Development of gating foils to inhibit ion feedback using FPC production techniques

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- Summary

- **Positive Ion Feedback in ILC TPC**

- Time Projection Chamber (TPC) with MPGD readout is proposed to be the central tracker of ILD detector for the International Linear Collider (ILC).
- Positive-ion feedback from the gas-amplification region to the drift region can deteriorate the position resolution of TPC.
- Required point resolution of better than 100 μm for long drift (~2.3 m) @3.5T

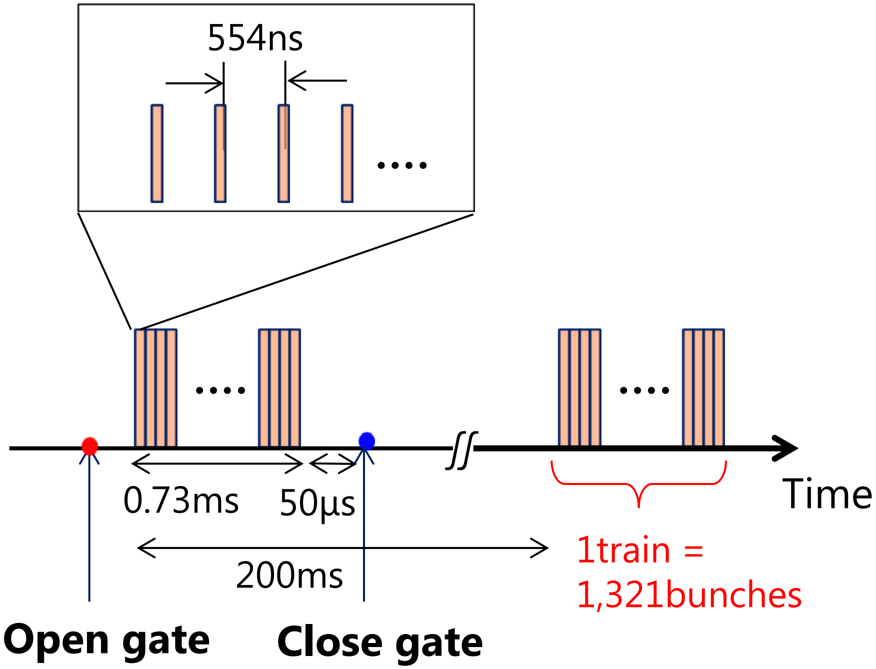


Fig 1-1. ILC beam structure

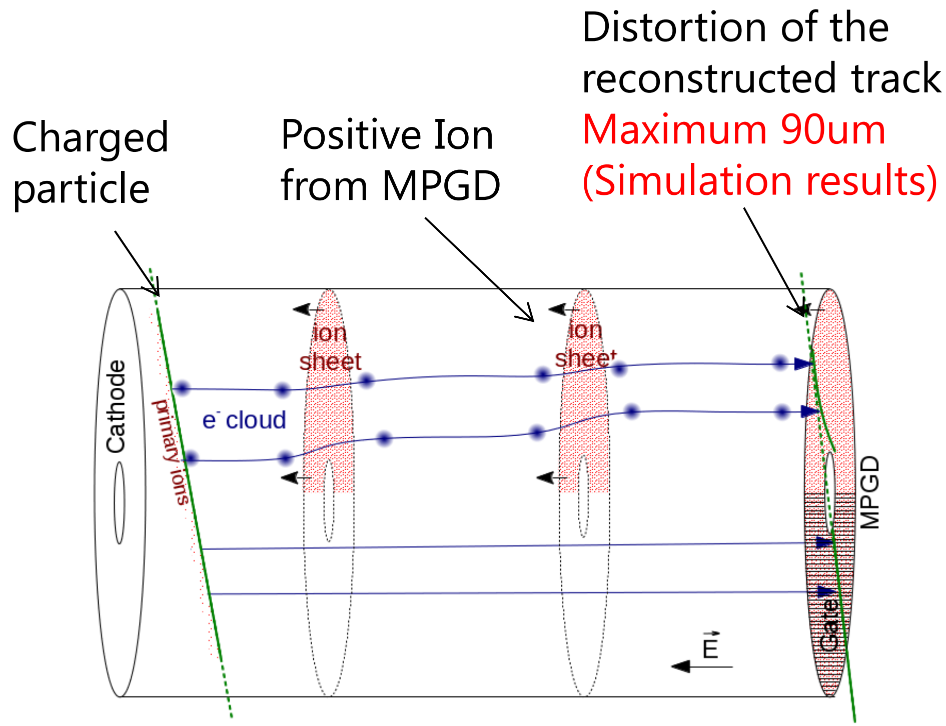


Fig 1-2. Positive ion feedback in ILC TPC

Gating foil

- **Gating foil for ILC TPC**

- Mounting the Gating foil near the MPGD to stop the feedback of positive ions.

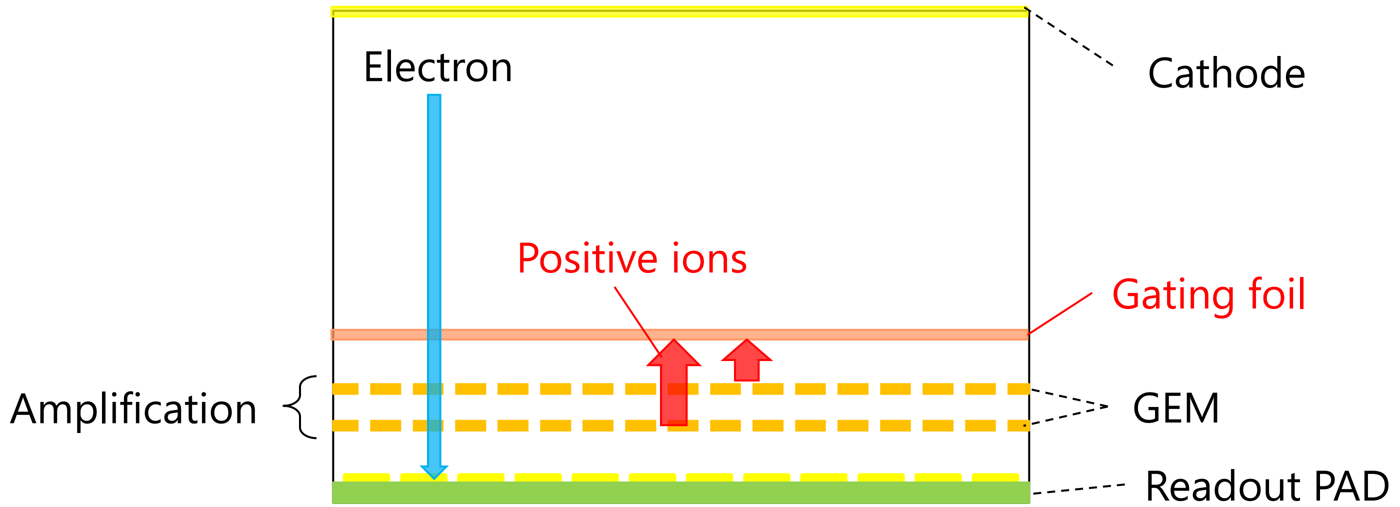


Fig 2. Mounting image of gating foil on the module

■ Gating foil

- Gating foil have GEM-like structure.
- Gating foil is operated in low voltage mode.
  (initially proposed by F. Sauli in 2006)
- Gating foil can easily be used as a closed gate by reversing the electric field.

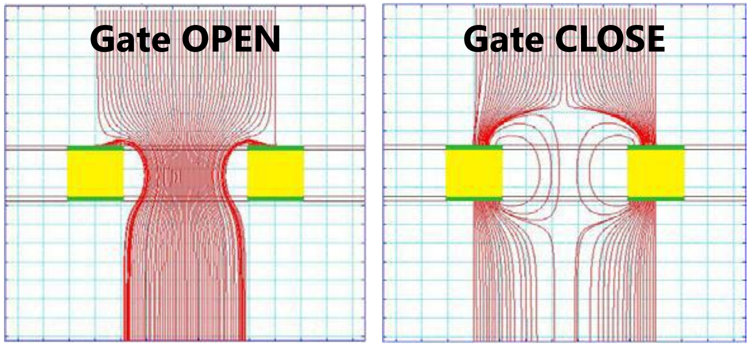


Fig 3. Electric field of gating foil

Requirement for Gating foil

- **Requirement for Gating foil of ILC TPC**
- 80% electron transmission is required to satisfy the performance of ILC-TPC.
- Endplate of ILC-TPC is consist of 240 modules, and 1 module size is 170mm x 220mm.
- From the simulation results by ILC-TPC group, the Gating foil is required according to the below spec.

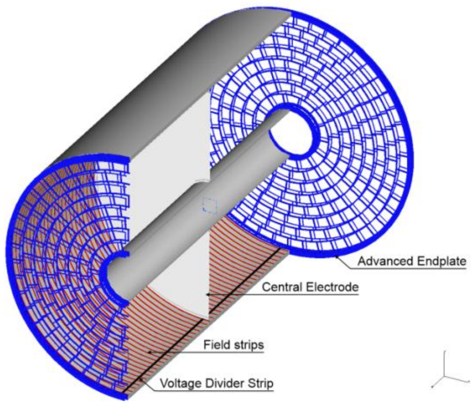


Fig 4. Image of ILC-TPC (model with 8 rows of modules)

■ Requirement spec for Gating foil and Amplification GEM

Item	Gating foil	Amplification GEM
Optical aperture ratio	≧80%	22.7%
Hole size	≦ 300μm	70μm
Hole pitch	≦335μm	140μm
Rim width (Hole pitch - Hole size)	≦35μm	70μm
Insulator thickness	≦25μm	50μm or 100μm
Foil size	170mm x 220mm	170mm x 220mm

Table 1. Requirement spec for Gating foil and Amplification GEM of ILC TPC

Production techniques of FPC and GEM

- **Why does Fujikura try to develop the Gating foil ?**

- Fujikura is one of major Flexible Printed Circuit (FPC) makers in the world.
- FPC is commonly applied to cables inside electrical appliances.
- Production techniques of GEM are the same as FPC production techniques.

