Development and properties of 100 mm-square size LTCC-GEM

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1-1. Introduction

- **Motivation : on-site non-destructive inspection**
  - Long-term field operation
  - Sealed gas detector
  - Reliable GEM

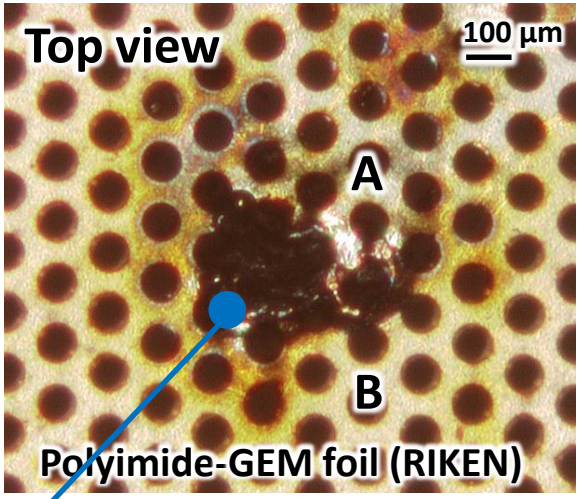
- **Breakdown of GEM due to discharge**

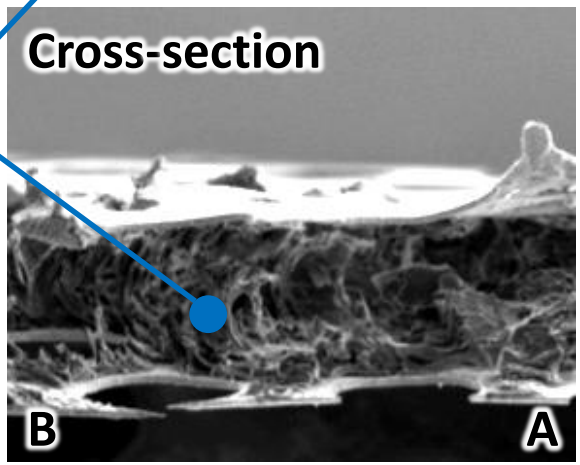
  PI- and LCP-GEM "sometimes" breakdown due to discharge at high gain and never recover.

- **Identify the cause**
  - Analyzed around the burn section with SEM-EDX
  - The insulator layer changed into the porous body and carbonized

- **Purpose of our study**

  Development of a reliable GEM against discharge
  → We select new materials for the insulator.



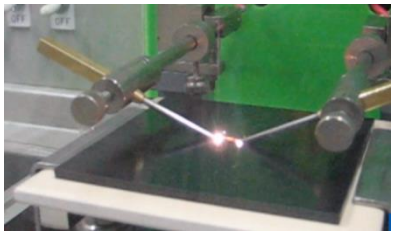


1-2. Candidate of insulator materials

Materials	PI (Polyimide)	LCP (Liquid Crystal Polymer)	Our Study: PTFE (Teflon ™)	Our Study: LTCC (Low Temperature Co-fired Ceramics)
Volume resistivity [Ω・cm]	10^{17}	6×10^{16}	$> 10^{18}$	$> 10^{14}$
Arc resistance [sec]	135	186	> 300	> 300
Melting point [degree C]	800	450	327	> 800
Density [g/cm^3]	1.43	1.35	2.13~2.2	~3
Dielectric Constant	~3.4	~3.5	2.1	~7.5

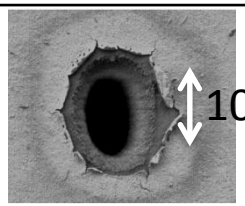
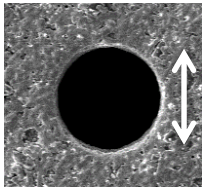
- Carbonization begins when arc-discharge occurs.
- We gave our attention to "arc resistance†".

  † The time period of the material resists the formation of surface-conduction path based on ASTM D 495 standard



- PTFE and LTCC show higher arc-resistance than PI and LCP.

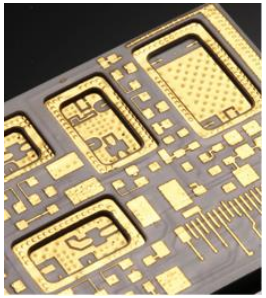
1-3. Prototype of PTFE- and LTCC-GEM

	PTFE-GEM	LTCC-GEM
Test size	20 mm x 20 mm	10 mm x 10 mm
GEM thickness	50 µm	100 µm
Drilling holes	Laser	Punch
Hole shape	 100µm	 100µm
The maximum gain	> 10^4	> 10^4
Number of discharges	> 10^4 No breakdown	> 10^4 No breakdown
reference	3rd MPGD(2013), Tamagawa+	4th MPGD(2015), Komiya+

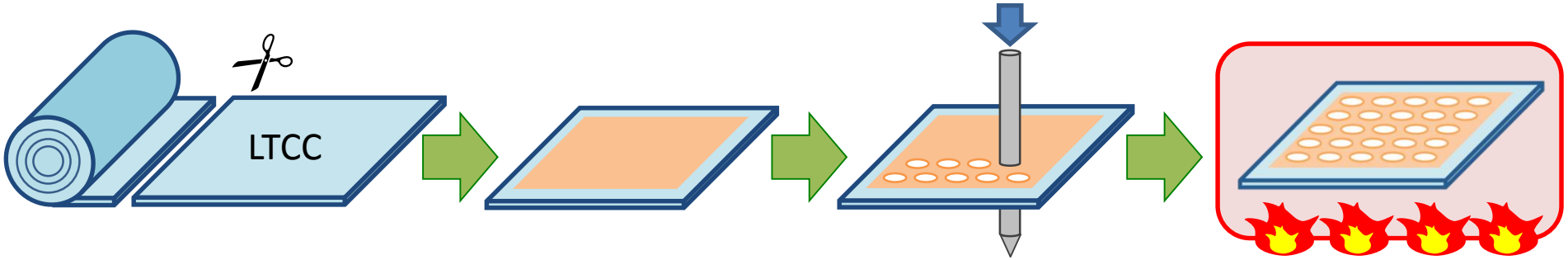
- We succeeded to fabricate both GEMs.
- LTCC-GEM is better hole shape and ease to drill than PTFE-GEM.
- We selected LTCC-GEM to study in detail.

1-4. Fabrication process of LTCC-GEM

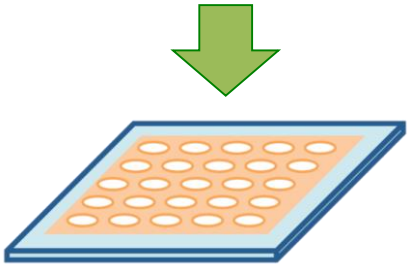
- Manufactured by Hirai Seimitsu Kogyo Corporation, Japan HIRAI
- Used for highly integrated circuits which embed electric parts



Process



1.Cutting Green Sheet 2.Applying Au paste 3.Punching 4.Sintering (<1000℃)



Completed !

Only 4 steps !!

1-5. Advantages of LTCC-GEM

LTCC-GEM (10 mm-sq. size) has 3 great advantages!

✧ Good operation

- High gain : ~10^4 @ΔV_{GEM} = 760 V
- Discharge tolerance : Although >10^4 discharges, No breakdown

✧ Easy to handle

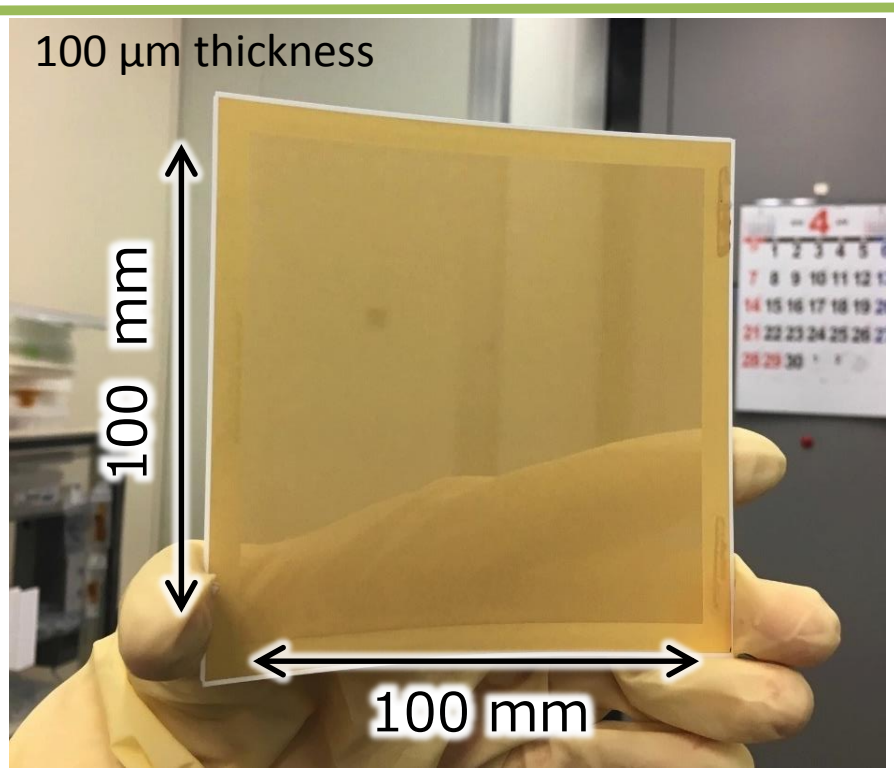
- Rigid structure
- Low outgassing (since LTCC is an inorganic material)

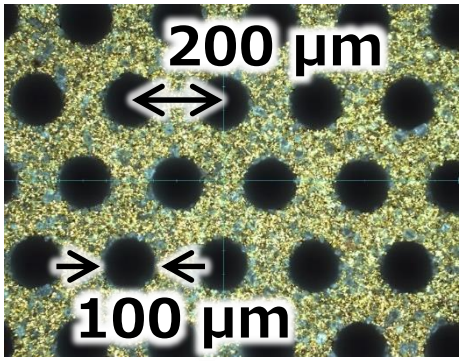
✧ Simplified fabrication process

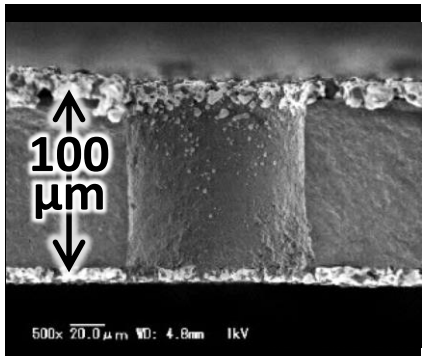
- Cost-effective
- Flexibility of GEM in a desired size and shape (mask less)

In this talk, we report fabricating LTCC-GEM of 100 mm-square size!

