Study of the GEM Foil Leakage Current

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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. In this study, leakage current of GEM foil is examined. Tests were performed on 30cm x 30cm 3M GEM foils by observing leakage current with respect to time under 400V potential difference. Other than normal GEM foils, a GEM foil coated with organic materials and Gold-coated GEM foils were tested. As a result, normal GEM foils showed lower leakage current compare to GEM foils with coatings.

1. Introduction

GEM foil is one of the core components in Hadronic Calorimeters (DHCal) using GEM. GEM amplifies input signals as following by following mechanisms. Double GEM chamber consists of anode and cathode located on both ends and two GEM foils sandwiched by the electrodes. In side of the camber is filled with mixture of argon and carbon dioxide. GEM foil is made of thin insulating sheet coated by copper layer on both side. GEM foil has tiny penetrating holes. As high voltage is applied between the copper layers, strong electric field is created around the holes. The input signal, negatively charged particle or electron, is accelerated by the electric field. This causes ionization of gas molecules and generates additional electrons. By reputation of this process, GEM can amplify the input dramatically.

Three kinds of 30 cm x 30cm GEM foils are provided from 3M. Normal GEM foil (just called 3M GEM foil), GEM foil with organic coating (GEM foil with coating), and GEM foil with gold coating (Gold-coated GEM foil).

The gain of the GEM is affected by the potential difference between the copper layers of the GEM foils, because strength of the electronic field is function of the potential difference. This potential difference is created by resistor-based voltage divider. Therefore, the leakage current changes the potential difference between the copper layers. In order to obtain predictable and stable gain, the study of leakage current is essential.

2. Certification Procedure for 3M GEM Foils

a. Strips Nomenclature

All 3M GEM foil, GEM foil with coating, and Gold-coated GEM foil have the same physical configuration. One side of the foil is divided into 12 strips and they are electrically insulated each other. The strips of GEM foil are named as shown in Figure

2.1. Ground Terminal (Strip 0) is located on the back side of the foil and there is no separation on the ground side.

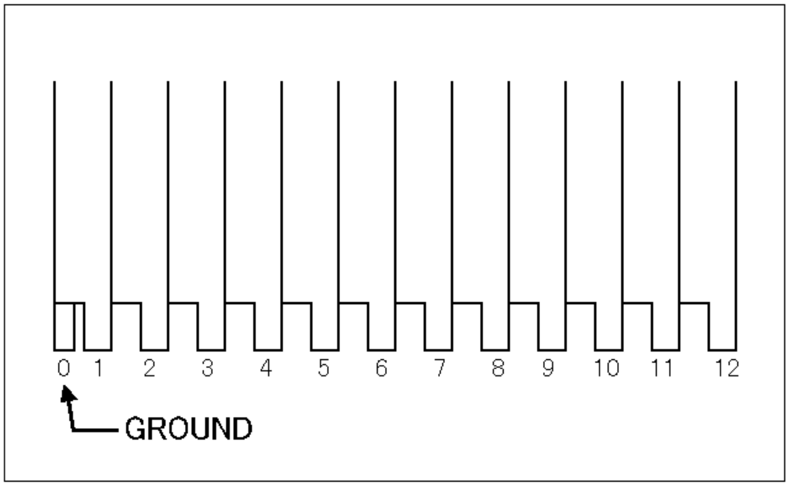

Figure 2.1 Strip nomenclature of 3M 30cm x 30cm GEM foil.

b. Experimental Program

1. Before the measurement, put on the basic information such as date, temperature, humidity, and ID number of GEM foil on the short term HV certification data sheet.
2. Connect one probe from High Voltage Source to the Ground terminal with a toothless alligator clip. NEVER pull the clip off of the foil.
3. Connect the other probe to strip #1. After each measurement, move this probe to strip 2, strip3, and so on.
4. Before turning on the power supply, make sure voltage setting is at 0V, and circuit tripper is in “HOLD TRIP” position. Be sure to check the current reading before the turn-on.
5. Turn on the power supply and write down the current reading. If the current reading is non-zero, turn off the power supply and unclip the toothless alligator clips and short them for 10 seconds. Clip back on the alligator clips and turn on the HV power supply. Be sure to take the current reading again.
6. Increase the voltage gradually up to 400V, keeping the current below the 80% of the maximum reading. If the strip takes excessively long time (more than 40 seconds) to bring up to 400 V, mark the strip as “long settling time” and proceed to the next step.
7. If power supply trips, turn off the power supply, set the voltage back to 0V, then reset the circuit breaker. If it still trips after three trials, mark X on the data sheet.
8. When the voltage reaches 400V, start the clock. Then measure the current and put down the measured values on the data sheet.
9. If the current is still high (higher than 10 nA) after 120 seconds, take extra data in 2 minutes intervals until the current settles down to a moderate value.

3. Results and Discussion

Table 3.1 Leakage current of 3M GEM #00 (Time in second, current in nA)

	0	15	30	45	60	90	120	150	180	210	240	270	300
1	20	13	11	10	10	9	8	7	5	7	6	6	6
2	23	11	9	8	7	6	5	5	5	5	5	4	4
3	23	8	7	6	6	5	5	4	5	4	4	4	4
4	17	10	8	7	6	6	5	5	4	4	4	4	4
5	19	13	11	9	8	7	6	5	6	5	5	5	4
6	15	9	8	7	6	6	4	4	4	4	4	3	4
7	17	9	8	7	7	5	5	4	5	4	4	4	4
8	X												
9	20	13	10	9	8	6	5	5	5	4	4	3	3
10	19	13	9	8	6	5	5	4	4	4	4	4	4
11	19	11	9	9	7	6	4	4	3	4	3	3	3
12	25	11	9	7	6	5	5	5	5	4	4	3	3