FPC (Flexible Printed Circuit)

■ Relationship between production of GEM and FPC

GEM production	Key techniques	FPC production
Single mask	Photolithography Insulator removing	Circuit formation
Double mask		
Laser drilling	Laser processing	Making through hole

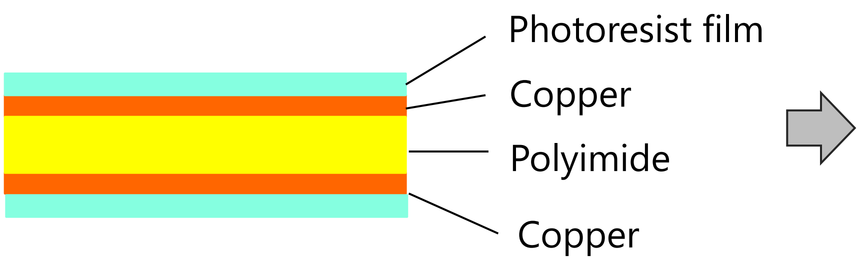
Table 2. Relationship between GEM and FPC

Key techniques of production

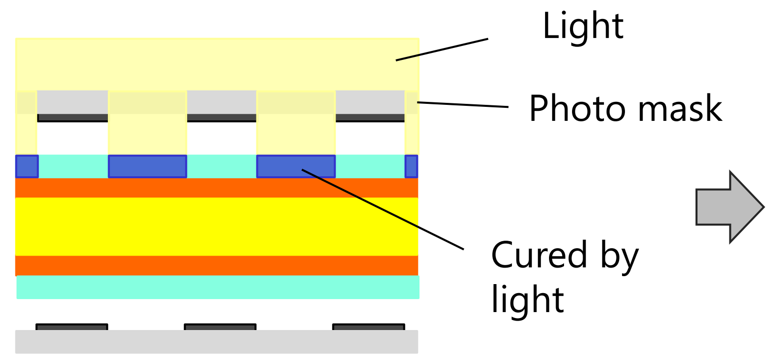
- **Key techniques of Gating foil production**

■ Production method of Double Layer FPC

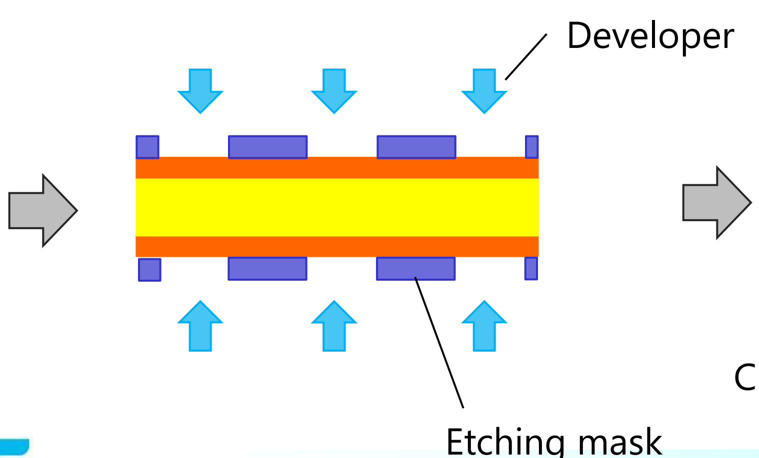
(1) Laminate the photoresist film on the CCL (Copper Clad Laminate)



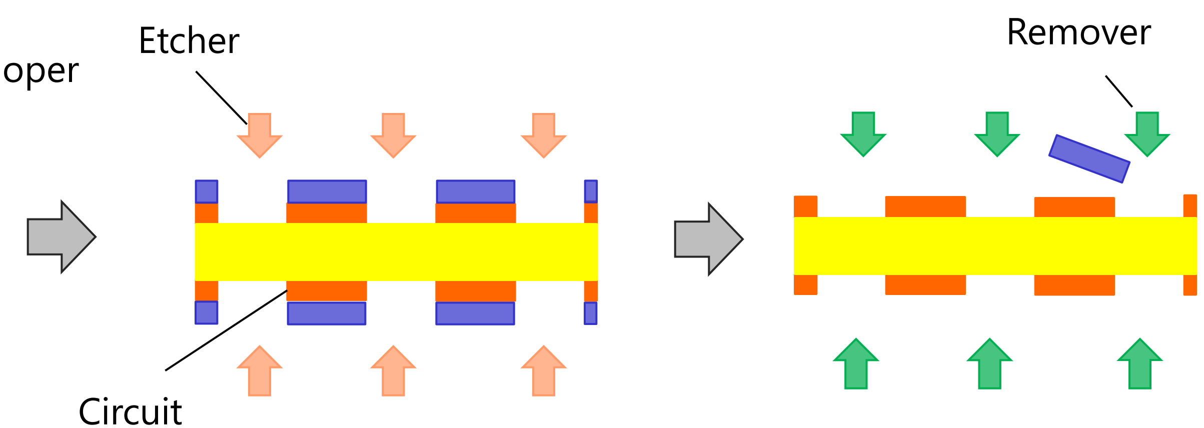
(2) Expose the film using the photo mask



(3) Photoresist development



(4) Etching and remove the photoresist

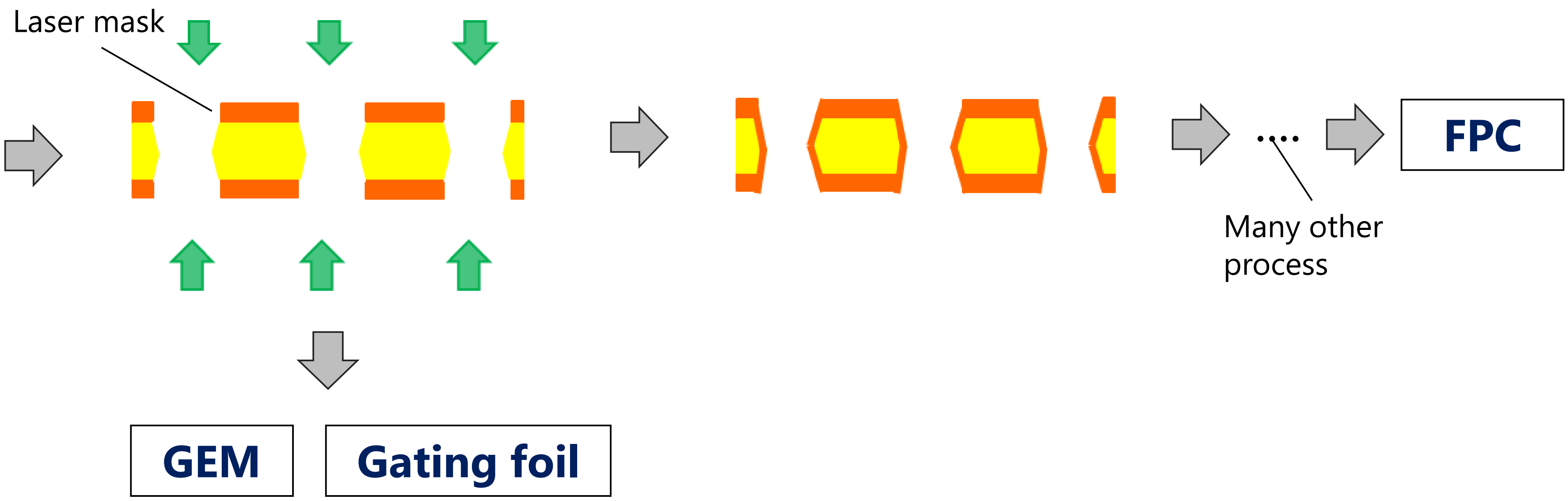


- **Key techniques of Gating foil production**

■ **Production method of Double Layer FPC**

(5) Remove the polyimide using the copper as etching mask

(6) Plating copper on the surface of polyimide to contact the circuit on both layers



Our Goal
Develop the Gating foil for ILC-TPC and solve the Positive ion feedback problem using the FPC production techniques.

- **Difficulty of Gating foil production on each process**

- We tried to study about 3 production methods.

GEM production	Key technique
Single mask	Photolithography Insulator removing
Double mask	
Laser drilling	Laser processing

Table 3. GEM production methods

1. Double mask process

- Double mask process need the photomask alignment, but the accuracy of the alignment is about ±10um over a large area.

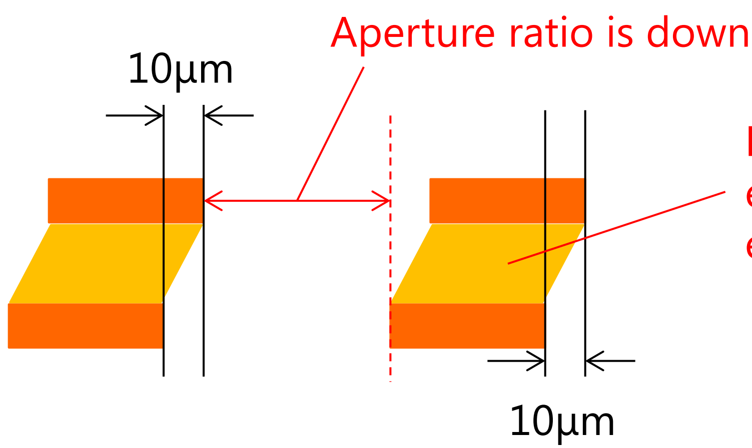


Fig 5. Image of rim (Double mask process)

2. Laser drilling process

- UV-YAG Laser is usually used in making through hole (TH) of FPC.
- Gaussian beam mode of UV-YAG Laser can process copper and polyimide at the same time.
  (beam size of Gaussian mode beam : 20~30μm)
- We confirmed the minimum rim width on Laser drilling process.

