Study of the Impact of the GEM Foil Leakage Current to Gains

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Abstract

This document provides the result of the study on 3M Gas Electron Multiplier (GEM) foil leakage current to the double GEM detector gains. By studying the double GEM chamber through observation and theory, we are able to approximate the loss of gain due to leakage current.

1. Introduction

The idea is to assemble a parallel system of two GEM foils in a sealed chamber of gas. The goal of the chamber is to produce as many electrons as possible by accelerating a few electrons through high electric fields and ionizing the surrounding gas. By applying a known voltage to a conducting material with a known resistance, then the resulting current shall be known. The GEM foils are incredibly thin and thus the vast majority of the current remains in the plane of the foil. However, there is a small amount of current that escapes this plane and goes through the tiny holes of the GEM foil, known as the leakage current. Even the tiniest fluctuation of leakage current can be detrimental to our overall gain of electrons. Thus, this small amount of leakage current must be measured and controlled to ensure optimal efficiency of the chamber.

2. Certification Procedure for 3M GEM Foils

The 3M GEM foils have the dimensions of 30cmx30cm with 70μm diameter and 140μm distance between centers of the holes. There are three types of foils experimented with that have these dimensions: copper plated, organic coated and gold coated. The copper plated foils proved to be the most useful and cost effective for our purposes. On the copper plated GEM foil, there is a thin layer of copper on both sides of the foil. Each of the foils is divided into 12 equal strips that are electrically insulated from each other to provide the option of individual high voltage testing. The high voltage testing is done on the strips one by one with an alligator clip and slowly increasing the voltage source from 0V to 400V. The average experimental leakage current value settles to ~5nA. However, a lower the amount of leakage current grants more current that can be applied to a higher electric field in these microscopic holes. This high electric field provides more potential acceleration for the incoming electrons. Here is an example of the leakage current to be expected in each type of foil.

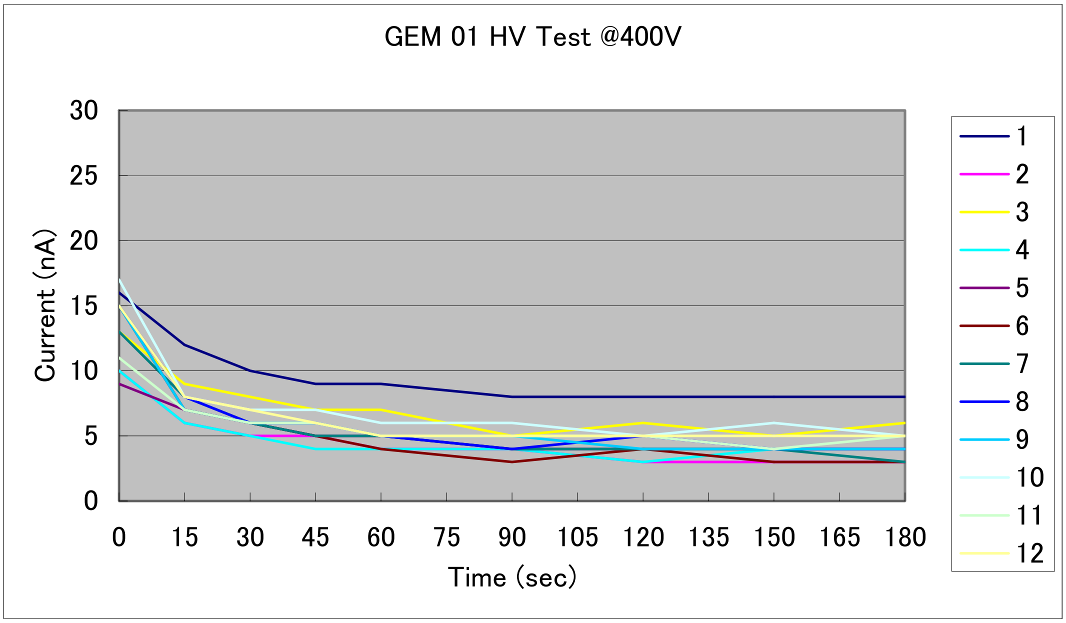


Figure 1. Leakage current of the 3M GEM copper plated foil as a function of time with 400V applied consistently across each of the 12 strips, [1].