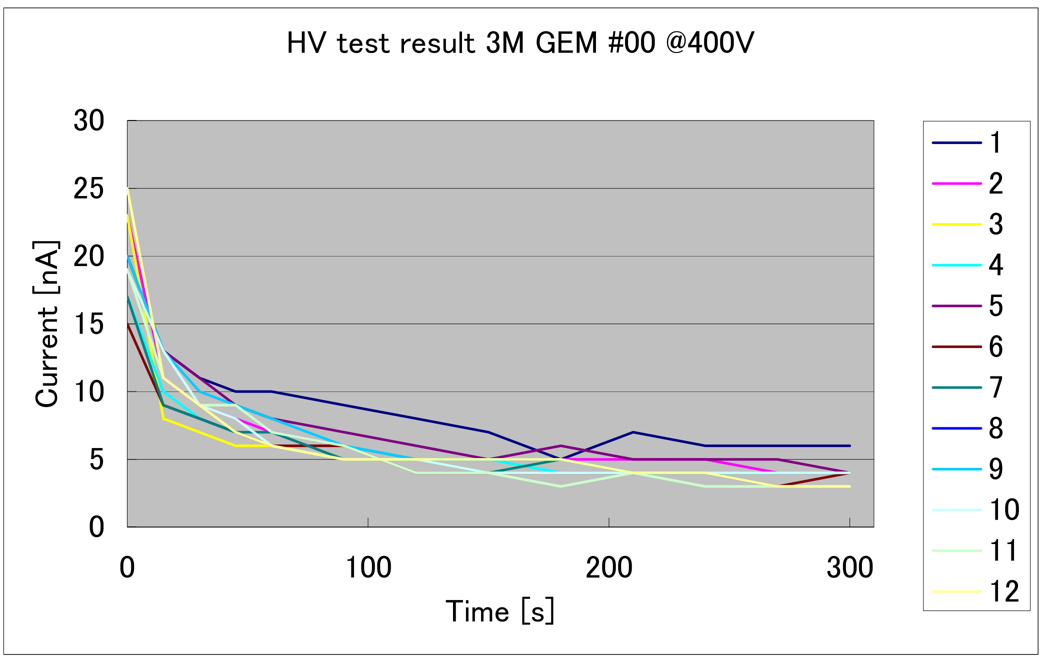

Figure 3.2 Leakage current of 3M GEM #00

Table 3.3 Leakage current of 3M GEM #01 (Time in second, current in nA)

	0	15	30	45	60	90	120	150	180	5 min
1	16	12	10	9	9	8	8	8	8	5
2	10	6	5	5	4	4	3	3	3	3
3	13	9	8	7	7	5	6	5	6	6
4	10	6	5	4	4	4	3	4	4	
5	9	7	6	5	5	4	4	4	4	
6	15	7	6	5	4	3	4	3	3	
7	13	8	6	5	5	4	4	4	3	
8	15	8	6	6	5	4	5	4	4	
9	15	7	6	6	5	5	4	4	4	
10	17	8	7	7	6	6	5	6	5	
11	11	7	6	6	5	5	5	4	5	5
12	15	8	7	6	5	5	5	5	5	

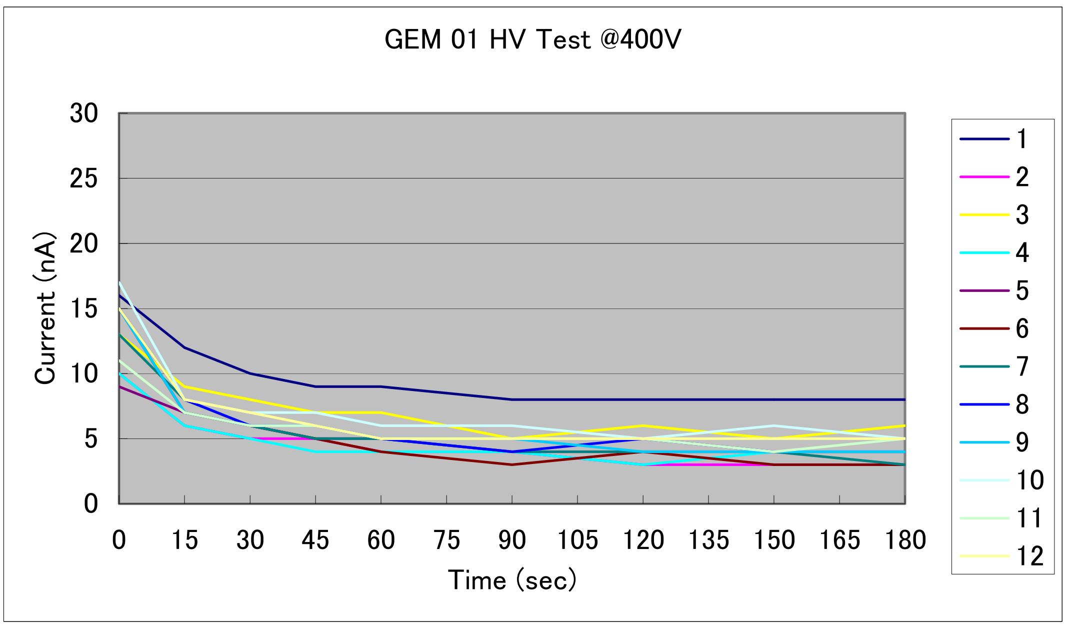

Figure 3.2 Leakage current of 3M GEM #01

Table 3.5 Leakage current of 3M GEM #02 (Time in second, current in nA)

	0	15	30	45	60	90	120	150	180	
1	15	11	10	10	11	11	11	10	9	9
2	17	7	6	6	6	5	5	4	5	
3	14	7	7	6	5	5	5	5	5	
4	15	8	7	6	6	6	5	5	6	
5	11	7	5	5	5	4	4	4	4	
6	15	7	6	5	5	5	5	5	4	
7	13	7	5	5	5	5	5	4	4	
8	17	9	6	5	5	5	4	4	4	
9	16	7	5	5	5	5	4	4	4	
10	15	7	5	5	5	5	5	4	4	
11	19	7	6	5	5	5	5	5	5	
12	45	30	26	23	21	19	17	16	13	10