2-1. LTCC-GEM of 100 mm-sq. size







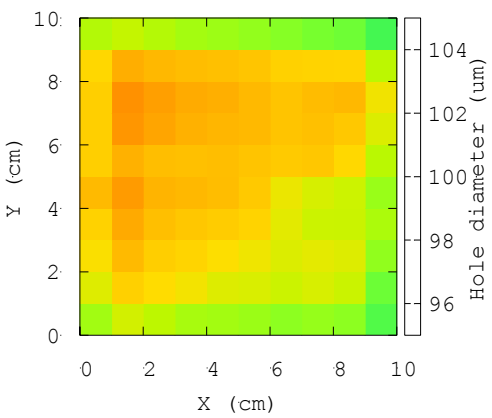
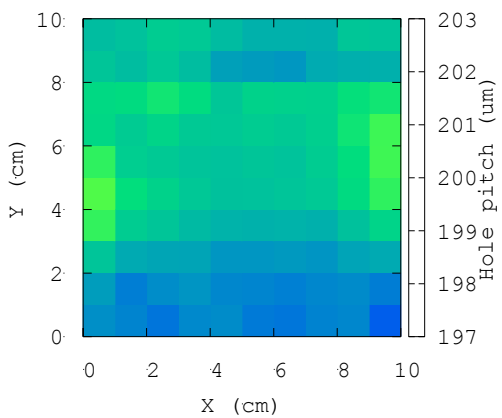
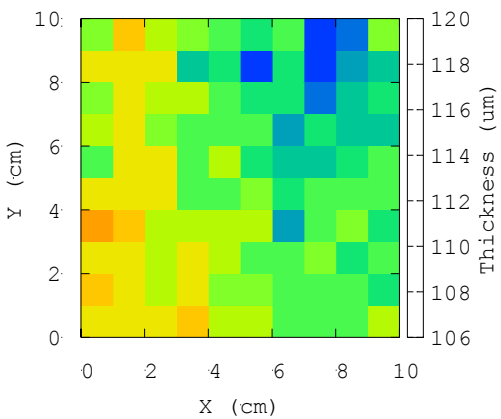
Substrate : 125 mm x 125 mm
Eff. Area : 100 mm x 100 mm

Hole Pitch : 200 µm
Hole size : ϕ 100 µm
Thickness : 100 µm (this work)
200 µm
(In detail, see Kato's poster#6)

Electrode : Gold (Au)
Resistance : ~ 160 GΩ @ 300 V

COST : ~ €800

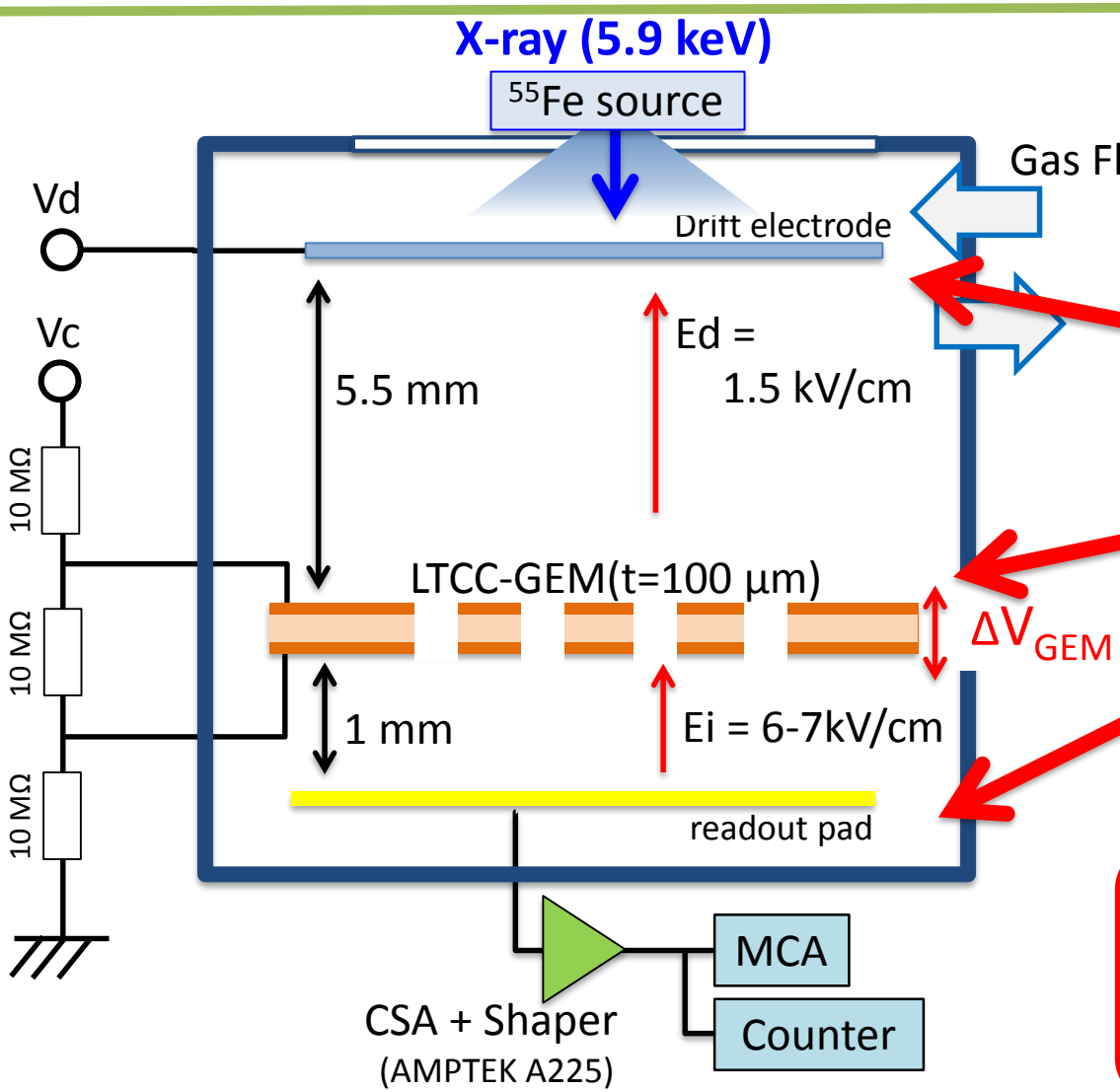
2-2. Mechanical accuracy

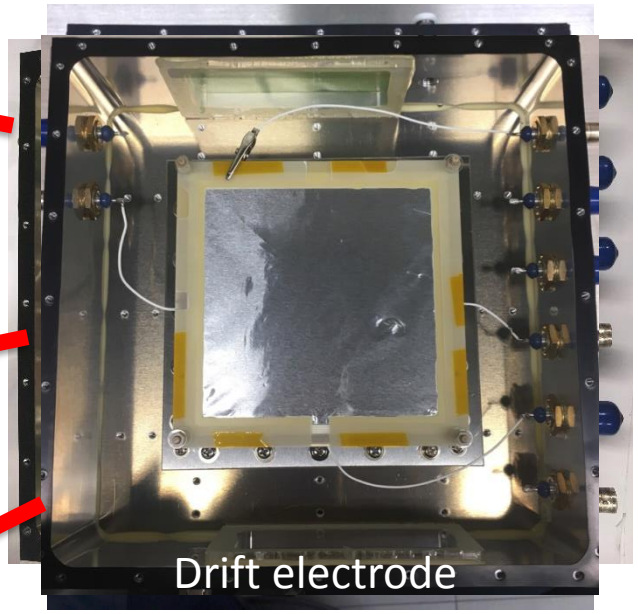
	Hole diameter	Hole pitch	Thickness
Design	Φ 100 μm	200 μm	100 μm
Measured Average	101.5 ± 3.2(1σ) μm	198.6 ± 5.1(1σ) μm	113 ± 2.2(1σ) μm
Uniformity map			

Comparing with design value,

- Hole diameter and pitch were formed within 3% error
- Thickness was controlled within 10% error