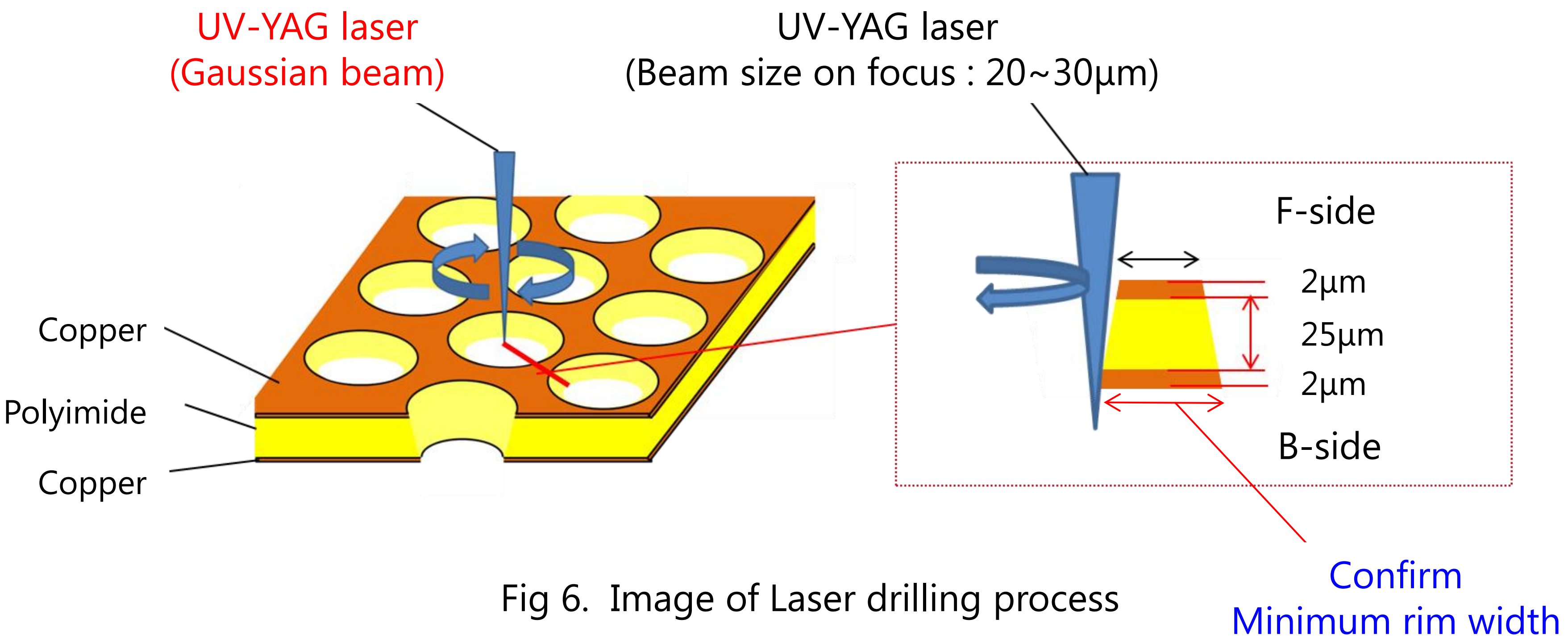
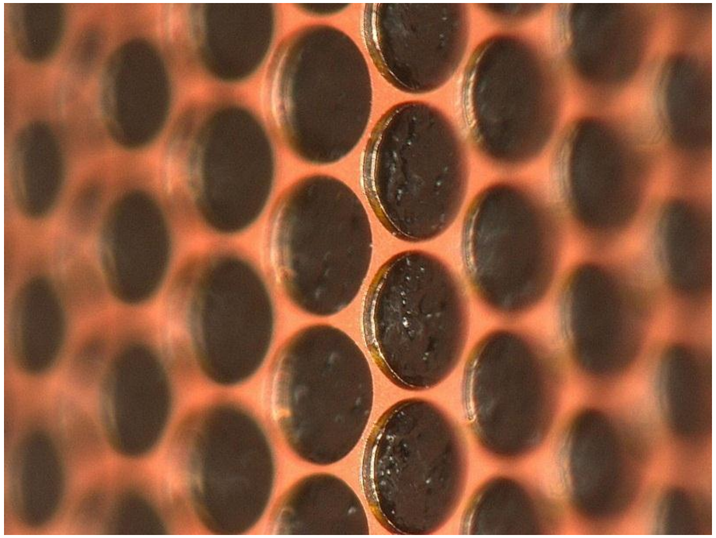


Fig 6. Image of Laser drilling process

2. Laser drilling process

■ Results

Item	Gating foil
Hole size	302μm
Hole pitch	330μm
Rim width : F-side	14μm
Rim width : B-side	28um
Insulator thickness	25μm (&12.5μm)
size	10mm x 10mm
Processing time	6 min (Only Laser)
Optical aperture ratio	75.8%



Pic 1. Surface of F-side

- Minimum rim width is 28μm. (Under 35μm)
- The rim didn't break and maintained the fine structure. (Pic.1)
- Copper removed from the polyimide on the F-side rim width 10μm.
  The limiting width of the rim by Laser drilling process is 25μm.
- Optical aperture ratio was 75%. (Under 80%)
- Processing time of 10mm x 10mm was 6min.
  In case of 170mm x 220mm, the processing time is about 2,240min...

2. Laser drilling process

- Circle structure Gating foil couldn't reach optical aperture ratio 80%.
- The Laser machine for FPC products is optimized to circle processing.

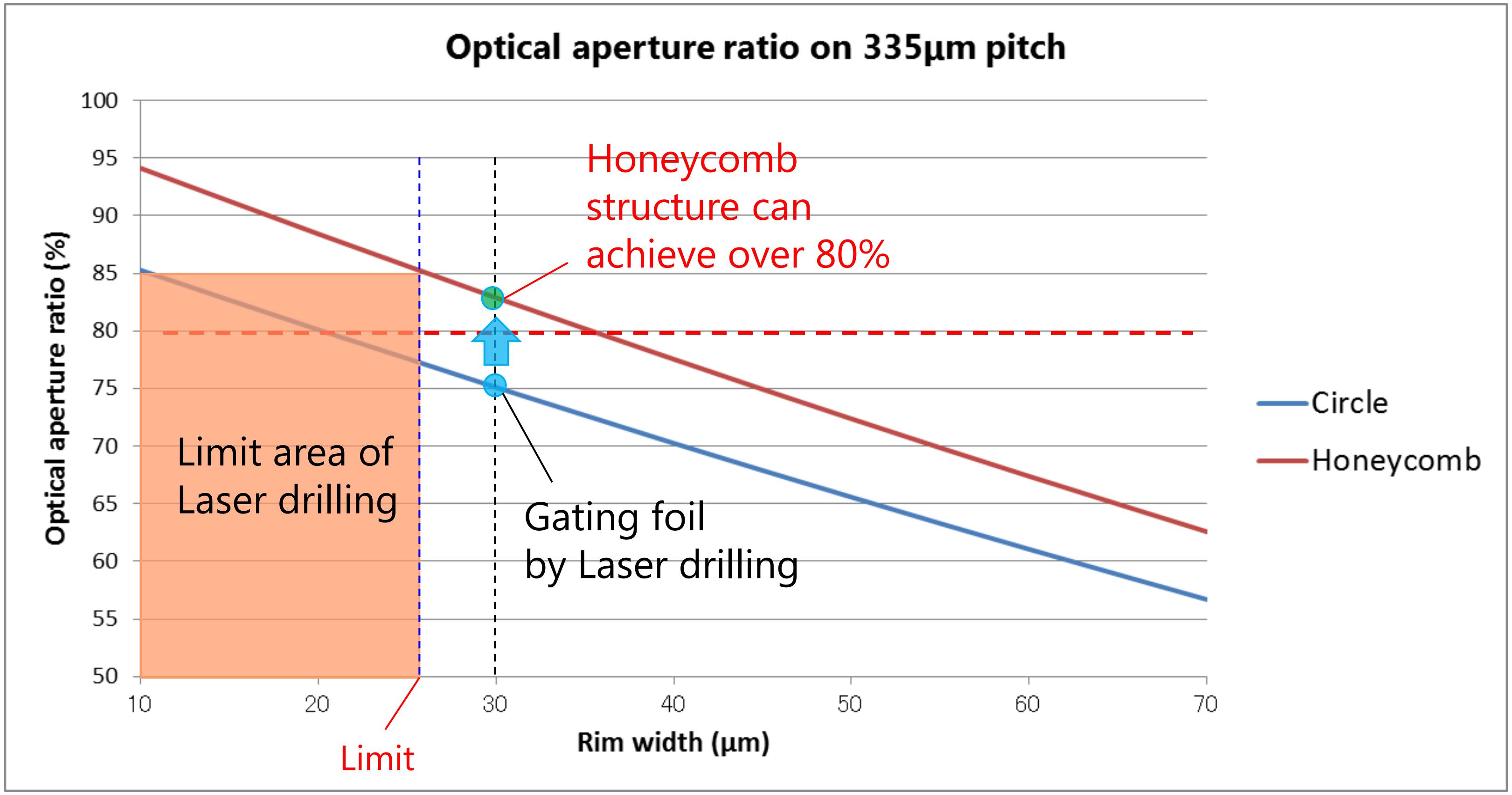


Fig 7. Relationship between Rim size and Optical aperture ratio on 335µm hole pitch

Laser drilling process isn't suitable for the Gating foil processing

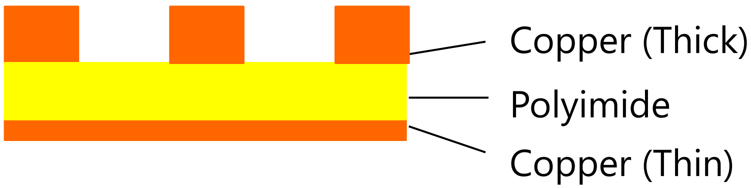
3. Single mask process

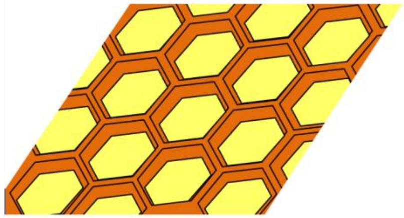
- Single mask process usually use Ni-plating as the etching mask for B-side copper etching.
- Gating foil is used in a magnetic field 3.5T, so we don't want to use Ni.
- So we need to develop a "No Ni plating single mask process".

■ No Ni plating Single mask process

(1) Laminate the photoresist film on CCL

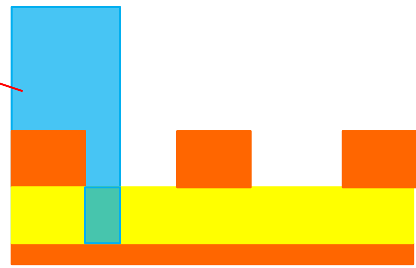
(2) Form Honeycomb structure circuit on the thick copper side

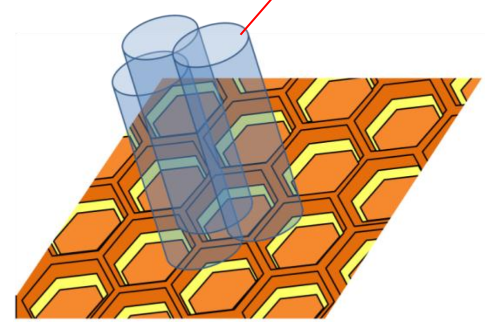




3. Single mask process

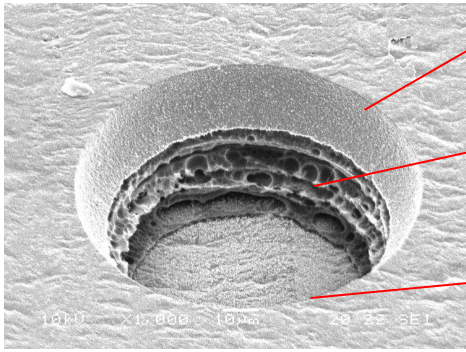
(3) Remove the polyimide by UV-YAG Laser

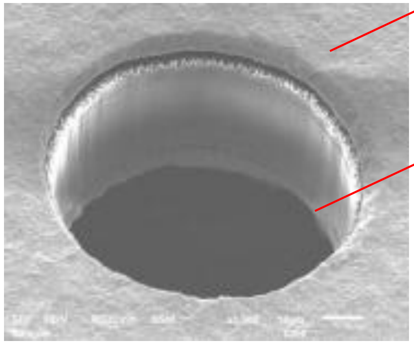




■ Why we select the UV-YAG Laser ?