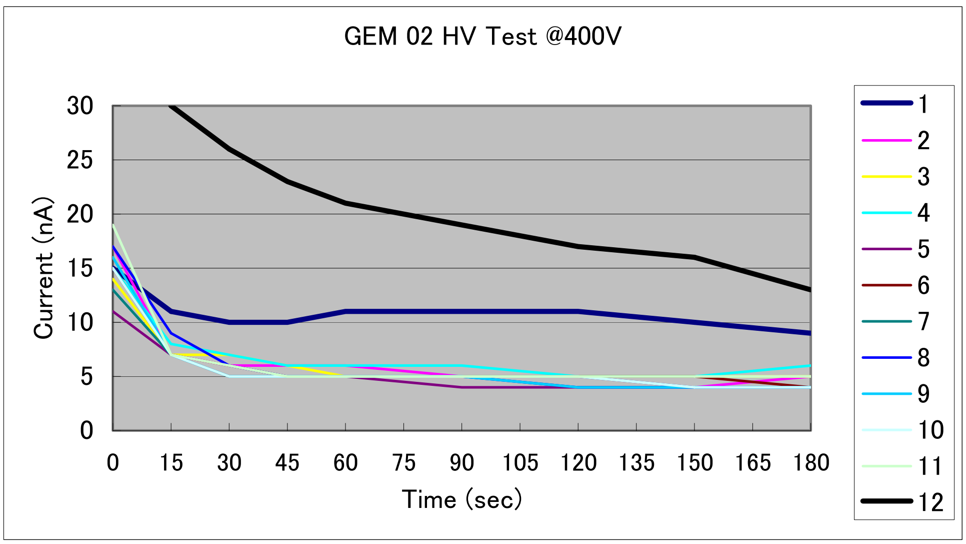

Figure 3.6 Leakage current of 3M GEM #02

Table 3.7 Leakage current of 3M GEM #03 (Time in second, current in nA)

	0sec	15	30	45	60	90	120	150	180	5min
1	15	8	6	6	6	5	5	5	5	
2	14	6	5	5	5	5	5	4	4	
3	13	6	5	5	4	4	4	4	4	
4	13	8	6	6	6	5	5	5	5	
5	15	7	6	5	5	5	5	4	4	
6	12	7	6	5	5	5	5	4	4	
7	25	11	9	8	8	7	6	5	6	
8	13	7	6	5	5	5	5	5	4	
9	25	13	12	15	13	9	9	7	5	5
10	14	7	6	5	5	5	5	5	4	
11	14	9	6	5	5	5	5	5	5	
12	17	7	6	5	5	5	5	5	5	

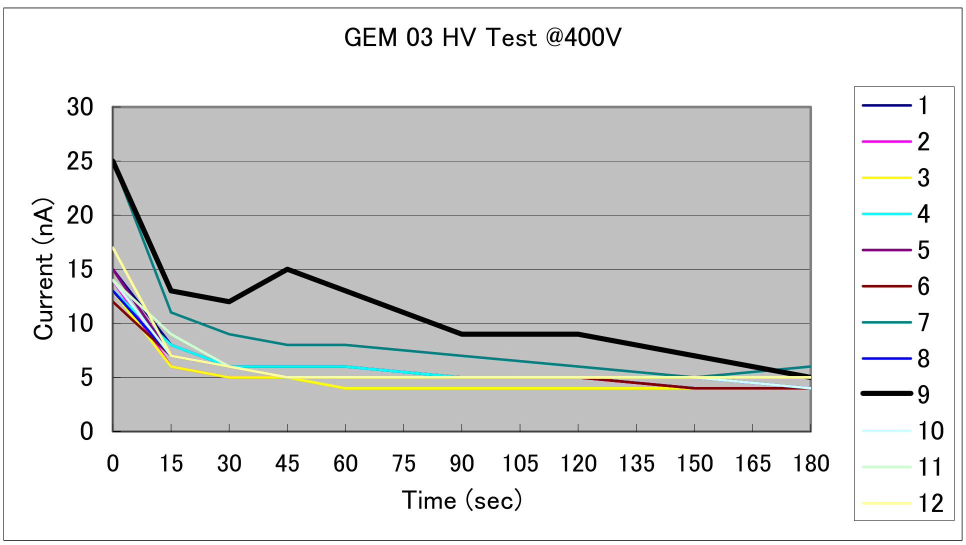

Figure 3.8 Leakage current of 3M GEM #03

Table 3.9 Leakage current of 3M GEM #04 (Time in second, current in nA)

	0sec	15	30	45	60	90	120	150	180	5min	10min
1	45	27	23	27	16	17	12	11	13	9	7
2	17	8	7	6	6	5	5	5	5		
3	15	6	6	5	5	5	5	5	5		
4	15	8	7	7	6	5	5	5	5		
5	13	7	6	5	5	5	5	5	5		
6	13	7	6	6	5	5	5	5	5		
7	12	7	5	5	5	5	5	5	5		
8	13	7	6	6	5	5	5	5	5		
9	13	7	7	5	5	5	5	5	5		
10	15	7	6	5	5	5	5	5	5		
11	13	7	6	5	5	5	5	5	5		
12	12	8	6	6	5	6	5	5	5		

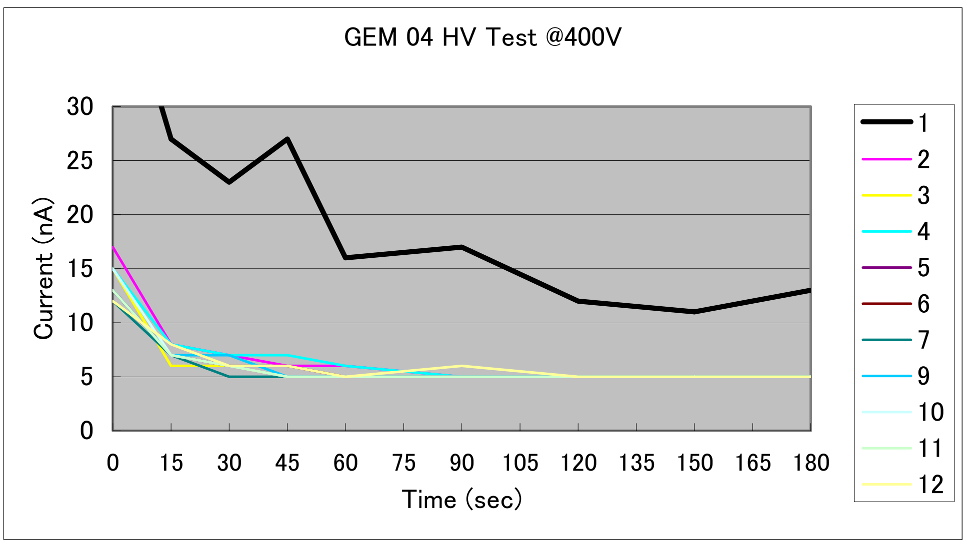

Figure 3.10 Leakage current of 3M GEM #04

Table 3.11 Leakage current of 3M GEM #05 (Time in second, current in nA)