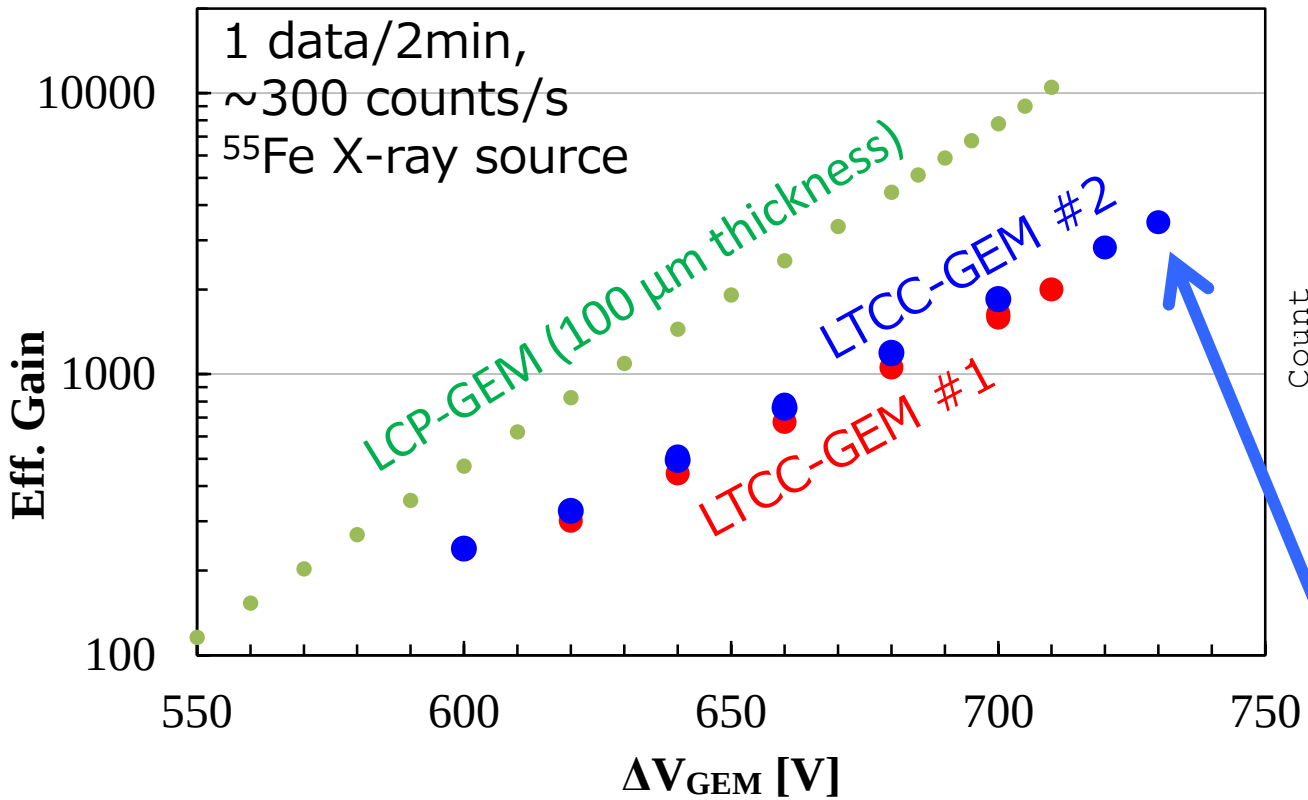
3-1. Experimental Setup

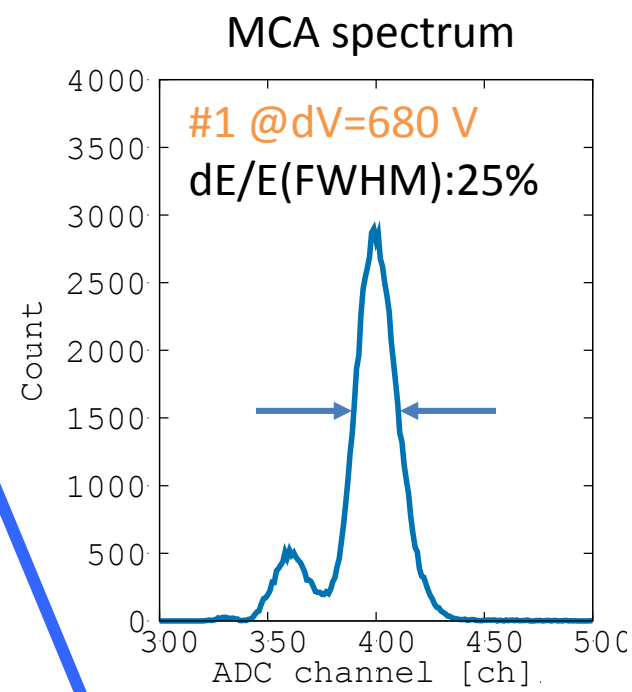




✧ Test items
- Gain curve
- Long time stability (14h)

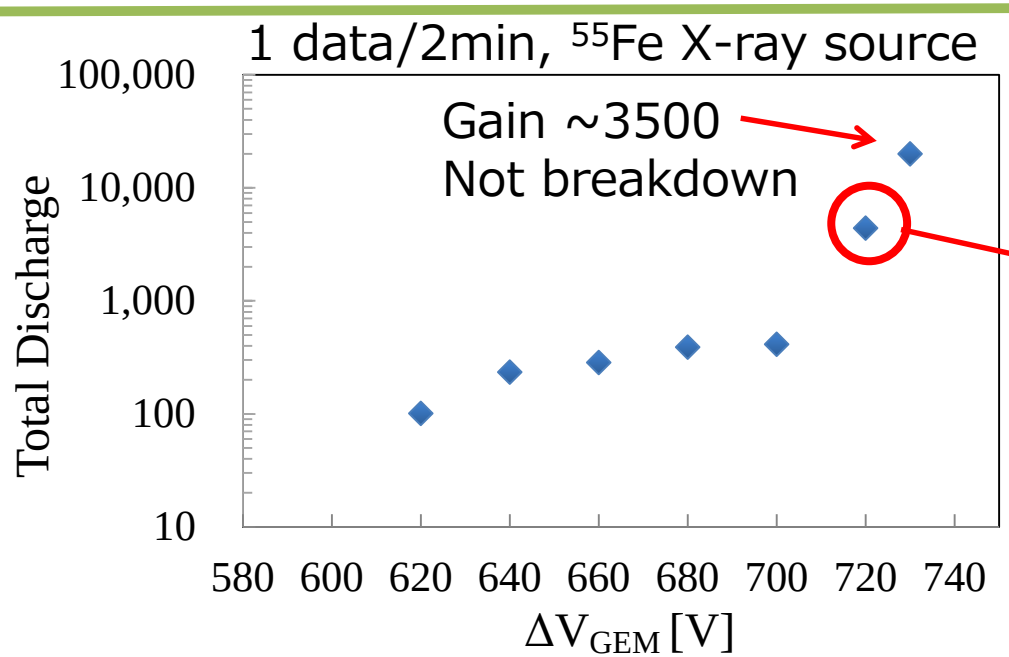
3-2. Gain curve



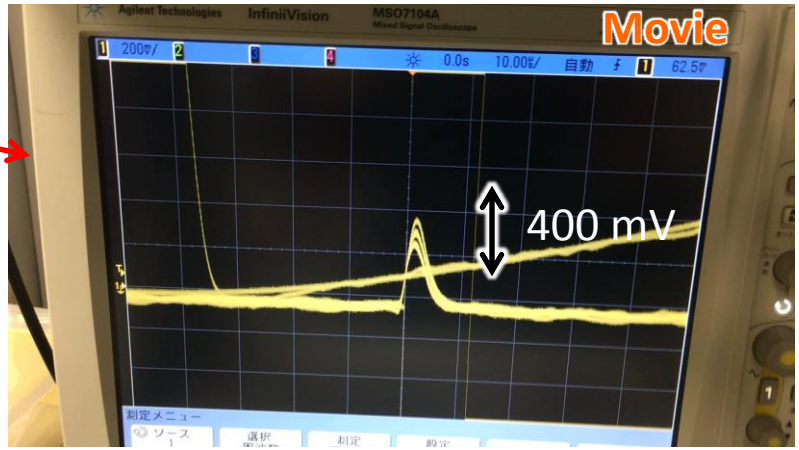


- The maximum gain was achieved approximately 3,500 at dV_{GEM} = 730 V.
- The energy resolution (FWHM) was obtained by 25%.