- Laser have higher processing accuracy and can process the higher angle-taper hole than the polyimide etching.
- UV-YAG Laser can remove polyimide with small damage. (better for making narrow rims)

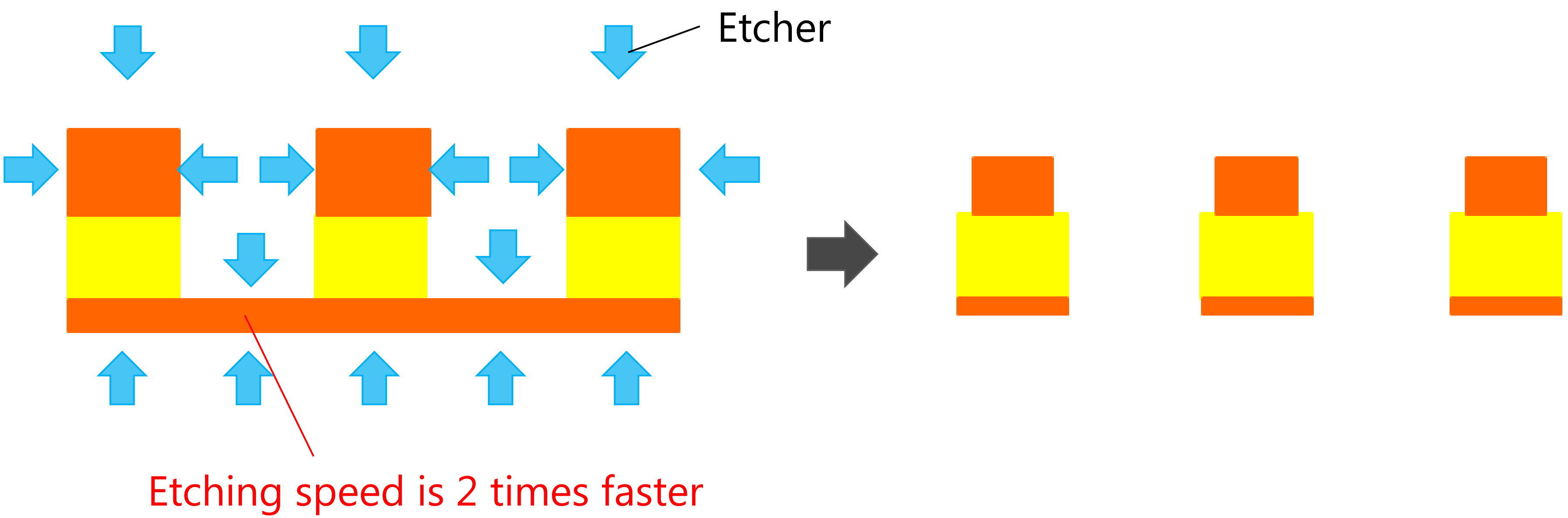




Pic 2. Damage of polyimide by UV-YAG Laser and CO2 Laser

3. Single mask process

(4) Etch the copper from both side by etching liquid



■ Point of No Ni-plating Single mask process

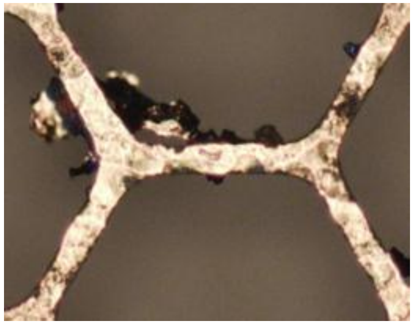
- Process is very simple, so the process has an advantage for the large area processing.
- We need to control copper thickness of F-side and B-side and the amount being etched is very severe.

3. Single mask process

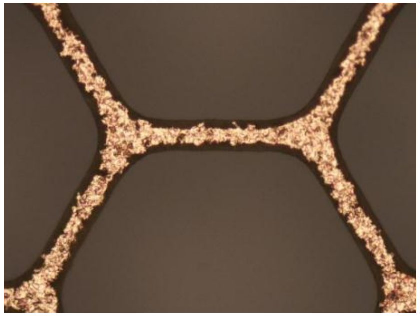
■ Results

Item	Gating foil
Hole size	304μm
Hole pitch	335μm
Rim width : F-side	27μm
Rim width : B-side	31um
Insulator thickness	12.5μm
size	100mm x 100mm
Processing time	70min (only laser)
Optical aperture ratio	82.3%

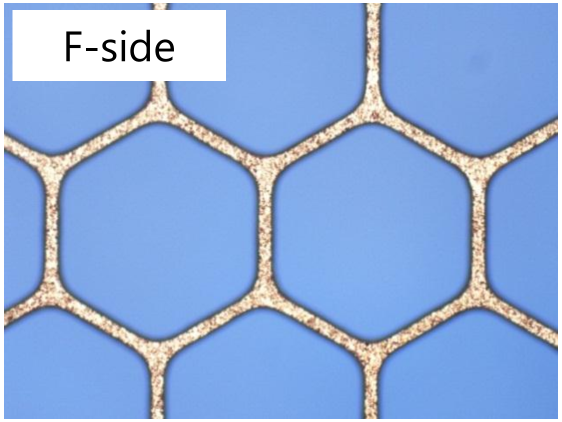
Many problems happened…



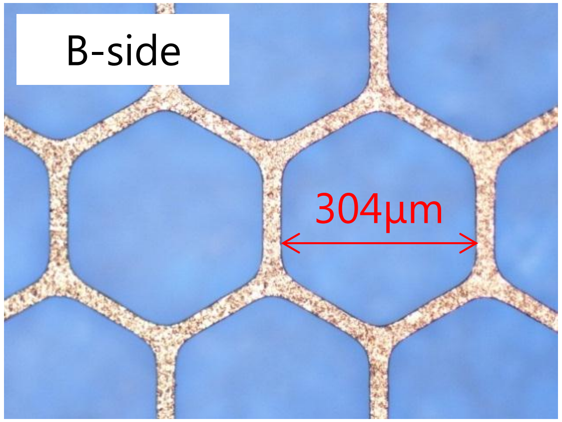
Pic3-1. Problem1
Effect of copper grain size



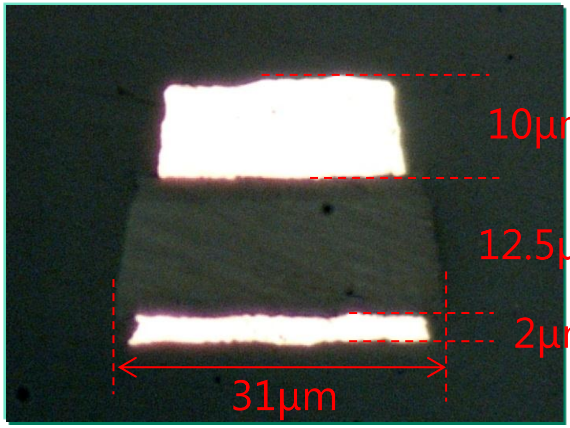
Pic3-2. Problem2
Effect of contact surface treatment on copper



Pic3-3. Surface of F-side



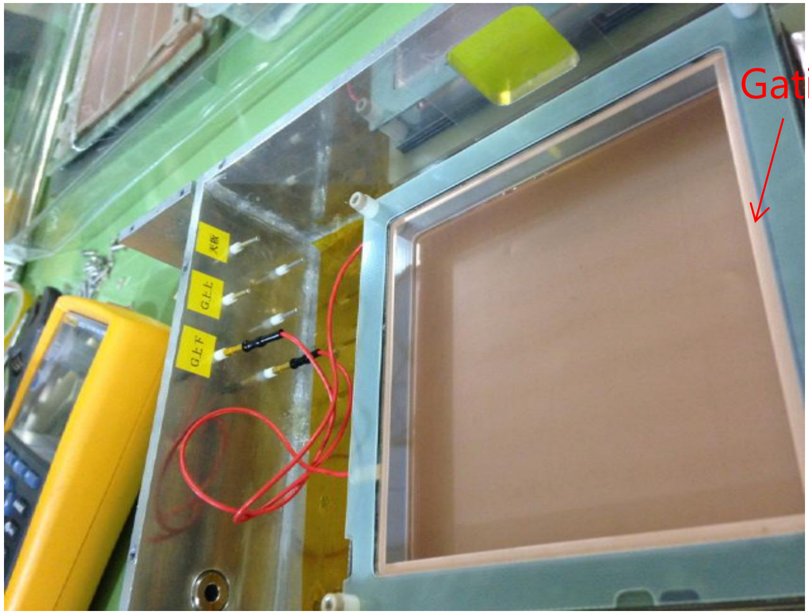
Pic3-4. Surface of F-side



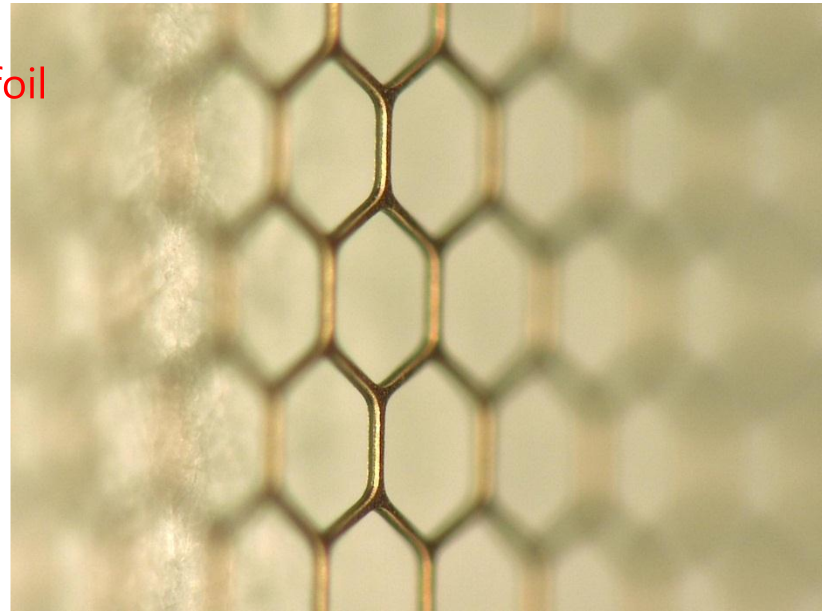
Pic3-5. Cross section of rim

3. Single mask process

We developed the Gating foil which optical aperture ratio is over 80% on 100mm x 100mm size with No Ni-plating single mask process !