	0sec	15	30	45	60	90	120	150	180	5min	10min
1	13	9	8	8	6	7	7	6	6		
2	12	10	7	7	7	7	5	5	5		
3	15	8	7	7	6	5	5	5	5		
4	14	8	7	6	6	5	5	x			
5	15	9	8	7	7	7	6	6	6		
6	16	10	9	8	8	7	7	7	7		
7	15	9	8	8	7	7	7	7	7		
8	20	11	10	8	8	7	7	7	7		
9	20	12	13	11	11	11	11	10	9	7	6
10	15	8	7	7	7	6	6	6	6		
11	14	8	7	7	7	7	6	6	6		
12	16	9	8	7	7	7	7	6	7		

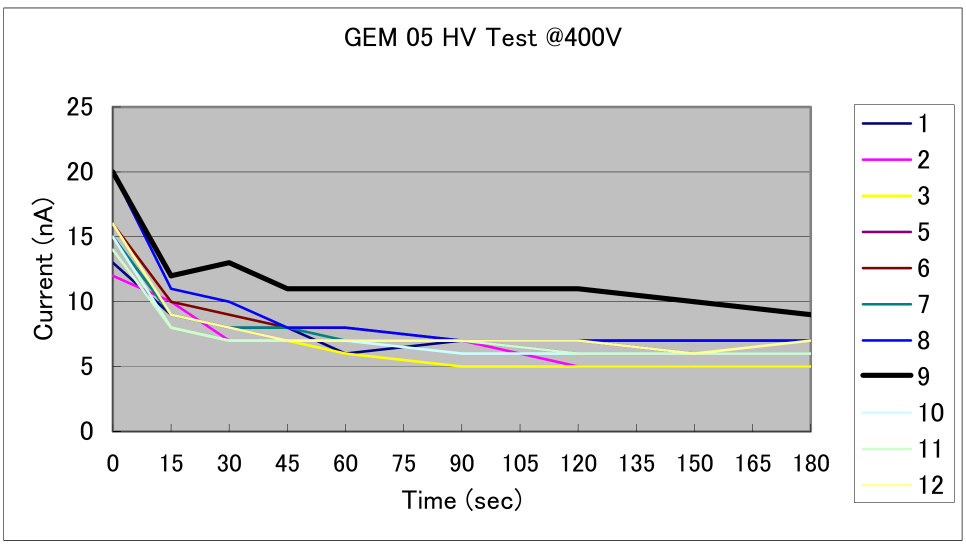

Figure 3.12 Leakage current of 3M GEM #06

Table 3.13 Leakage current of 3M GEM #06 (Time in second, current in nA)

	0sec	15	30	45	60	90	120	Note
1	10	5	4	4	4	4	3	
2	15	6	4	4	3	4	3	
3	10	6	4	4	4	3	3	
4	10	6	4	3	3	3	3	
5	12	6	5	4	3	4	3	
6	20	4	4	4	4	4	4	
7	12	5	3	3	2	3	3	
8	25	6	5	4	4	4	3	
9	12	5	4	4	3	3	3	
10	8	4	3	3	2	2	2	
11	10	6	4	3	3	3	3	
12	8	6	4	4	3	3	3	

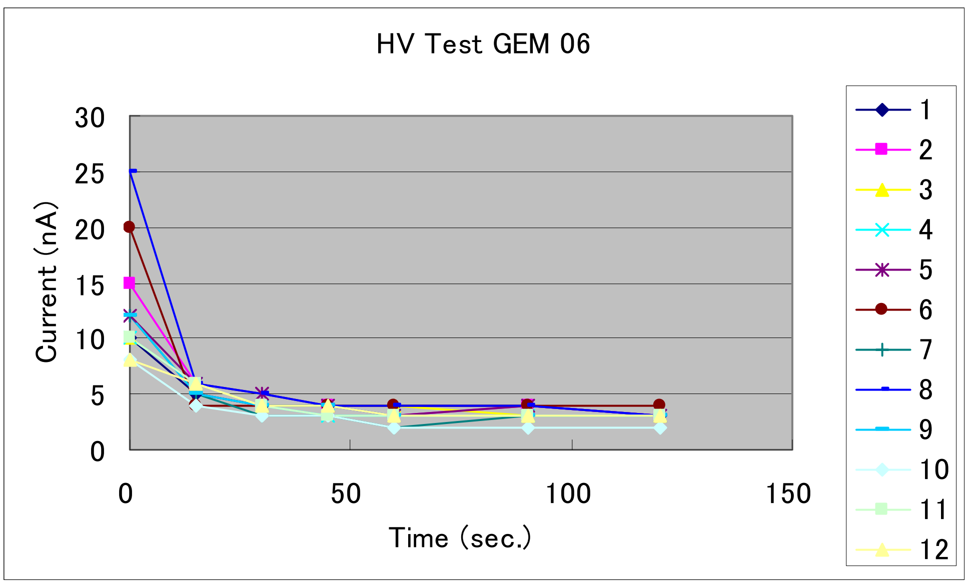

Figure 3.14 Leakage current of 3M GEM #06

Table 3.15 Leakage current of 3M GEM #07 (Time in second, current in nA)

	0sec	15	30	45	60	90	120	Note
1	18	6	5	4	4	3	3	
2	13	5	4	3	4	3	3	
3	15	4	3	3	3	3	3	
4	18	4	3	3	3	2	2	
5	22	3	2	2	2	2	2	
6	22	4	3	3	2	2	2	
7	10	3	3	2	2	2	2	
8	22	5	3	2	2	2	2	
9	8	3	2	2	2	2	2	
10	10	3	2	2	2	2	2	
11	8	3	2	2	2	2	2	
12	8	4	3	3	3	2	2	