3-3. Number of discharges



Shaper output signal @ 720 V

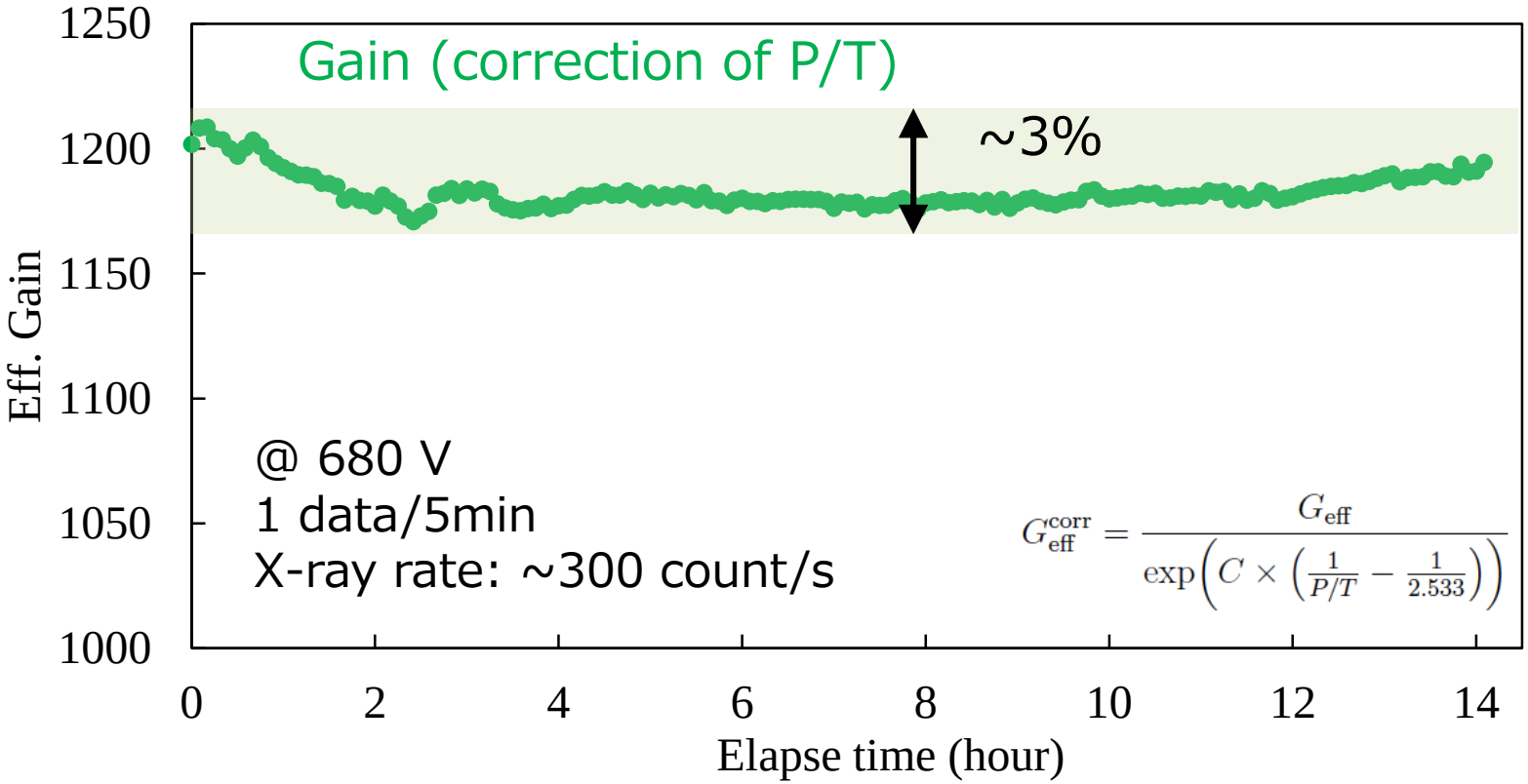


- We heard spark sounds from the chamber and watched flashes on GEM surface.
- Confirmed clear signals of X-ray after heavy discharge

Movie of discharges
top-view of GEM Eff. area

The LTCC-GEM was <u>NEVER broken</u> although it experienced more than 20,000 discharges at dV=730V.

3-4. Time stability

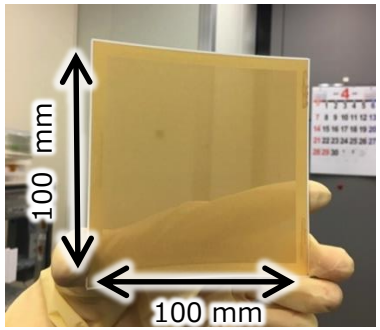


- The gain had a corrected pressure and temperature.
- We measured over 1,000 discharges during running data.
- **<u>The gain variation was 3% in 14 hours operation.</u>**

Excellent

Summary

✧ Succeed in fabrication of LTCC-GEM



- 100 mm × 100 mm size
- Using simple fabrication process
- Mechanical accuracy :
  - Hole size & pitch : Controlled under 3% error
  - Thickness : Controlled under 10% error

✧ Experiment results

- Maximum gain : ~3,500 at dV_{GEM}=730 V
- Discharge tolerance : > 20,000 discharges, but no breakdown!
- Time stability (14 hours): gain variation < 3%

Future plan

✧ Decrease discharge in operation

✧ Develop a sealed gas detector using LTCC-GEM

✧ Continue R&D with collaborators interested in LTCC-GEM

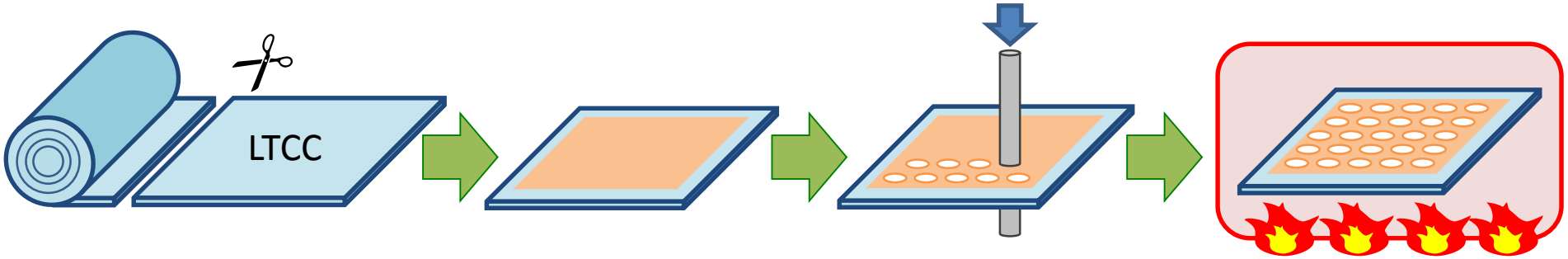
Thank you for your attention

TIRI official mascot : TIRIN®

Back up

Plan of discharge prevention

Process



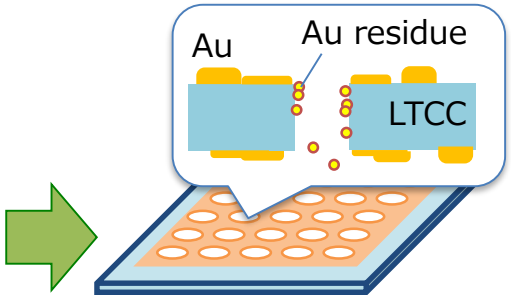
1.Cutting Green Sheet

2.Applying Au paste

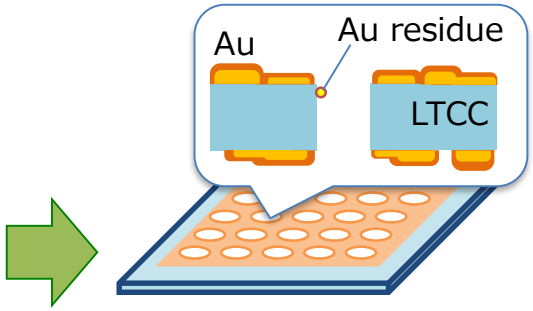
3.Punching

4.Sintering
(<1000℃)

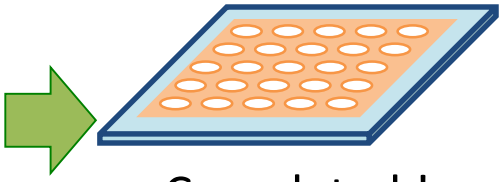
Additional process for discharge prevention



5.Etching
For removing Au residue
in the holes



6. Au non-electrolytic plating
For recovering Au electrode
lost by etching

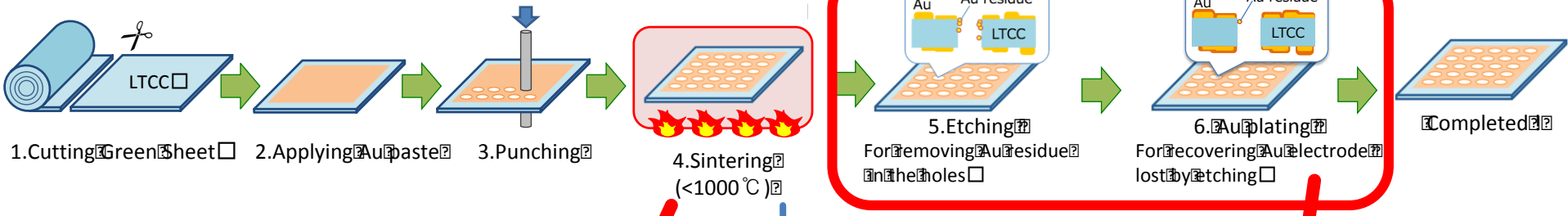


Completed !

Plan of discharge prevention -- SEM image --

Additional process for discharge prevention

Process



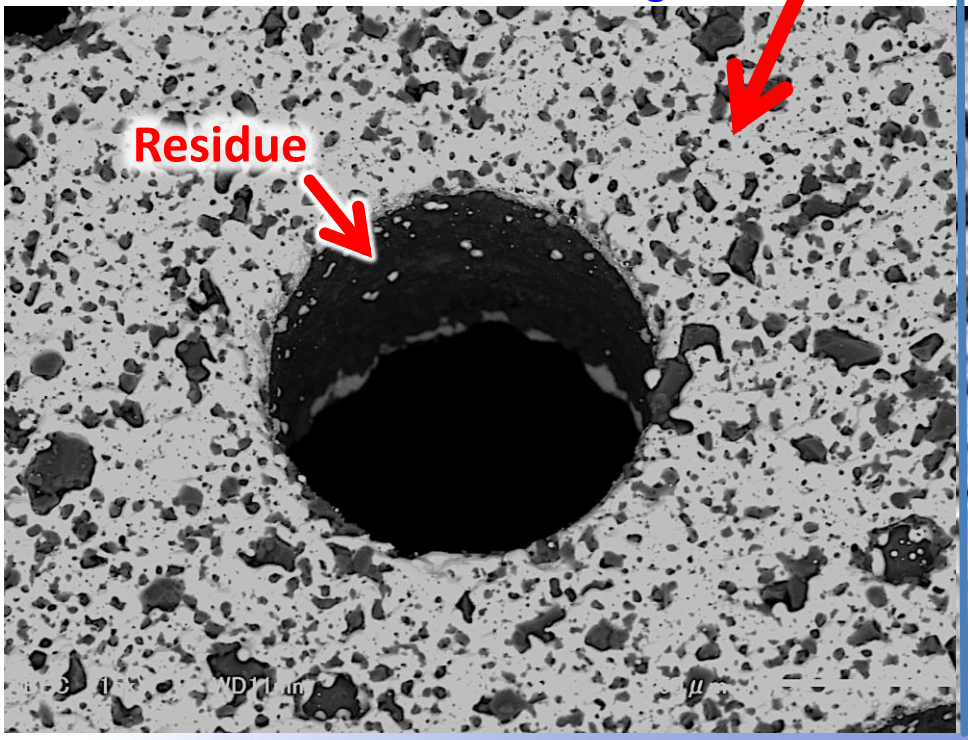
1.Cutting Green Sheet　2.Applying Au paste　3.Punching　4.Sintering (<1000℃)