Pic4-1. Gating foil on the Test module
(Test by Saga Uni. and ILC-TPC Gr)

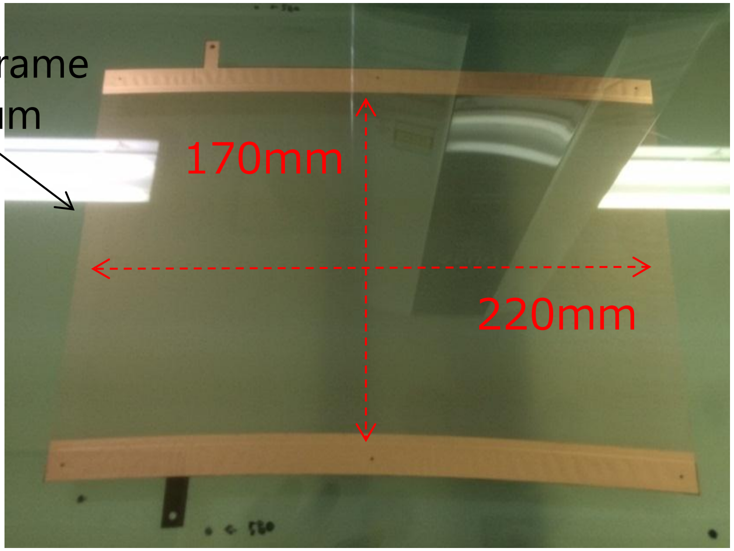


Pic4-2. Side view of Gating foil

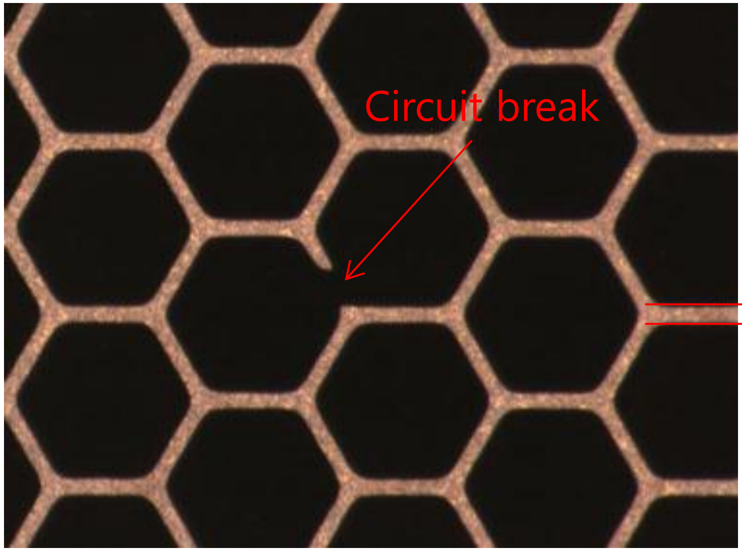
We established the stable process, and we tried to develop 2 items.

(1) Large size processing
(2) Fine electrode processing

- **Difficulty of Large size Gating foil production**
- We already developed the 170mm x 220mm size Gating foil with the No Ni-plating process.
- But there were a few electrode breaks in the Gating foil we developed.
- No electrode breaks are required for the 170mm x 220mm size.
- The cause of the electrode breaks is contamination on Photolithography process(=circuit formation process).



Pic5-1. Gating foil 170mm x 220mm size (but include a few electrode breaks)



Pic5-2. Circuit break after circuit formation

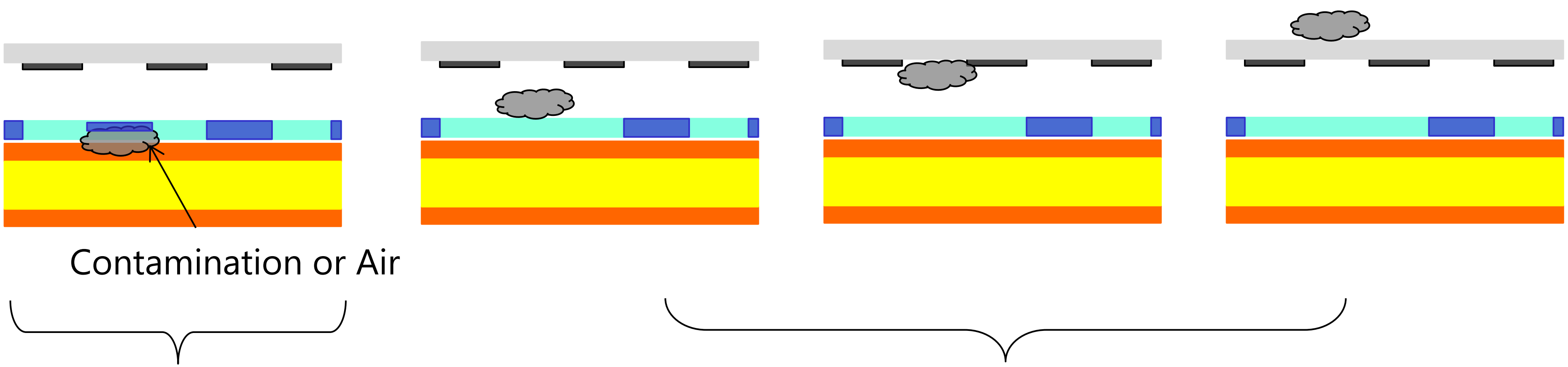
Large size processing : Problem

- **Difficulty of Large size Gating foil production**

■ Cause of circuit breaking

- The cause of circuit breaking is due to contamination on 4 possible places.
- The size of contamination is a few tens of μm.

(1) Under the photoresist (2) On the photoresist (3) Below the photomask (4) On the photomask



Optimization of photoresist

Improvement of cleanness on processing environment

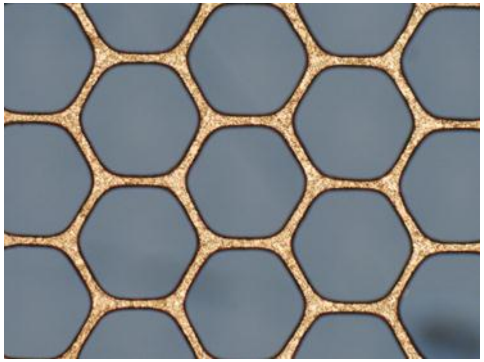
We already solved this problem by improving the cleanness of processing environment and optimization the photoresist.

Processing of Fine electrodes : Minimum rim width

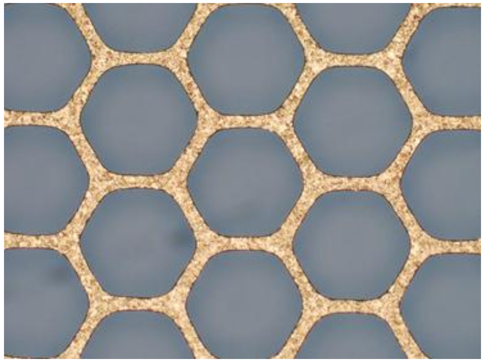
- **How fine can we process the electrodes?**
- We tried to process more fine electrodes using No Ni-plating single mask process.
- This time we processed only 30mm x 30mm size.
- We confirmed the diameter of the Gating foil holes of on 100µm, 150µm and 200µm.

■ Minimum rim width

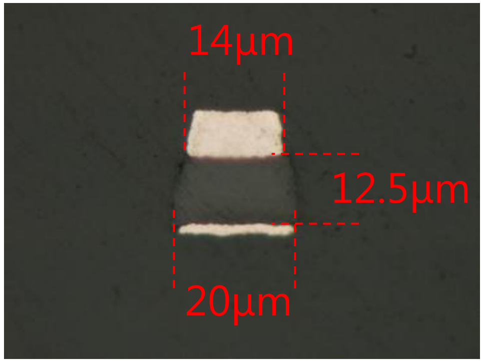
(1) φ205µm, 225µm pitch, Rim width : 20µm, Polyimide 12.5µm



Pic6-1. F-side
φ225µm, rim width 20µm



Pic6-2. B-side
φ225µm, rim width 20µm



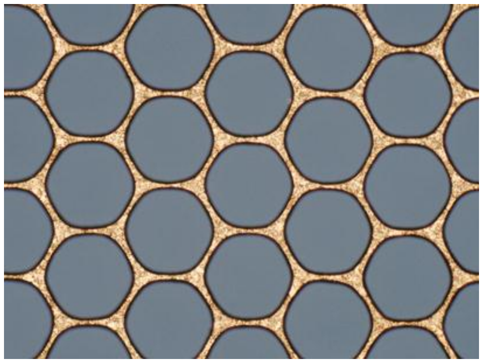
Pic6-3. Cross section
φ225µm, rim width 20µm

- Rim width : F-side 14µm , B-side 20µm
- We can process 20µm rim width and φ200µm honeycomb structure holes.