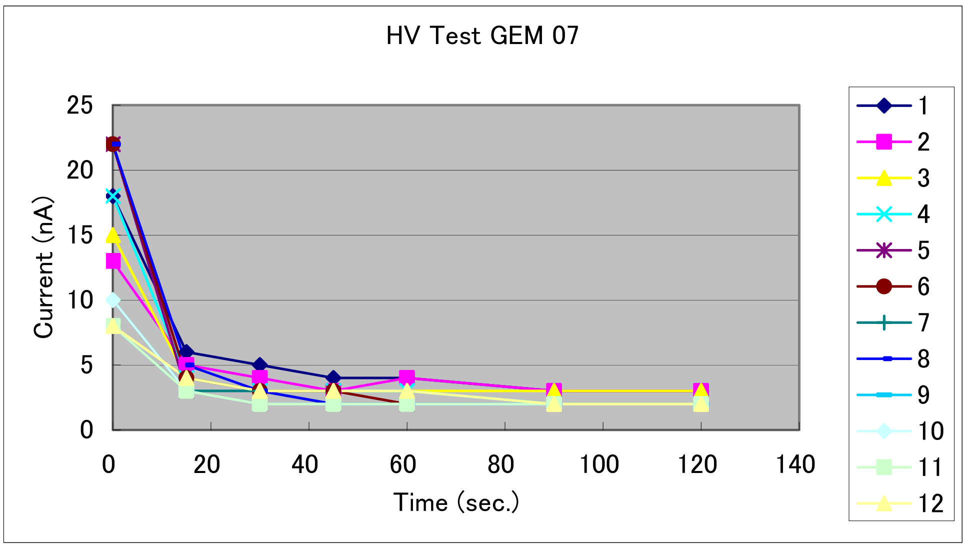

Figure 3.16 Leakage current of 3M GEM #07

Table 3.17 Leakage current of 3M GEM #A (Time in second, current in nA)

Range	R (Ω)		0	15	30	45	60	90	120	NOTE
0.1 μA	inf.	1	40	30	25	22	21	18	18	
1 μA	inf.	2	60	60	60	60	70	100	90	
	36.1	3								
1 μA	inf.	4	40	40						
1mA	inf.	5								The current exeeded 1mA (full scale) at around 30V.
1 μA	inf.	6	40	30	30	30	20	30	30	
1mA	inf.	7								The current exeeded 1mA (full scale) at around 60V.
1 μA	inf.	8	140	90	90	80	80	60	60	
1 μA	inf.	9	140	80	80	60	60	120	100	
1mA	inf.	10								The current exeeded 1mA while increasing the Voltage.
1mA	inf.	11								The current exeeded 1mA (full scale) at around 20V.
0.1 μA	inf.	12	75	52	41	40	38	36	36	

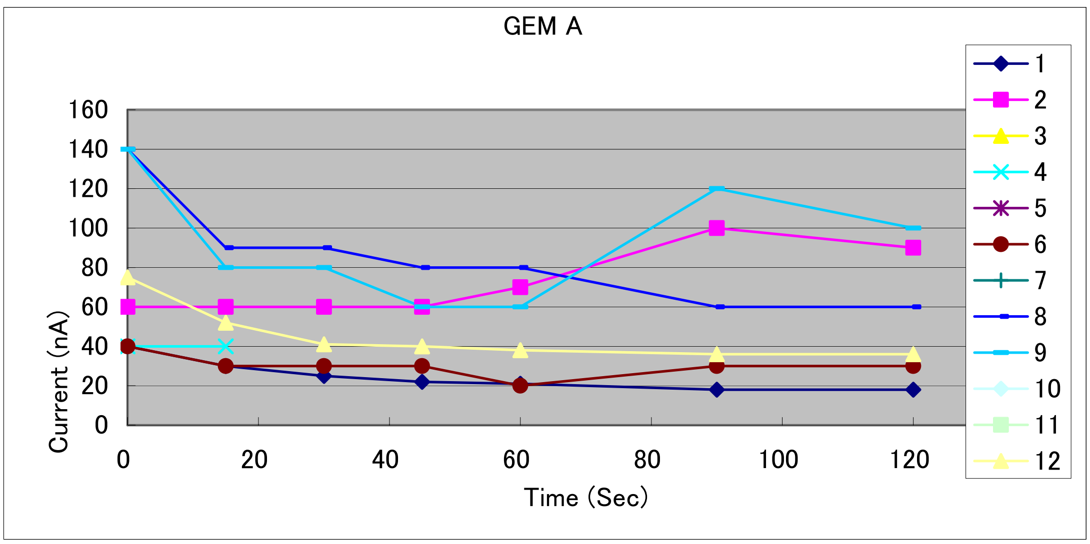

Figure 3.18 Leakage current of 3M GEM #A

Table 3.19 Leakage current of 3M GEM #B (Time in second, current in nA)

	0sec	15	30	45	60	90	120	Note
1	18	15	14	14	14	12	12	tripped off with sound @ 6s
2	16	10	9	8	8	8	8	
3	14	9	8	8	7	7	8	
4	24	16	14	12	12	9	8	
5	24	16	14	12	12	9	8	tripped off with sound @ 6s
6	40	25	19	16	14	12	12	
7	42	25	20	17	15	13	12	
8								R = 0.078 Ohm
9	18	13	12	12	12	11	11	
10	20	10	8	8	8	7	6	
11	32	22	22	22	22	22	22	
12	30	22	20	20	19	19	19	