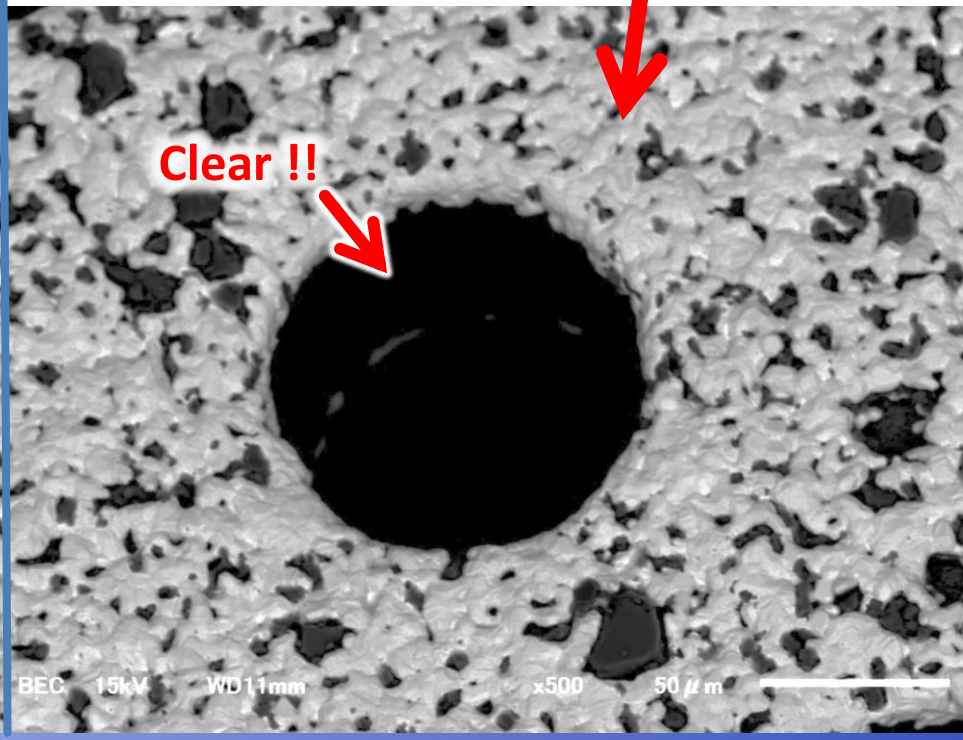
5.Etching For removing Au residue in the holes

6.Au plating For recovering Au electrode lost by etching

Completed

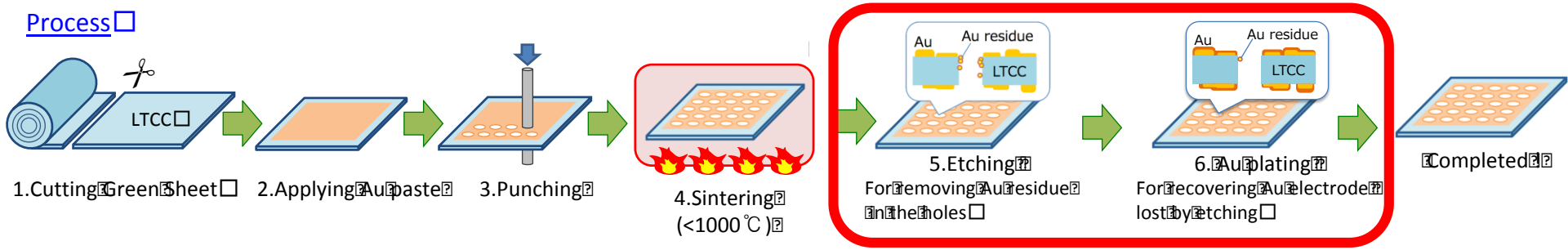
backscattered electron SEM image

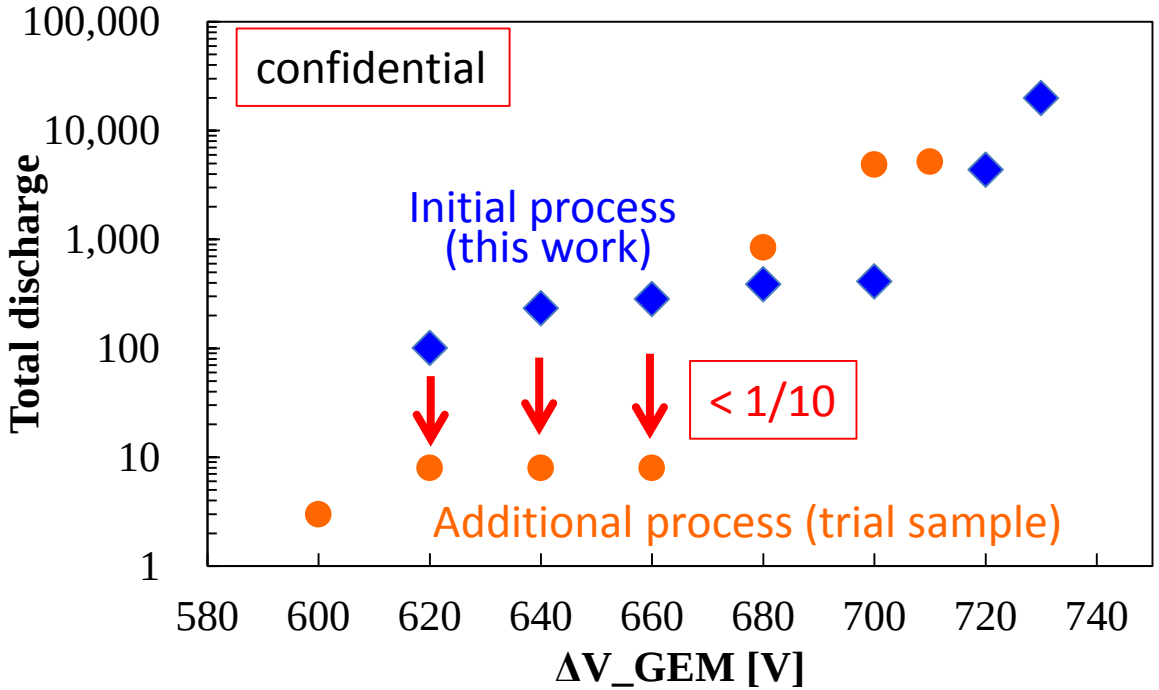




Plan of discharge prevention -- test --

Additional process for discharge prevention



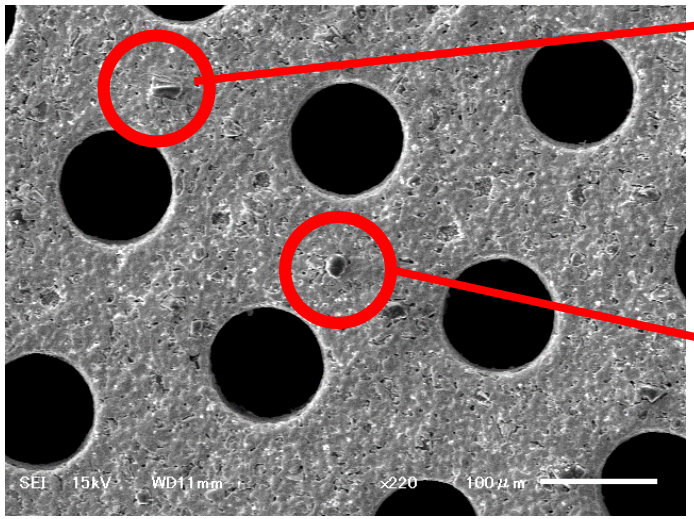


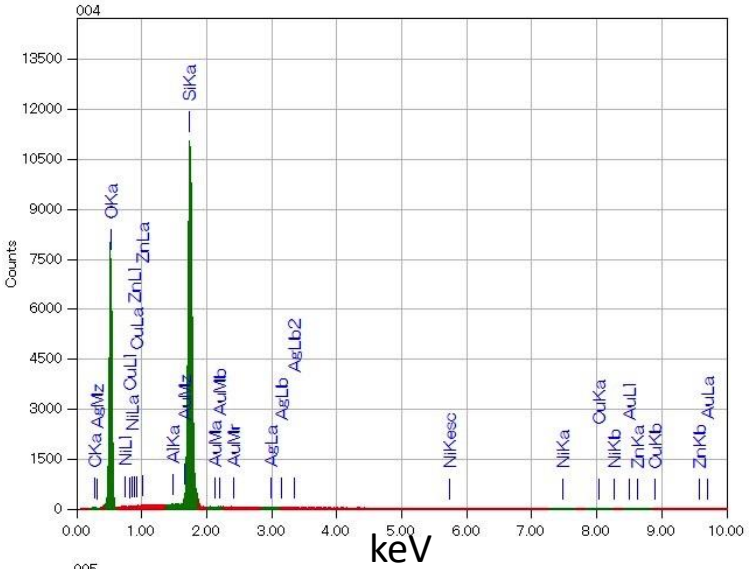
- At $\Delta V_{GEM} \leqq 660$ V, discharges decrease using GEM of additional process.
- The process has effect.
- We must search optimum parameters of etching time and plating time in future work.

