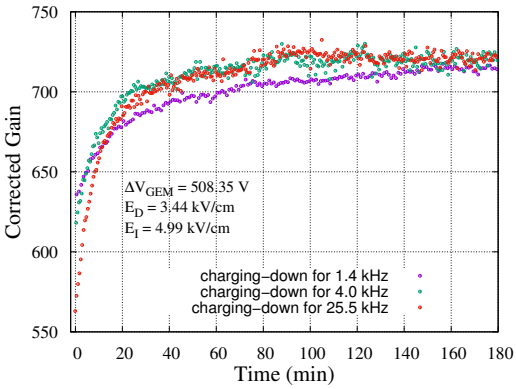

Figure 7. Charging-down using 0.49 kHz after charging-up with higher rates.

5.1. Radiation charging-up with strong and weak source

To verify the results obtained in section 5, the experiment involving radiation charging-up has been performed with two different sources. The results obtained are similar as seen in figure 8 which exhibits more gain reduction with the strong source as compared to the weaker one.

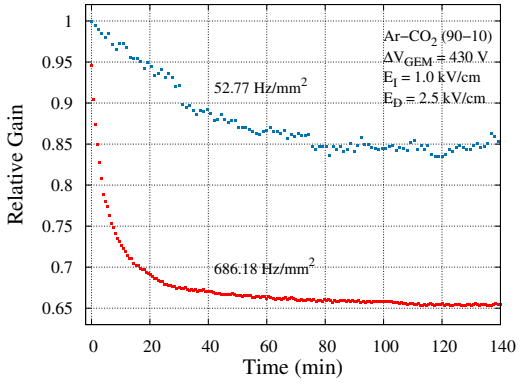

Figure 8. Radiation charging-up with diffrent sources using same collimator (relative gain has been used since the gas mixture and voltage configuration is quite diffrent here).

6. Conclusion

Both the charging-up processes have significant effects on detector gain. The polarization charging-up increases the gain whereas the gain reduces due to radiation charging-up. The gain of the detector saturates within few hours after both the charging-up processes. The gain increases on raising the potential across the GEM foil and so does the charging-up. Radiation charging-up increases with the rate of radiation leading to reduction in steady state value of the gain.

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