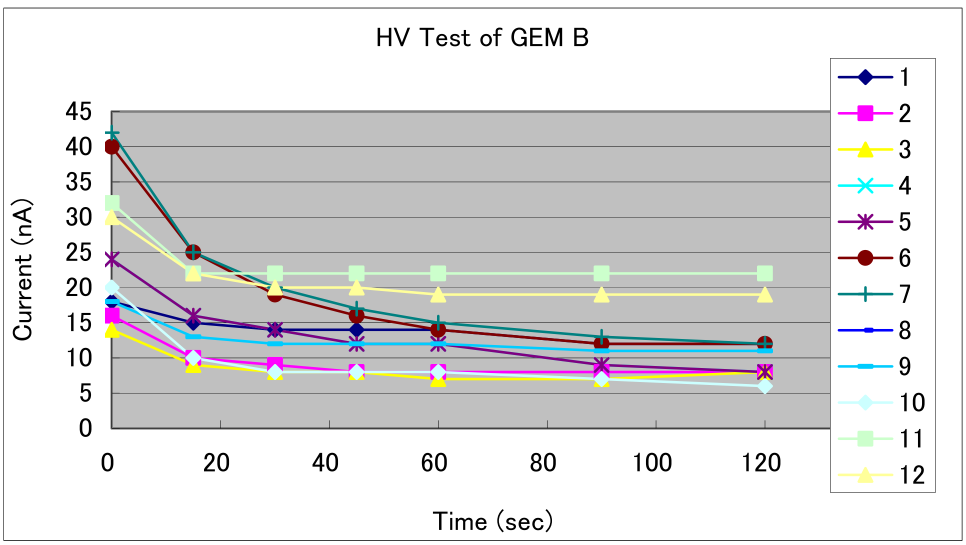

Figure 3.20 Leakage current of 3M GEM #B

Table 3.21 Leakage current of GEM with organic coating

	0	15	30	45	60	90	120	150	180	210	240	270	300
1	42	20	16	14	12	11	10	10	10	8	9	8	8
2	17	11	10	9	8	8	8	8	6	6	6	6	6
3	x												
4	15	10	9	8	7	6	5	5	5	5	5	5	4
5	14	10	8	7	6	6	5	5	5	6	5	6	6
6	20	10	9	7	6	6	5	5	5	5	5	5	5
7	20	13	10	9	9	10	6	6	6	6	6	6	6
8	42	26	22	18	17	19	18	14	11	9	10	9	9
9	40	25	24	21	21	18	14	14	14	13	13	12	11
10	47	34	26	23	22	19	19	17	15	13	12	12	11
11	32	18	16	14	12	12	10	10	10	10	10	9	9
12	32	17	14	12	11	9	9	8	9	8	7	7	7

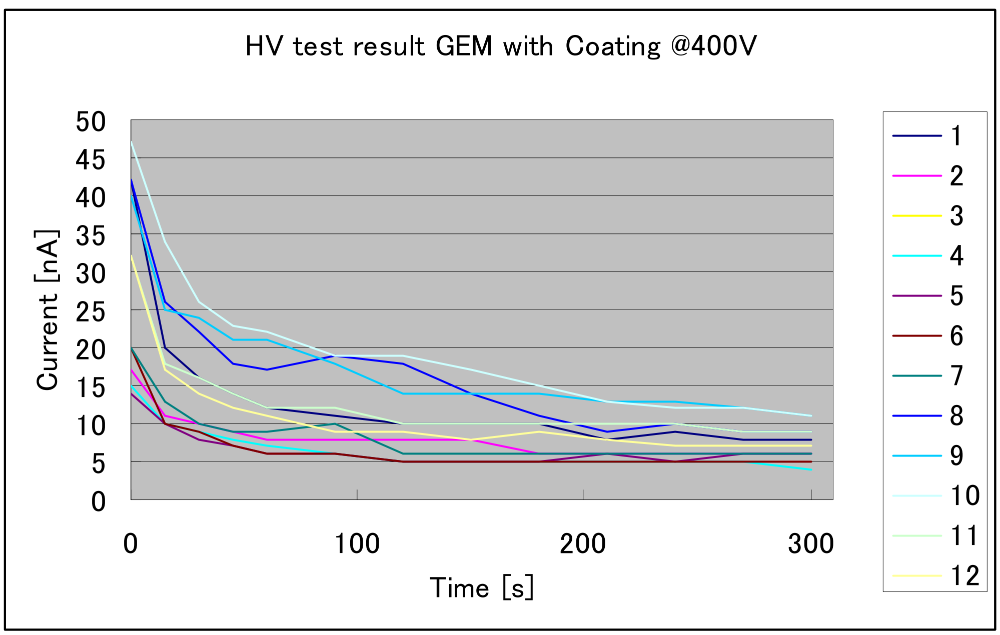

Figure 3.22 Leakage current of GEM with coating

Table 3.23 Leakage current of Gold-coated GEM #Au18
(Time in second, current in nA)

	0sec	15	30	45	60	90	120	Note
1	35	30	28	30	29	28	28	
2	34	12	8	8	8	8	8	
3	10	6	5	6	6	6	6	
4	22	12	10	8	8	20	14	Current is not stable
5	18	9	8	8	8	7	7	
6	10	6	5	6	6	5	5	
7	10	6	6	6	5	5	5	
8	25	6	5	5	5	5	6	
9	12	7	7	7	7	6	5	
10	14	8	7	7	6	6	6	
11	12	8	7	7	6	6	6	
12	45	37	35	34	33	32	30	

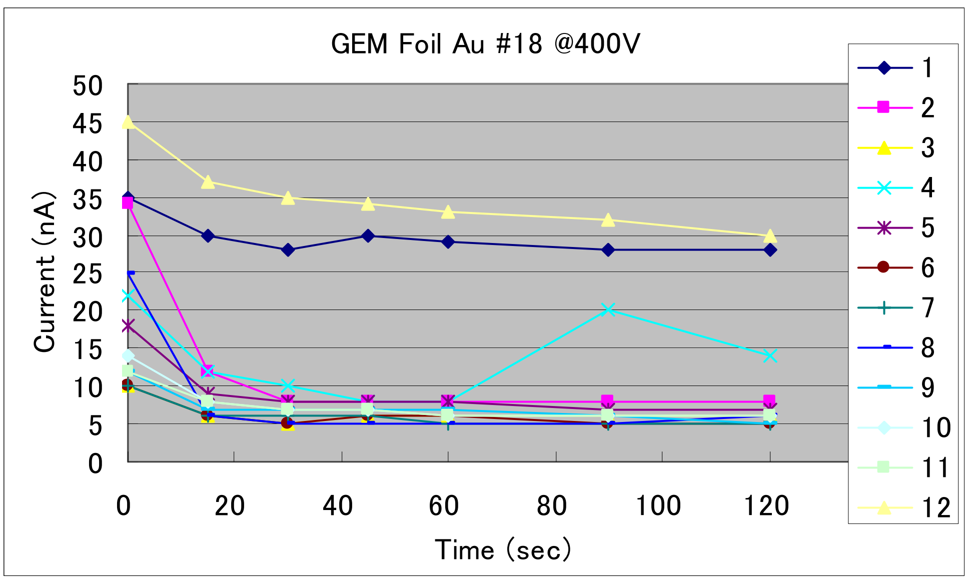

Figure 3.24 Leakage current of Gold-coated GEM #Au18

Table 3.25 Leakage current of Gold-coated GEM #Au32
(Time in second, current in nA)