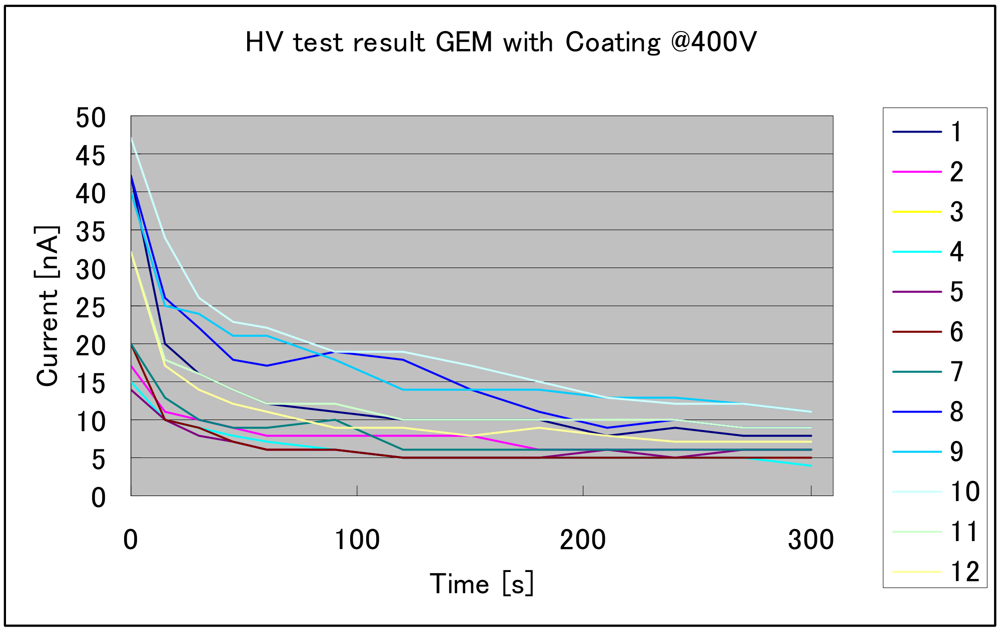


Figure 2. Leakage current of the 3M GEM foil with organic coating as a function of time with 400V applied consistently across each of the 12 strips, [1].

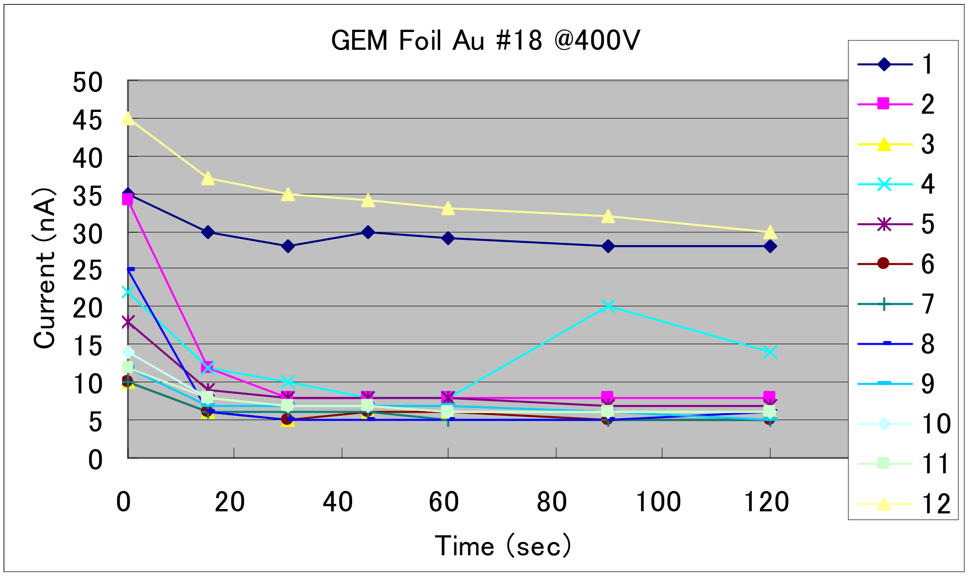


Figure 3. Leakage current of the 3M GEM foil with gold coating as a function of time with 400V applied consistently across each of the 12 strips, [1].

3. Relationship Between Leakage Current and Gain Variation

Two main mathematical steps were taken to find an algebraic relationship between the leakage current and the change in gain of electrons. It is important to note that the only unknown quantities are the leakage currents flowing through the foils and the resistance of the foils.