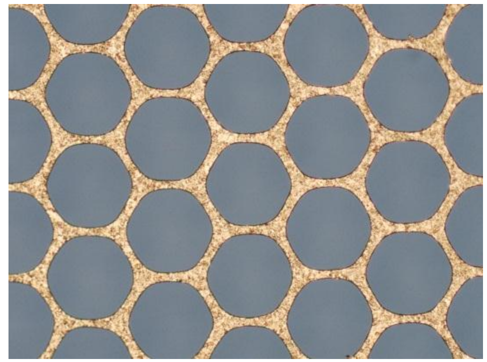
- **How fine can we process the electrodes ?**

■ Minimum rim width

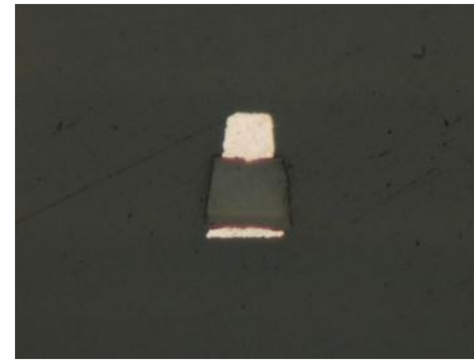
(2) φ153μm, 168μm pitch, Rim width : 15μm, Polyimide 12.5μm



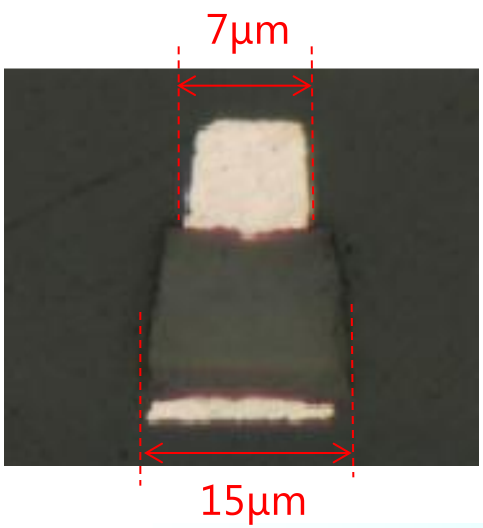
Pic7-1. F-side
φ168μm, rim width 15μm



Pic7-2. B-side
φ168μm, rim width 15μm



Pic7-3. Cross section
φ168μm, rim width 15μm



- F-side electrode width was 7μm.
- Copper was stripped from polyimide when the electrode width was about under 7μm.

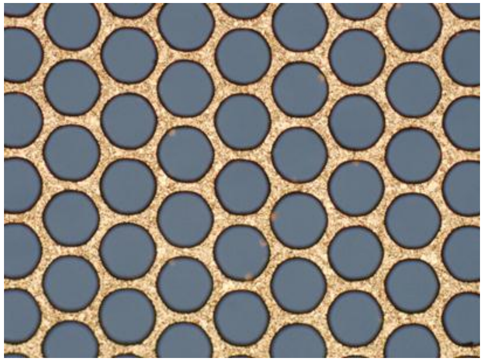
We confirmed the minimum rim width is 15μm.

Processing of Fine electrodes : Minimum hole size

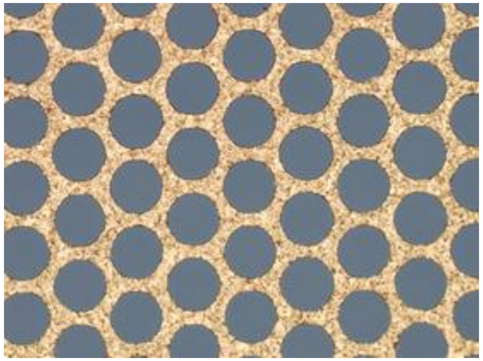
- **How fine can we process the electrodes ?**

■ Minimum hole size

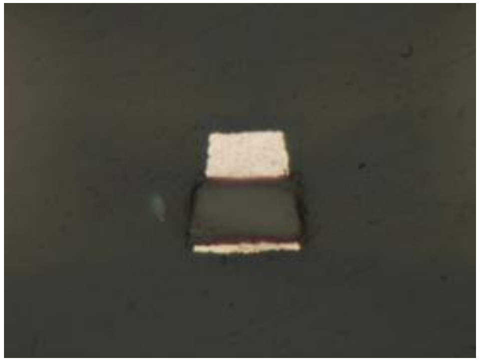
(3) φ97μm, 120μm pitch, Rim width : 23μm



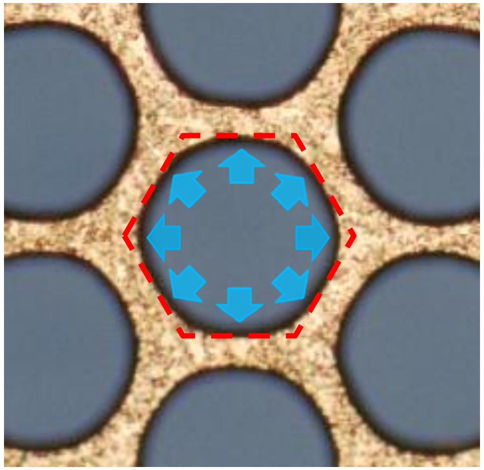
Pic8-1. F-side
φ97μm, rim width 23μm



Pic8-2. B-side
φ97μm, rim width 23μm



Pic8-3. Cross section
φ97μm, rim width 23μm

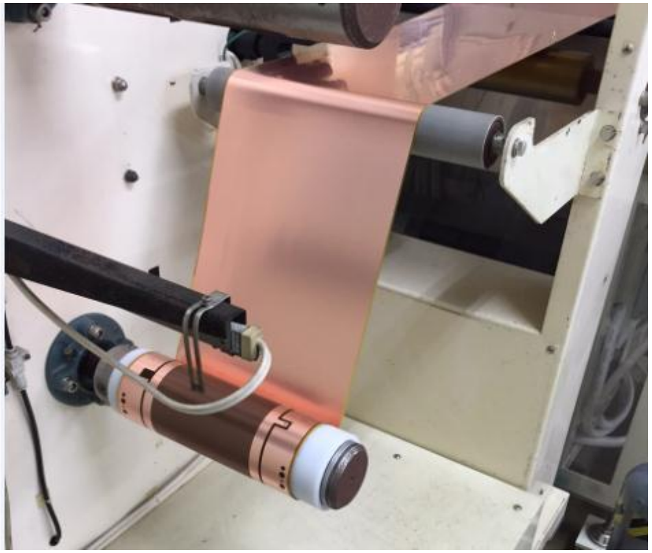


- Etching liquid etch the copper isotropically.
- It is difficult to make sharp edge especially for the small hole.

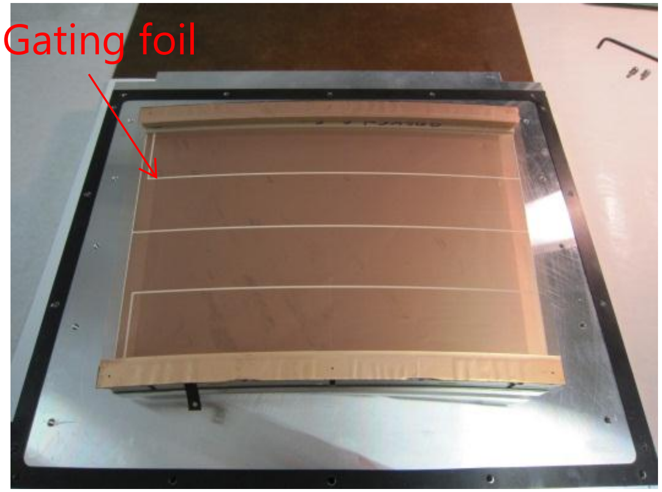
We can't process the honeycomb structure hole with a hole size of less than 150 μm

Summary

- ILC-TPC is planned to be equipped with a gating foil to inhibit the positive ion feedback.
- Gating foil like GEM structure which optical aperture ratio is over 80% is required.
- We tried to develop the Gating foil using FPC techniques especially Photolithography and Insulator removing.
- We developed the Gating foil with optical aperture of greater than 80% on 100mm x 100mm size with the No Ni-plating Single mask process.
- Large size (170mm x 220mm) processing had a problem with circuit breaking, but we already solved this problem.
- We confirmed the minimum rim width and hole size on 30mm x 30mm size. (minimum rim width : 15μm, minimum hole size 150μm)