	0sec	15	30	45	60	90	120	Note
1	250	290	280	280	280	270	270	
2	250	310	340	480	360	220	150	
3	20	15	25	15	13	13	12	
4	40	12	12	12	10	10	10	
5	70	30	24	20	20	20	18	
6	25	20	20	18	16	18	15	
7	22	18	17	16	16	17	16	
8	15	10	10	10	10	10	10	
9	35	X						
10	15	12	10	10	10	10	10	
11	28	28	28	27	25	23	22	
12	400	460	320	250	200	150	120	

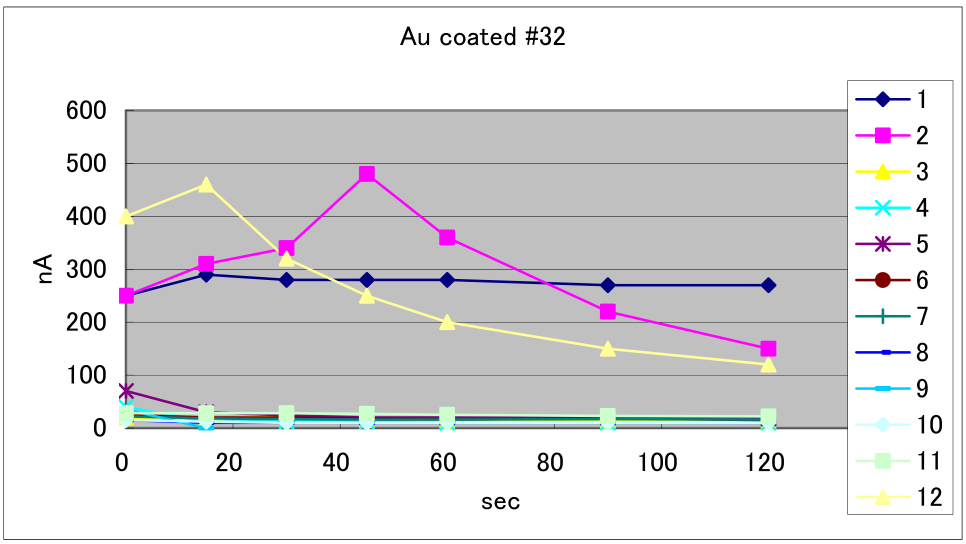

Figure 3.26 Leakage current of Gold-coated GEM #Au32

Table 3.27 Leakage current of Gold-coated GEM #Au34
(Time in second, current in nA)

	0sec	15	30	45	60	90	120	Note
1	X							1uA range; spark discharging
2	80	60	80	110	120	90	60	1uA range
3	90	80	100	80	90	70	60	1uA range
4	100	50	40	40	40	40	40	1uA range
5	40	40	30	30	30	30	30	1uA range
6	30	25	25	24	30	21	22	0.1uA range
7	60	40	23	18	17	24	23	0.1uA range
8	100	70	40	40	40	30	30	1uA range
9	600	350	220	170	130	100	70	1uA range
10	90	40	10	10	10	10	10	1uA range
11	180	210	80	70	70	40	10	1uA range
12	X							100uA range; current exceeded 25uA

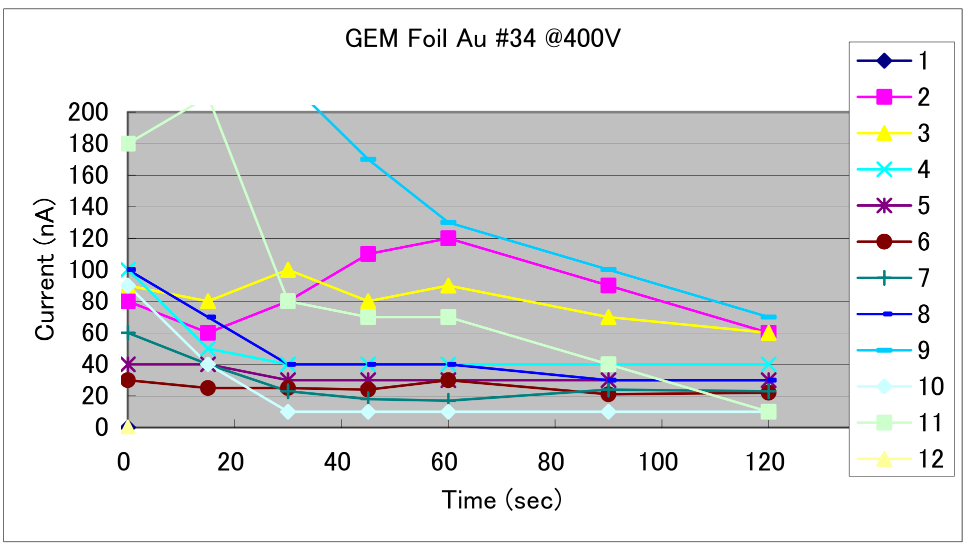

Figure 3.28 Leakage current of Gold-coated GEM #Au34

Table 3.29 Leakage current of Gold-coated GEM #Au36
(Time in second, current in nA)

	0sec	15	30	45	60	90	120	Note
1	40	32	30	30	29	27	26	
2	15	12	11	11	10	10	10	
3	14	11	10	10	10	10	10	Spark once
4	22	14	12	10	11	10	10	
5	60	32	25	22	20	17	17	
6	20	10	10	10	10	10	10	
7	18	12	11	11	11	10	10	
8	17	12	12	12	11	11	11	
9	20	12	12	12	11	11	11	
10	16	12	10	10	10	10	10	
11	15	12	13	11	10	10	10	
12	25	15	15	16	16	15	15	