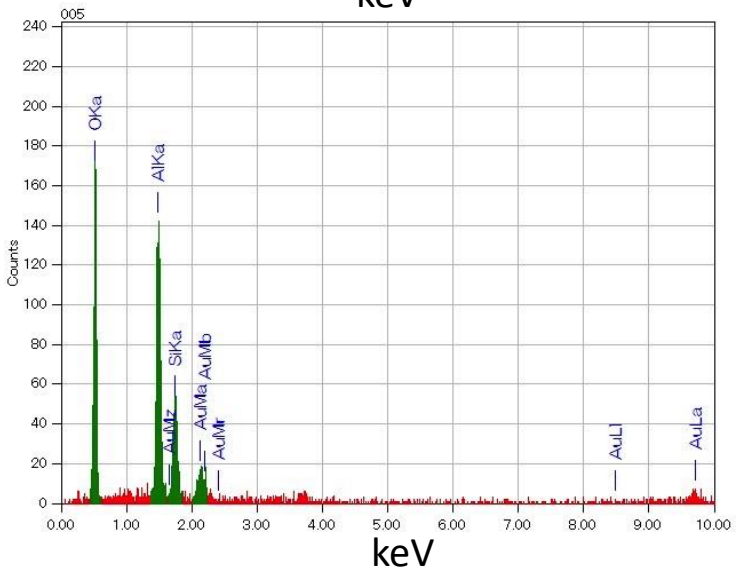
LTCC-GEM SEM-EDX analysis

EDX: Energy Dispersive X-ray

What is some clods put on LTCC-GEM?







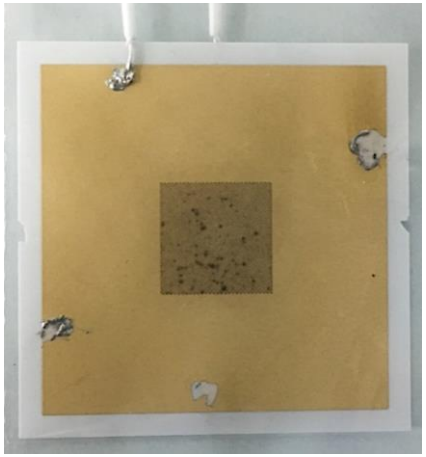
LTCC composition : Glass + Alumina

(CaO,SiO_2,B2O3etc) (Al_2O_3)

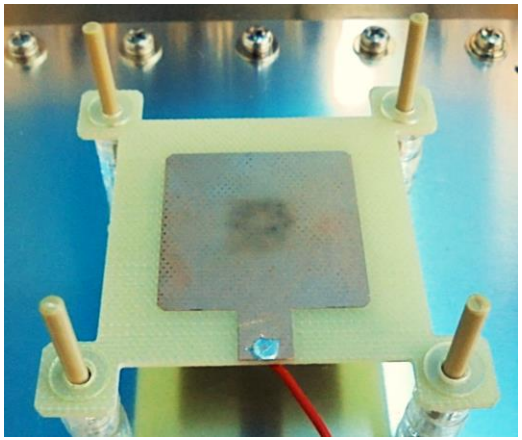
The clods is LTCC contained within Au paste.

Aging with discharge

- LTCC-GEM must need the aging with discharge to use without discharge.
- After aging, the weak points of discharge become non-discharge point.



After heavy discharges (aging)

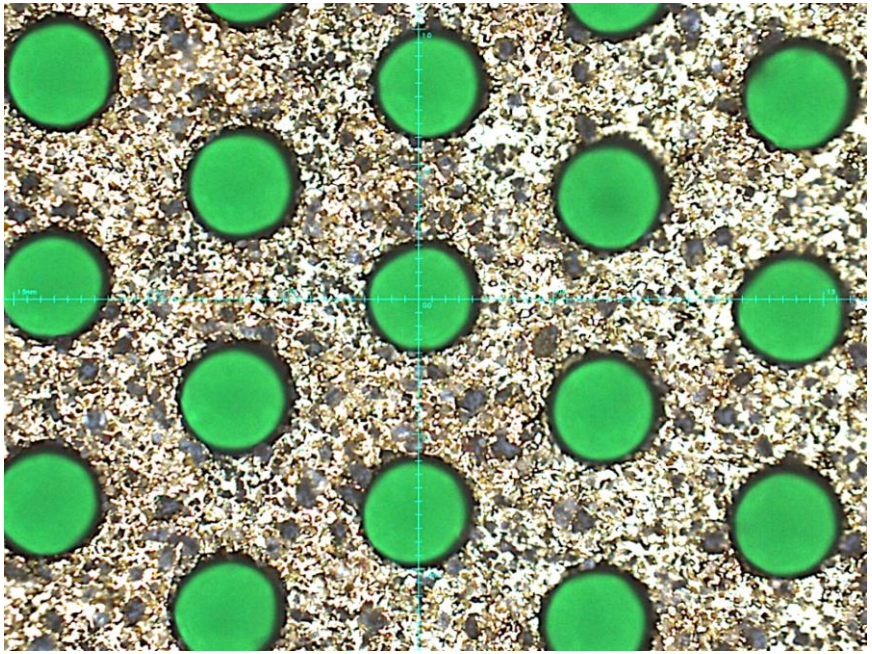


Contamination on readout pad

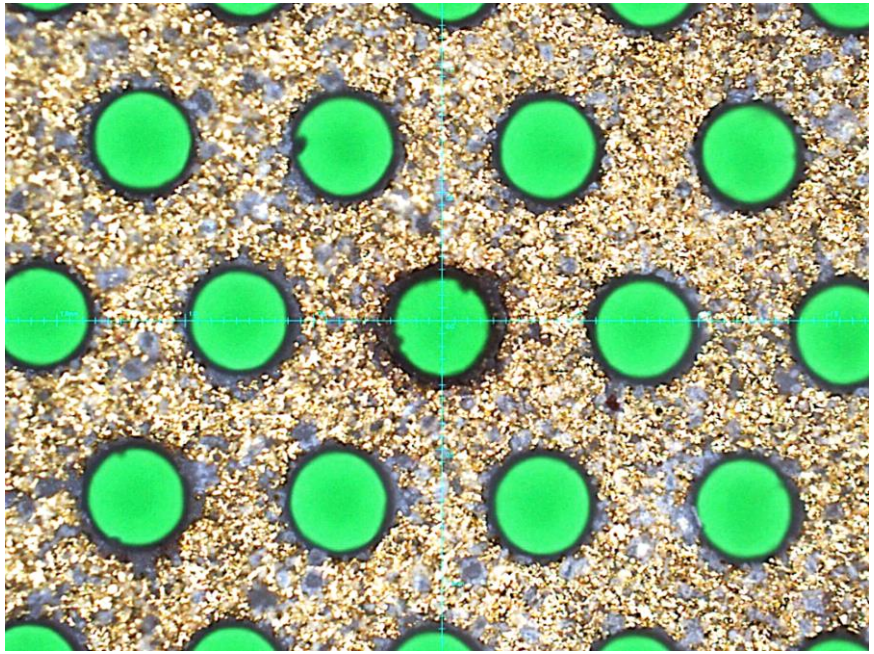
【problems】

- The contamination on readout pad and inside of chamber
- Troublesome task : essential aging before test