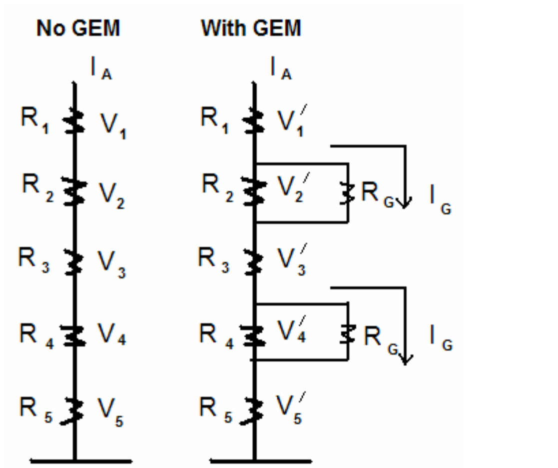


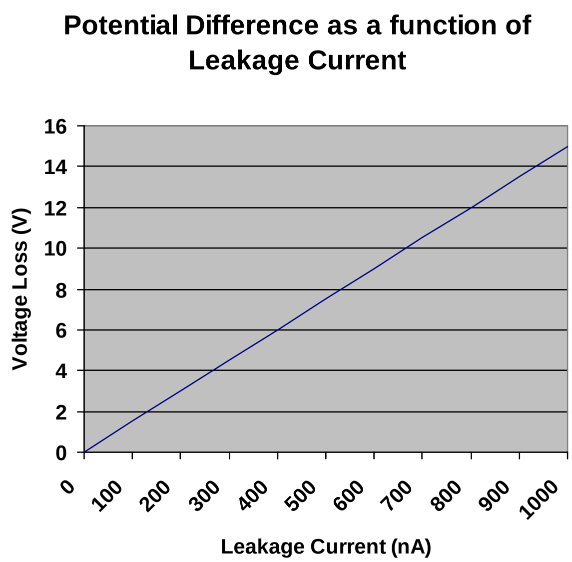
Figure 4. An initial system with only five resistors in series (No GEM) versus the same system with added voltage dividers representing the potential difference provided by the GEM foils (With GEM).

First, the association between leakage current and potential difference of the foil needed to be recognized and was found to be $\Delta V_2 = \frac{3}{5} I_L R_2$ where I_L is representing the leakage current and R_2 is corresponding to the unchanging value of one of the five equal resistors. This proportion was derived using a few relationships:

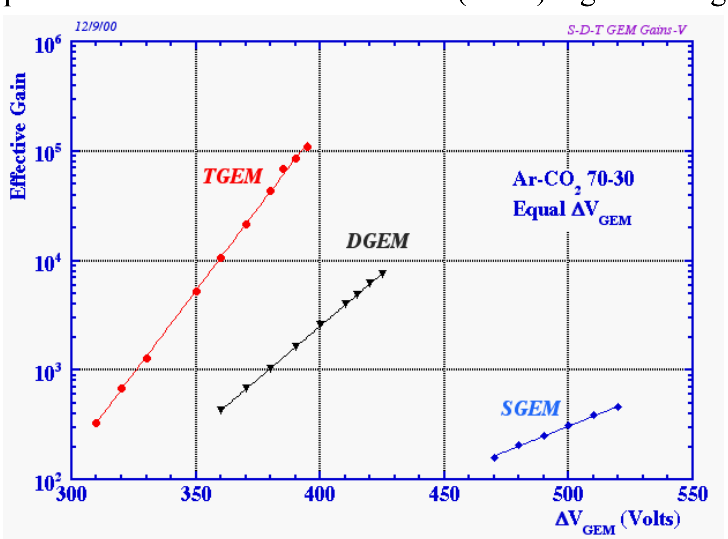
- $V_2' = I_L R_G$
- $V_2 = \frac{R_2}{R_T} V_T$ and $V_2' = \frac{R'_2}{R'_T} V_T'$
- $\Delta V_2 = V_2 - V_2' = \left(\frac{R_2}{R_T} - \frac{R'_2}{R'_T}\right) V_T$
- $R_T = \frac{3R_2^2 + 5R_2R_G}{R_2 + R_G}$, $R_G = \text{GEM}$

I_L (nA)	5	10	15	20	25	50	75	100	200	500	1μA
ΔV_2 (V)	7.5	15	22.5	30	37.5	75	112.5	150	300	750	1500

Figure 5. Coordinates table (Above) for the graph of leakage current per potential difference change (Below).