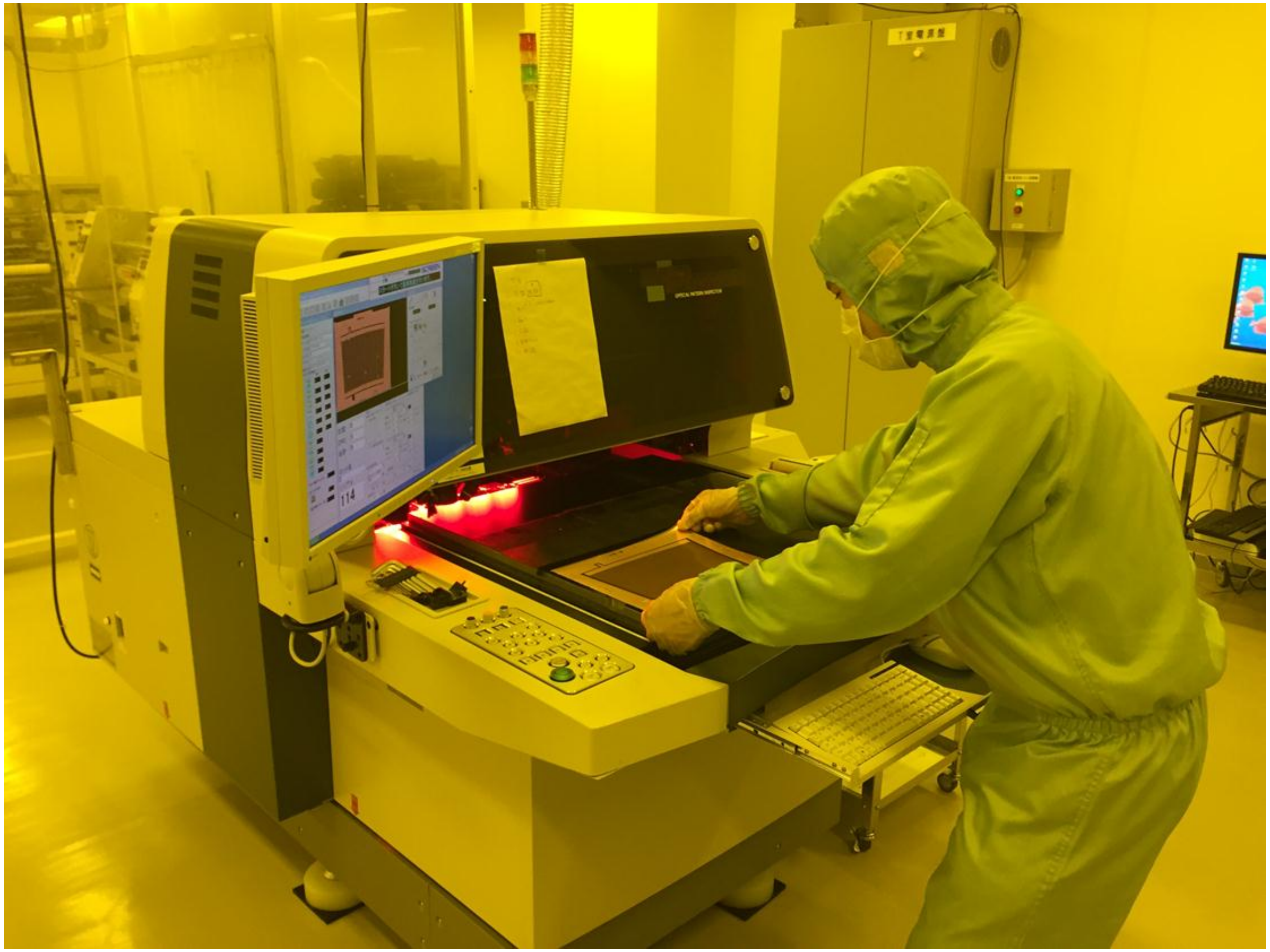


Pic9-1. Circuit formation process



Pic9-2. Gating foil on the TPC module 170mm x 220mm size

Thank you for your attention



Pic. Inspection of Circuit breaks by AOI (Automated Optical Inspection) machine

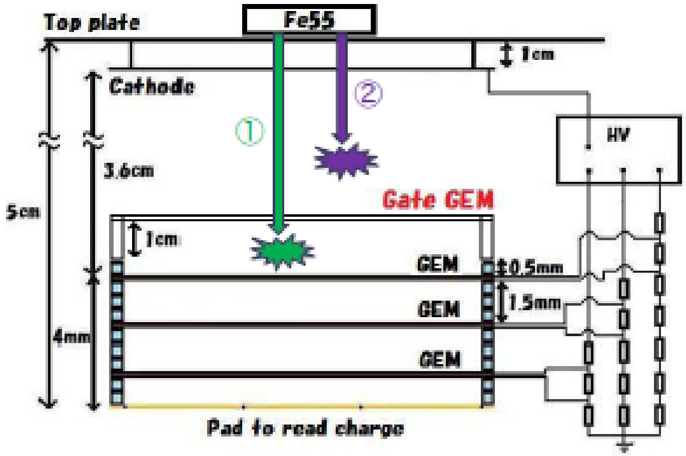
Back up

1. Electorn transmission

(1) Measurement method of Electron transimission

by comparing signal charge passing through the Gate-GEM to signal without Gate-GEM using a small test chamber irradiated with an 55Fe source, which is installed in a 1T MRI type super-conducting solenoid at KEK cryo center

Pic10-1. 1T MRI tpype super-conducting solenoid



Pic10-2. Measuremant module

using a CERN standard GEM readout (triple stack) and one of Fujikura Gate-GEM samples placed 10 mm above

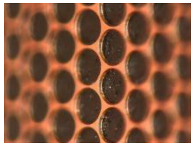
- **Case (2):** the conversion happens in the drift region, so that the produced electrons have to pass the gate and **the signal is affected by the gate transmission**
- **Case (1):** a small portion of the X-rays are converted in the region **between the gate and the amplification GEM,** which produces **signal without any effect of the gate**
- **Electron transmission:** calculated as **the ratio of the two signals**

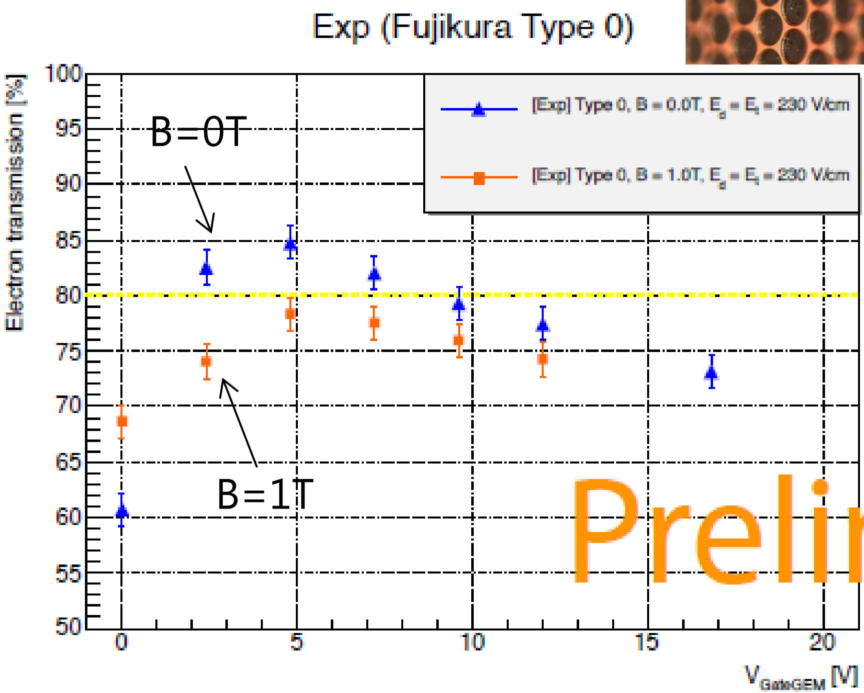
Refer from "Development of Large-Aperture GEMs as a Gating Device of ILC-TPC for Blocking Positive Ion Feedback" Katsumasa Ikematsu (Saga Uni.)

(2) Results of Electron transimission

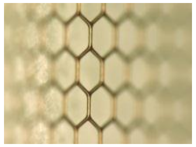
- We confirmed the electorn tronsimission of the honeycomb sturucture is over 80%.

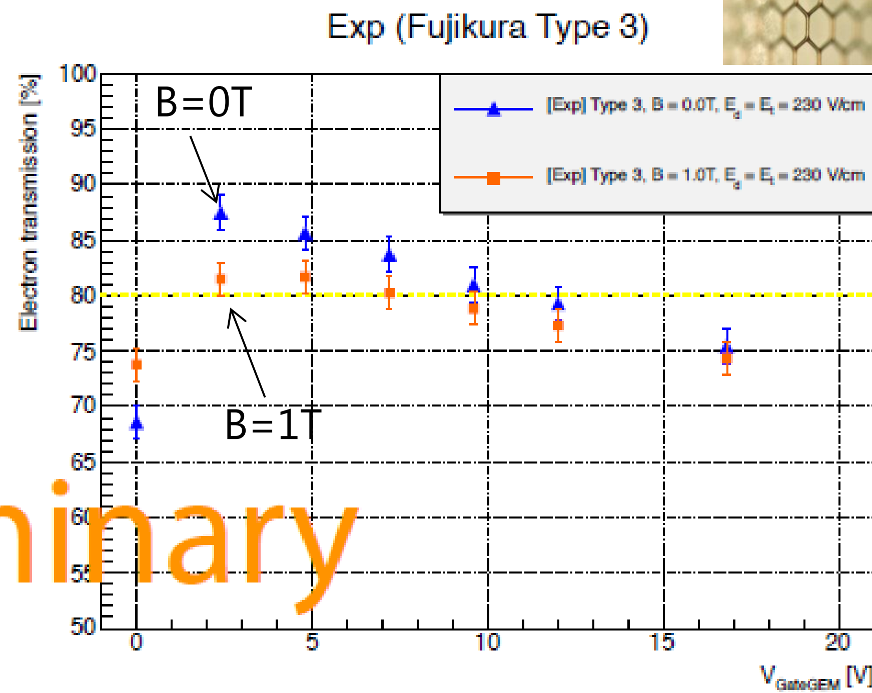
(2-1) Circle structure Gating foil
(Optical aperture ratio : 75.8%)





(2-2) Honey comb structure Gating foil
(Optical aperture ratio : 82.3%)



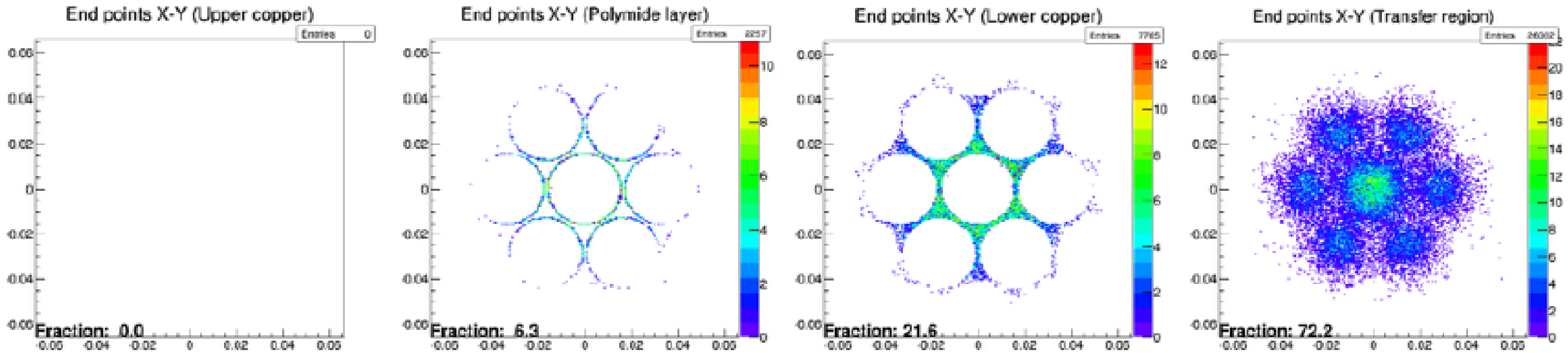


Preliminary

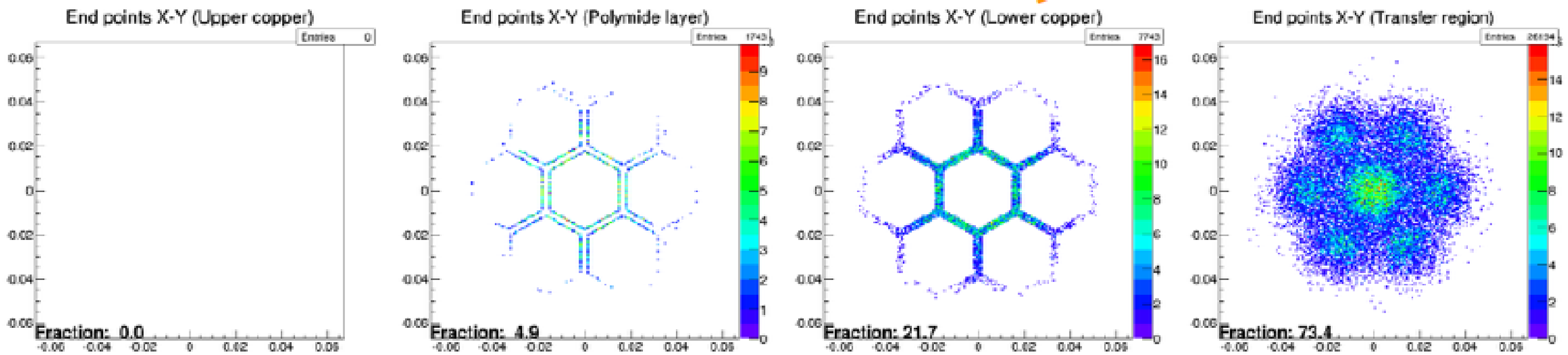
Refer from "Development of Large-Aperture GEMs as a Gating Device of ILC-TPC for Blocking Positive Ion Feedback"
Katsumasa Ikematsu (Saga Uni.)