Spark tolerance



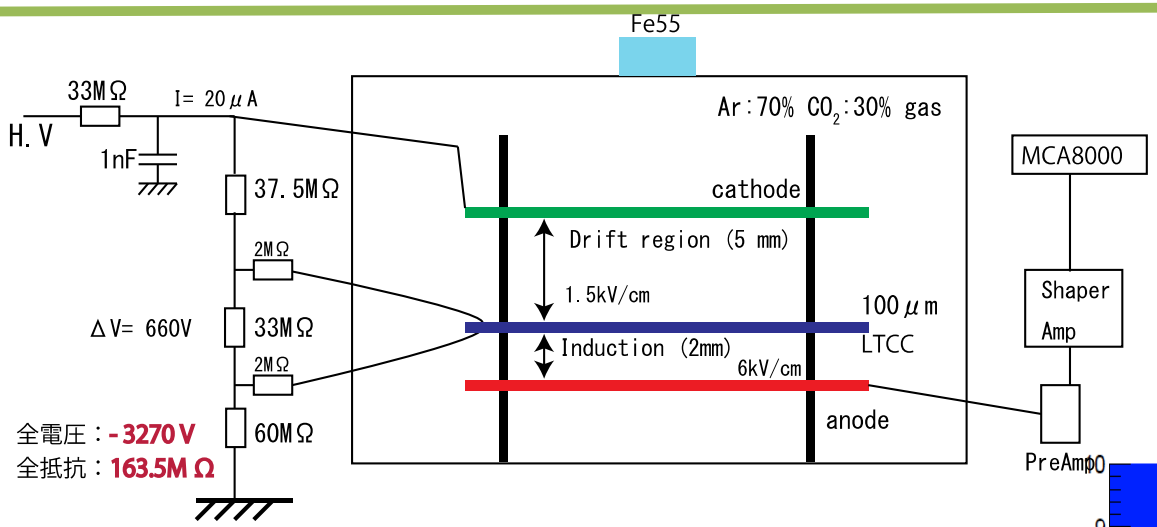
Before the experiment



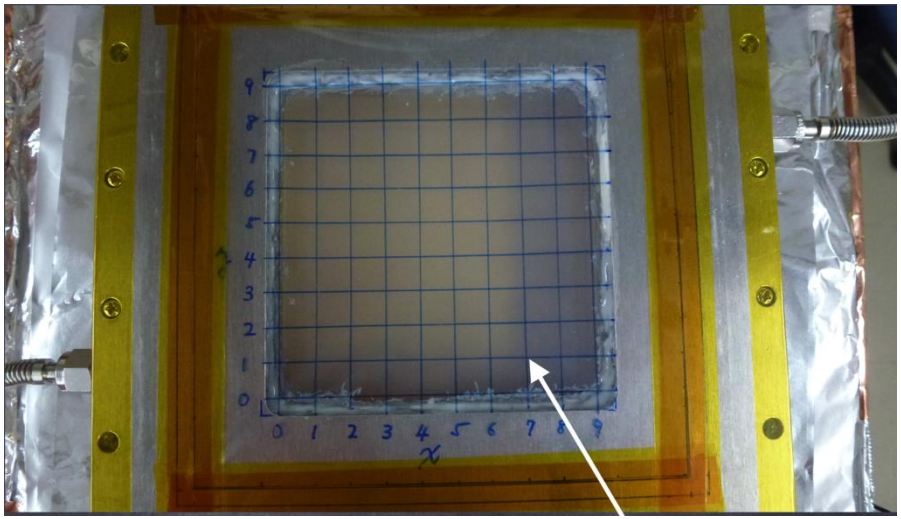
After the experiment
(Discharged part)

- Some burned print where observed around the hole, but no change of gas gain and energy resolution.
- LTCC substrate has a tolerance against sparks.

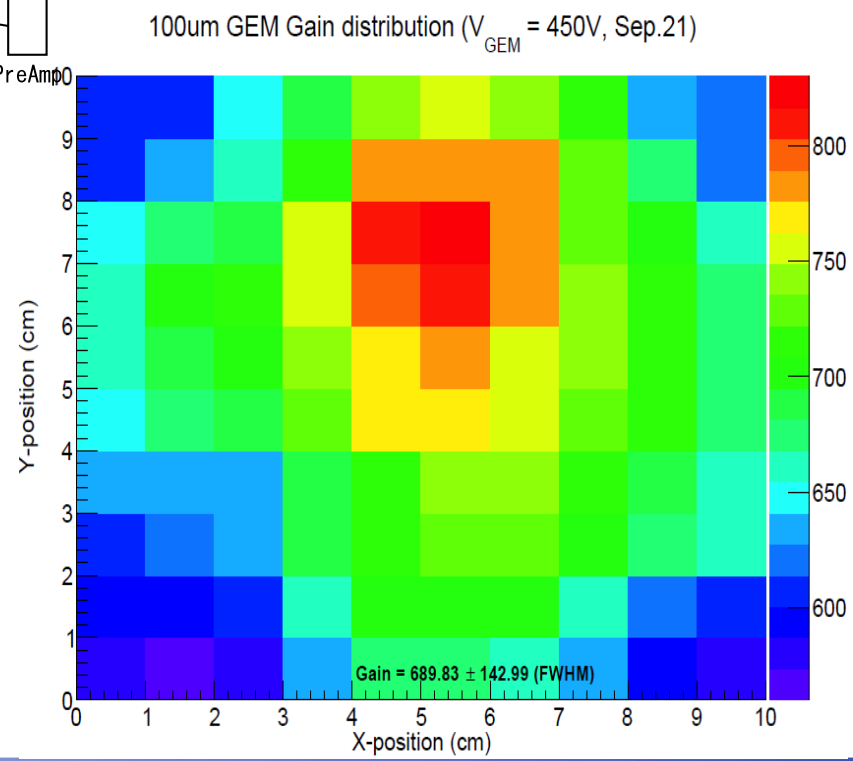
Gain uniformity



Measurement by Kato-san (Kindai Univ., Japan)

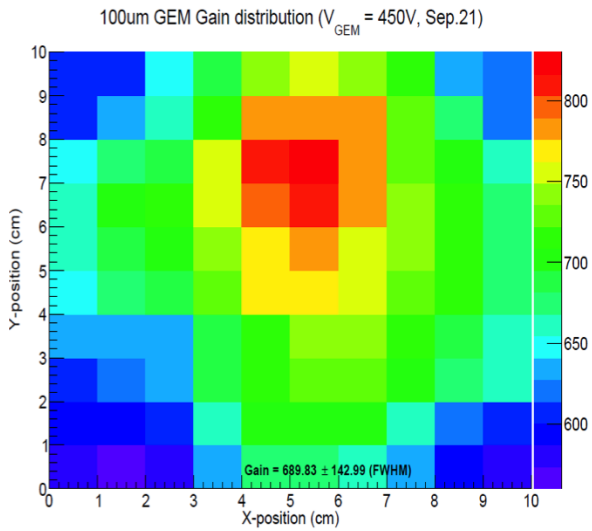


Put ^{55}Fe source on a cross point

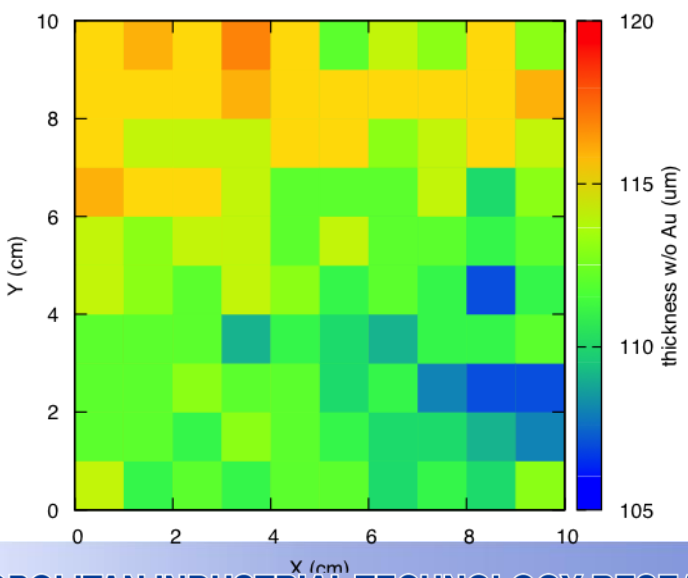


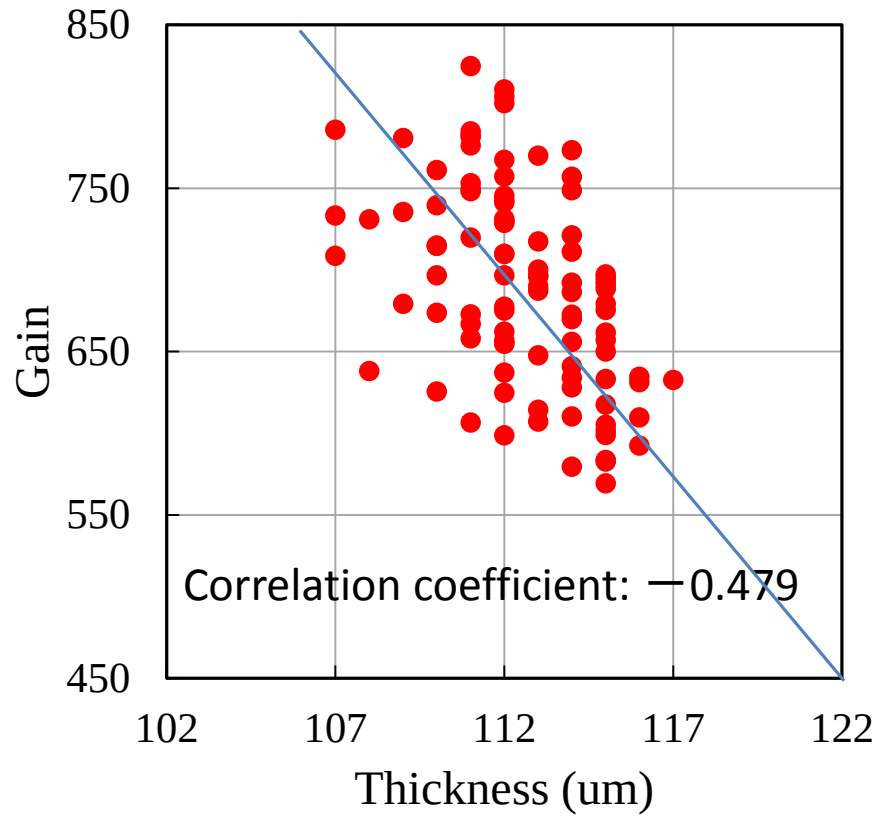
Gain uniformity vs Thickness

Gain



Thickness





Loose correlation !!

Gain = exp(α・d)

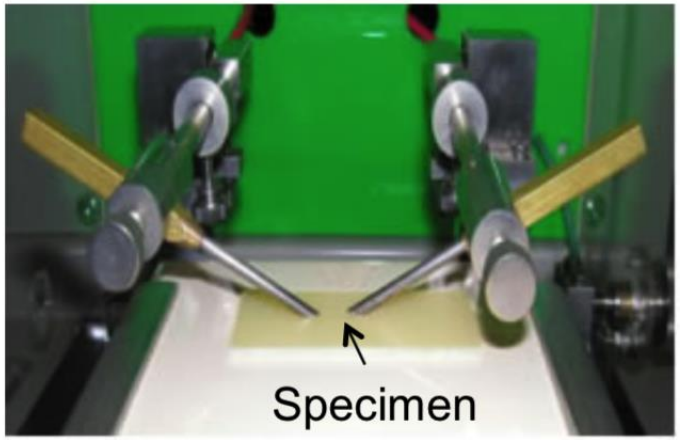
ΔV_{GEM} = const.

$$\frac{\alpha}{P} = A \exp\left(-B \frac{P}{E}\right),$$

If thickness is shorter, E-field & gain is higher.