Once this linear relationship was found, the next step was to find the correlation between leakage current and the gain of electrons using the given graph of effective gain vs. potential difference for the DGEM (black) logarithmic graph.

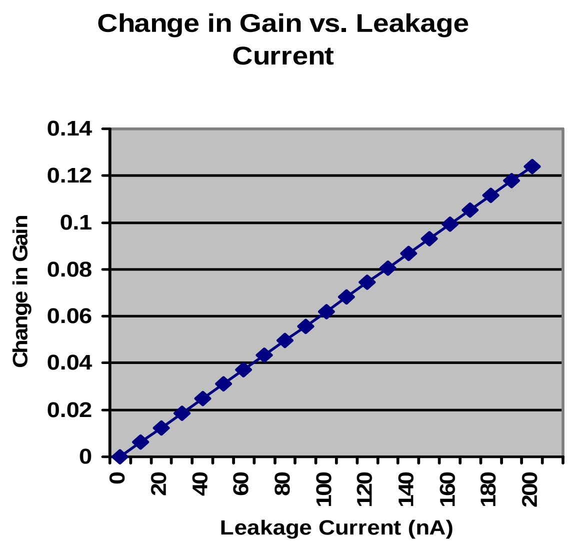


G	ΔV(V)
360	400
370	700
380	1000
390	1750
400	2750
410	4000
415	5000
420	6000
425	7000

Figure 6. Graph showing the effective gain relative to the potential difference loss, [2].

Using this information, a correlation between leakage current and the effective gain can be obtained directly. Assume the above graph is of the form $\text{Ln}(G_{EFF})=A(\Delta V)+B$ where A and B are constants to be found by inserting a few of the coordinates above for G_{EFF} and ΔV. Once an equation is found for G_{EFF}, the derivative can be taken to find

ΔG_{EFF} as a function of G_{EFF} and ΔV. The resulting equation is $\frac{\Delta G_{EFF}}{G_{EFF}} = 6.2 \times 10^{-4} I_L$, with I_L measured in nA.



I_{LEAK}	$\triangle G$
25nA	41.8
50nA	83.7
75nA	125.5
100nA	167.4
125nA	209.2
150nA	251.0
175nA	292.9
200nA	334.7
225nA	376.6
250nA	418.4
275nA	460.2
300nA	502.1

Figure 7. Final graph of the change in gain as a function of the leakage current.

4. Results

Reviewing the experimented leakage current between the twelve independent strips of the three types of foils, we see that copper plated is the best performing. The copper plated, organic coated and gold plated foils all seemed to stabilize in amount of leakage current in different time intervals, measured in seconds. In the copper plated foils, the average leakage current after settling down around 180 seconds is 4.5nA. The organic coated took longer, roughly 300 seconds, and stabilized at a much higher leakage current of 7.45nA. With even higher current lost, ranks the gold plated foils at only 120 seconds with a whopping 10.5nA. This comparison shows the reasoning behind working with only copper plated foils in the future.

Focusing on the copper plated foils, we can compare theoretical and experimental loss of gain. The current setup of the high voltage testing is applying 400V in parallel to the strips. This causes the total amount of leakage current affecting the gain to be the ratio of total voltage applied across the GEM to the total resistance of the GEM. This works out so that the average leakage current is the amount affecting the gain. With an average measured value of 4.5nA of leakage current, then the loss of gain is a mere 0.279%! If the high voltage system was set up in series, then not only would the failure of one strip affect the current traveling to the other strips, but would cause the sum of individual strip leakage current to collectively affect the amount of gain. This loss would be much higher.

5. Conclusions

The formula derived expressing the impact of gain as a function of leakage current provides a starting point from which to improve. The high voltage system should continue to be setup in parallel to keep minimizing the amount of leakage current. In order to keep the amount of leakage current low, the total voltage applied to the whole GEM should be as high as possible with maximum resistance of the GEM.

6. Bibliography

1. **Study of the GEM foil leakage current** by A. Nozawa
2. **Digital HCAL using GEM** by J. Yu