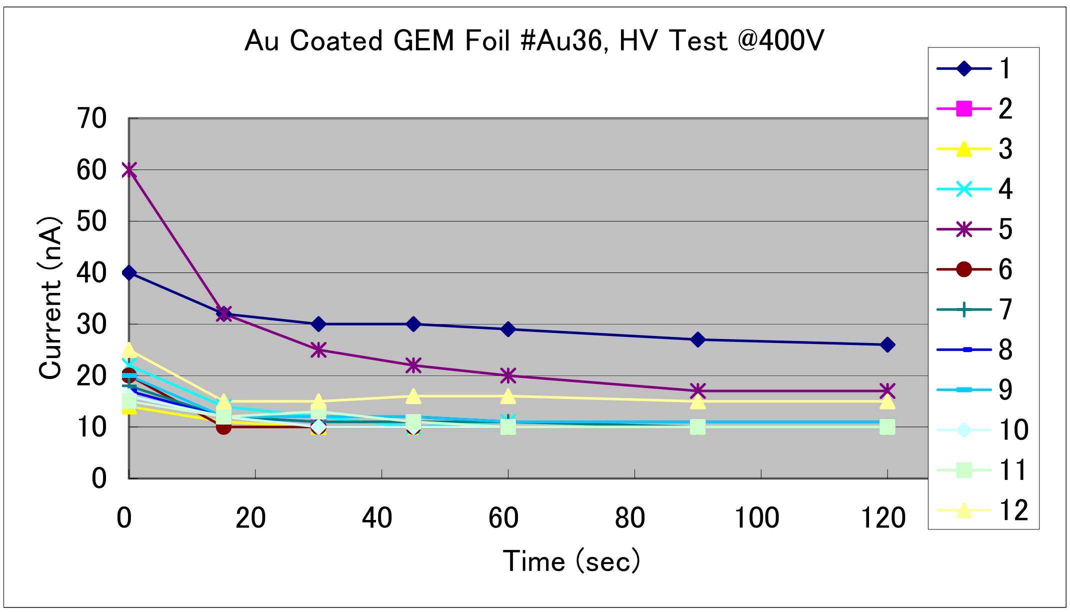

Figure 3.24 Leakage current of Gold-coated GEM #Au36

The summary of the result is shown in Table 3.25. In the table, the result is shown in terms of pass or fail. Data were analyzed based on two different criteria, which is leakage current of less than 10nA and less than 15nA per strip. Analysis was also done in terms of strip basis and foil basis. If all 12 strips were passed, the foil was considered as passed foil.

Table 3.25 Summary of high voltage test

GEM ID	Pass Criterion: I≦10nA			Pass Criterion: I≦15nA		
	HV TEST	Number of Strips		HV TEST	Number of Strips	
		PASS	FAIL		PASS	FAIL
GEM # 00	FAIL	11	1	FAIL	11	1
GEM # 01	PASS	12	0	PASS	12	0
GEM # 02	FAIL	11	1	PASS	12	0
GEM # 03	PASS	12	0	PASS	12	0
GEM # 04	FAIL	11	1	PASS	12	0
GEM # 05	FAIL	11	1	FAIL	11	1
GEM # 06	PASS	12	0	PASS	12	0
GEM # 07	PASS	12	0	PASS	12	0
GEM # A	FAIL	0	12	FAIL	0	12
GEM # B	FAIL	5	7	FAIL	9	3
GEM Organic Courting	FAIL	8	4	FAIL	11	1
GEM # Au18	FAIL	9	3	FAIL	10	2
GEM #Au 32	FAIL	0	12	FAIL	5	7
GEM #Au 34	FAIL	2	10	FAIL	2	10
GEM #Au 36	FAIL	7	5	FAIL	10	2
Total	4	123	57	6	141	39

The leakage current in Gold-courted GEM foils is higher compare to one without coating. Pass rate of Gold-coated GEM is very low, as shown in Table 3.26 and Table 3.27. During the measurement, unstable leakage current variations were observed. This is not appeared in measurement data, because the leakage current was recorded in relatively rough interval of 15 seconds. Small vibration of the needle of amperemeter was observed during this measurement. This phenomenon was not seen during the testing of normal GEM foils.

Table 3.26 High Voltage test result of Gold-coated GEM foils

GEM ID	Pass Criterion: I≦10nA			Pass Criterion: I≦15nA		
	HV TEST	Number of Strips		HV TEST	Number of Strips	
		PASS	FAIL		PASS	FAIL
GEM # Au18	FAIL	9	3	FAIL	10	2
GEM #Au 32	FAIL	0	12	FAIL	5	7
GEM #Au 34	FAIL	2	10	FAIL	2	10
GEM #Au 36	FAIL	7	5	FAIL	10	2
Total	0 Passed	18	30	0 Passed	27	21
Probability	0%	38%	63%	0%	56%	44%

Table 3.27 High Voltage test result of Normal GEM foils

GEM ID	Pass Criterion: I≦10nA			Pass Criterion: I≦15nA		
	HV TEST	Number of Strips		HV TEST	Number of Strips	
		PASS	FAIL		PASS	FAIL
GEM # 00	FAIL	11	1	FAIL	11	1
GEM # 01	PASS	12	0	PASS	12	0
GEM # 02	FAIL	11	1	PASS	12	0
GEM # 03	PASS	12	0	PASS	12	0
GEM # 04	FAIL	11	1	PASS	12	0
GEM # 05	FAIL	11	1	FAIL	11	1
GEM # 06	PASS	12	0	PASS	12	0
GEM # 07	PASS	12	0	PASS	12	0
GEM # A	FAIL	0	12	FAIL	0	12
GEM # B	FAIL	5	7	FAIL	9	3
Total	4 Passed	97	23	6 Passed	103	17
Probability	40%	81%	19%	60%	86%	14%

4. Conclusions

Different amount of leakage current was observed in Normal GEM foils, Gold-coated GEM foils, and a GEM foil with organic coating. The result is summarized in Table 4.1.

Table 4.1 High voltage test summary

Types of GEM Foil	Number of Sample	Pass Criterion: I≦10nA				Pass Criterion: I≦15nA			
		Foil Basis		Strip Basis		Foil Basis		Strip Basis	
		PASS	FAIL	PASS	FAIL	PASS	FAIL	PASS	FAIL
Normal	10	4 (40%)	6	97 (81%)	23	6 (60%)	4	103 (86%)	17
Organic Coating	1	0 (0%)	1	8 (67%)	4	0 (0%)	1	11 (92%)	1
Gold Coating	4	0 (0%)	4	18 (38%)	30	0 (0%)	4	27 (56%)	21

By the results, it can be concluded that Normal GEM foils are superior to GEM foils with coatings in terms of the reduction of the leakage current. In this testing, two different pass criteria are set, leakage current of less than 10nA and less than 15nA per strip. For both criteria, more than 80% of normal GEM foil strips were passes the high voltage test. However, as a whole GEM foil, only 40% or 60 % of GEM foils are passes the test, respectively. Most of failed GEM foils have only one bad strip out of twelve. Therefore, in order to increase the pass rate of GEM foil, much stricter quality management is required.