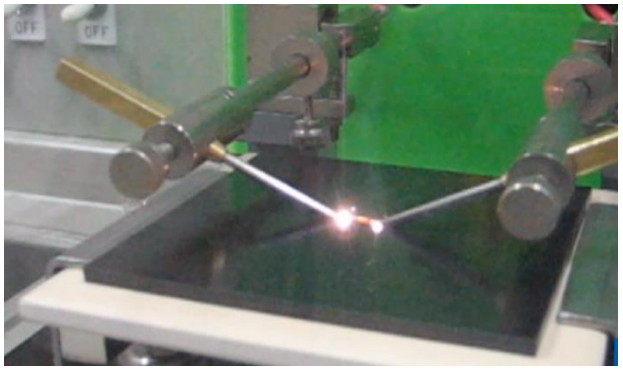
Arc resistance test

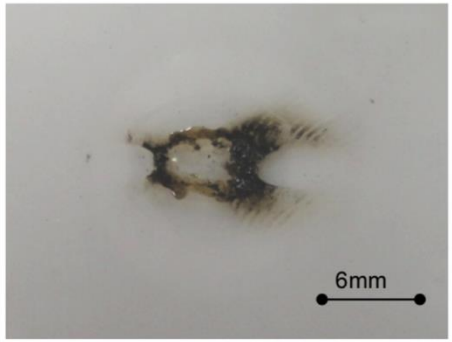
ASTM D495.



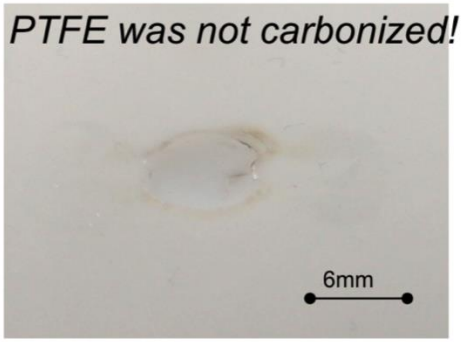
- Arc resistance is defined as the time period that a material resists the formation of a surface-conducting path.
- The test is carried out under the intermittently occurring arc of high voltage at low current characteristics.

Tungsten electrodes: 6.35 mm apart each other
Applied voltage: 12.5 kV



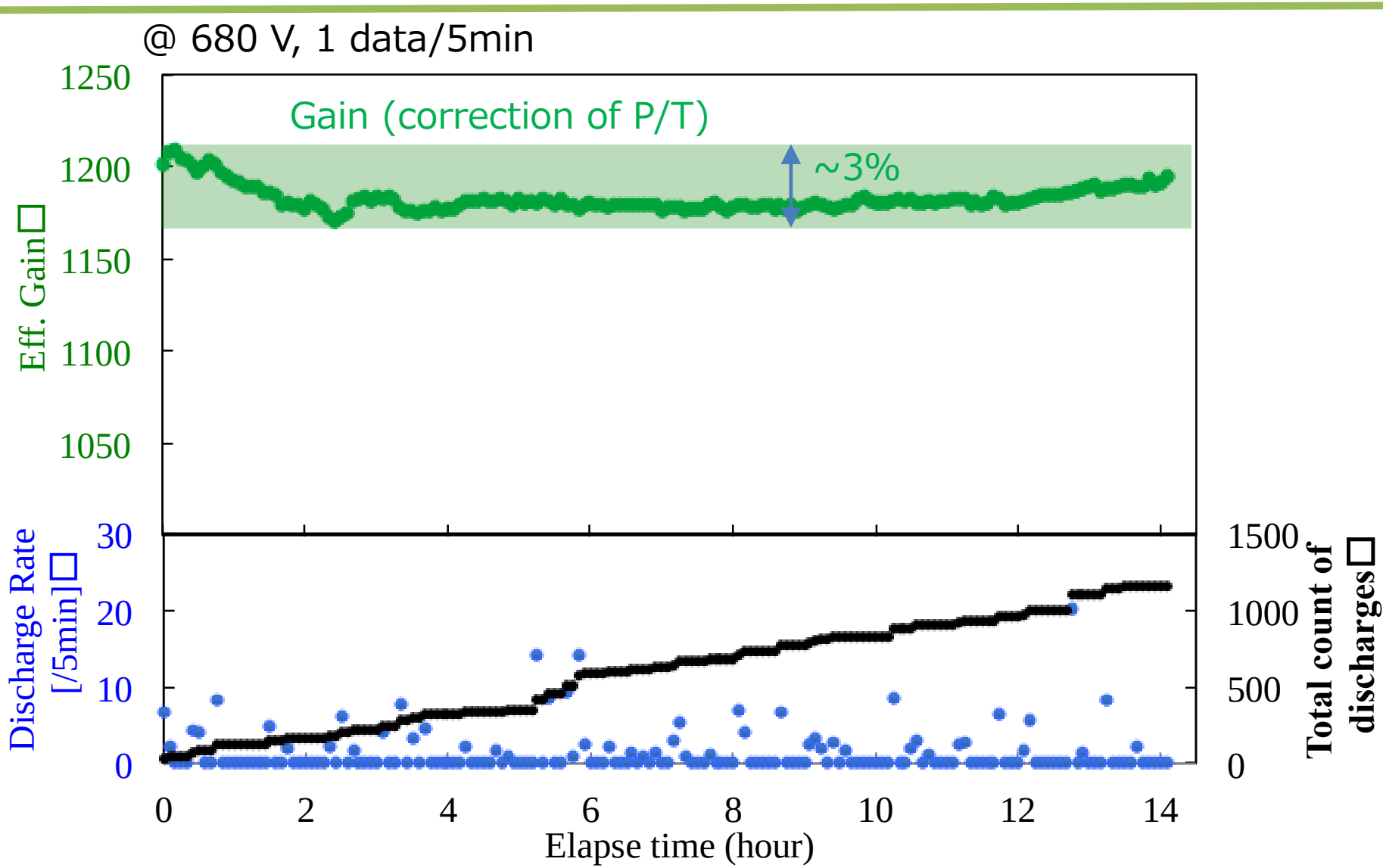


PET 82 s



PTFE >239 s

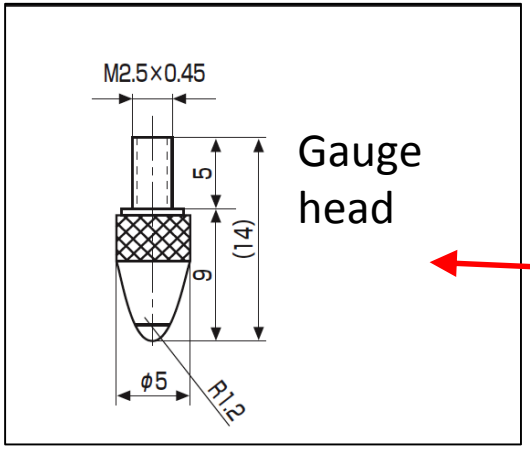
Time stability



Measurement of LTCC-GEM thickness

- Contact type film thickness measuring gauge
  (Nikon Digmicro MFC-101)

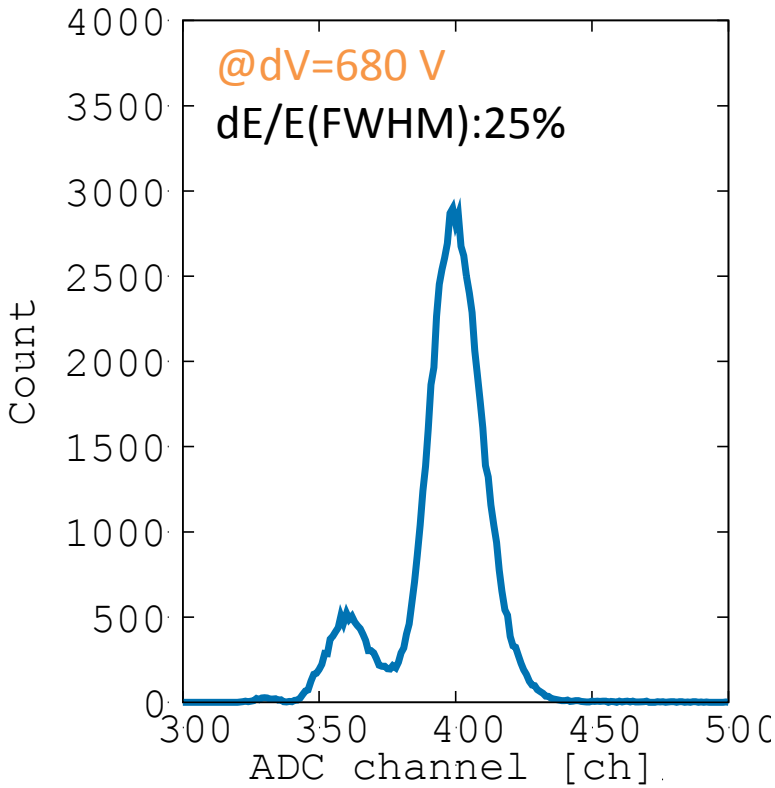
- Measurement accuracy : 1um



- Measured area : 100 points (10 x 10 points)
  1cm step

MCA spectrum

MCA spectrum w/o discharge



MCA spectrum with discharges