(3) Simulation results of electron transmission

ANSYS-Garfield++ simulation (0 T, V_{gate} = 20 V)



Preliminary

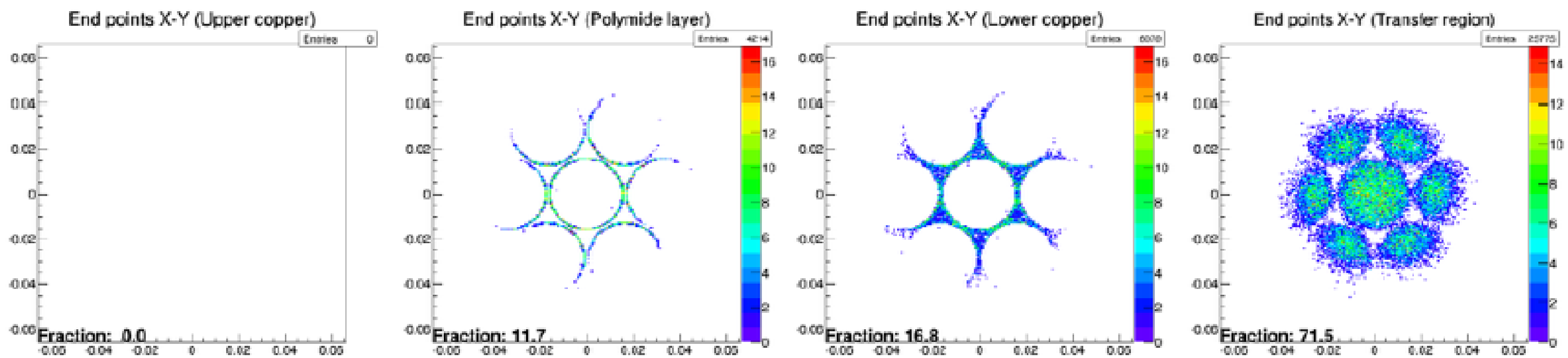


Refer from "Development of Large-Aperture GEMs as a Gating Device of ILC-TPC for Blocking Positive Ion Feedback" Katsumasa Ikematsu (Saga Uni.)

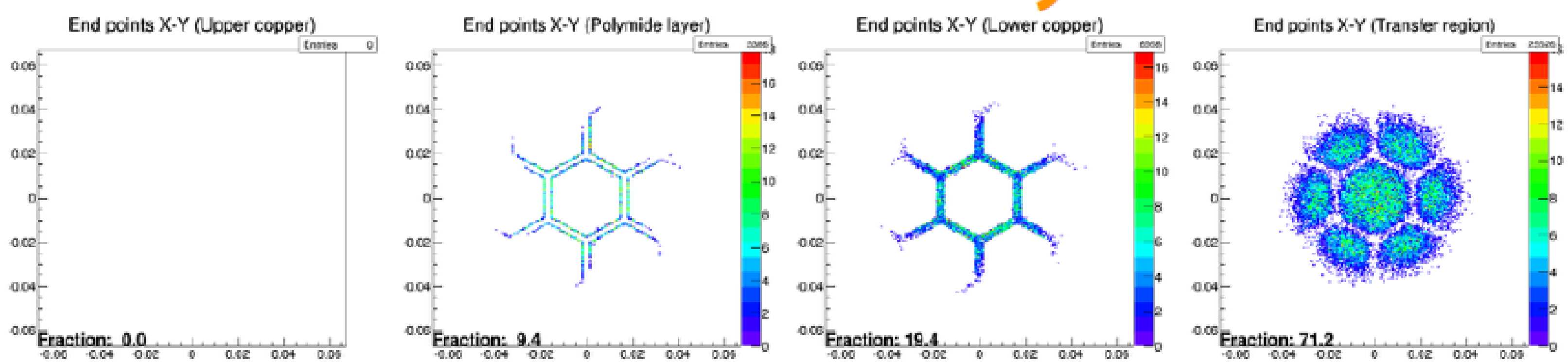
Fujikura

(3) Simulation results of electron transmission

ANSYS-Garfield++ simulation (1 T, V_{gate} = 20 V)



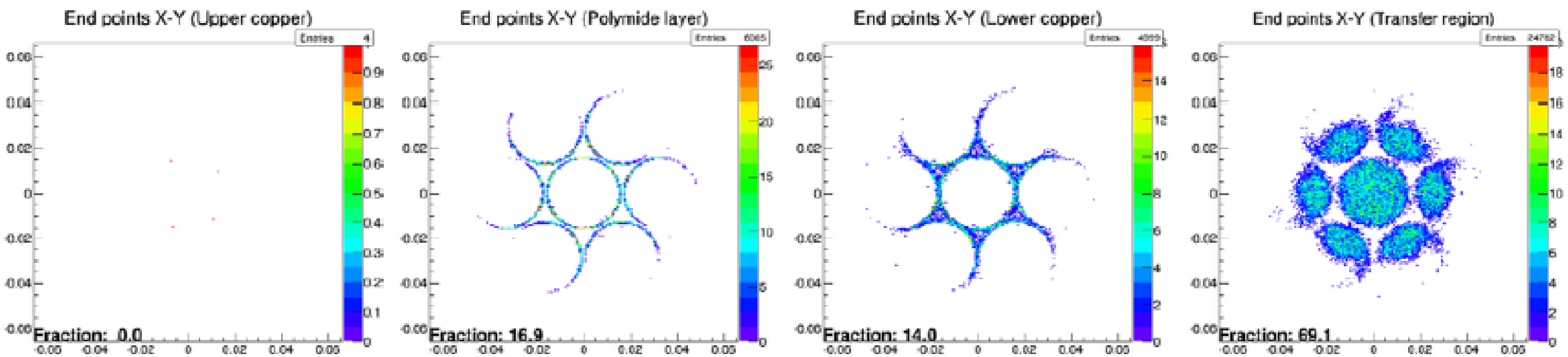
Preliminary



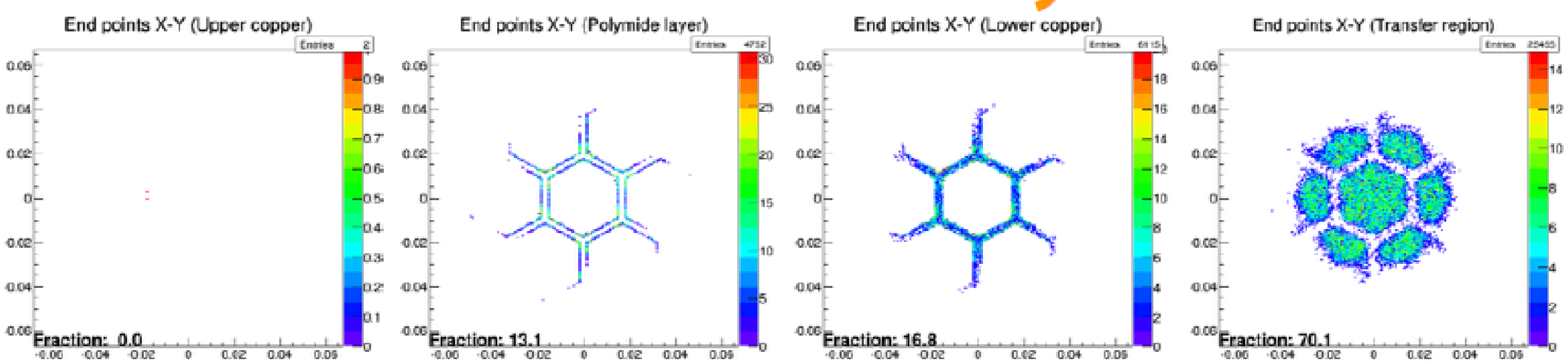
Refer from "Development of Large-Aperture GEMs as a Gating Device of ILC-TPC for Blocking Positive Ion Feedback" Katsumasa Ikematsu (Saga Uni.)

(3) Simulation results of electron transmission

ANSYS-Garfield++ simulation (3.5 T, V_{gate} = 20 V)



Preliminary

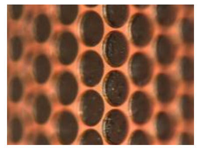


Refer from "Development of Large-Aperture GEMs as a Gating Device of ILC-TPC for Blocking Positive Ion Feedback" Katsumasa Ikematsu (Saga Uni.)

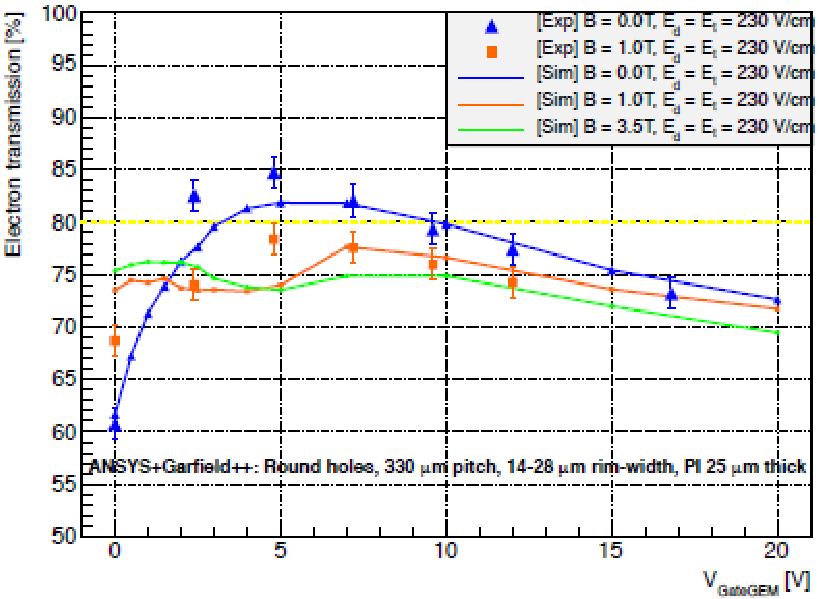
(3) Simulation results of electron transmission

- From the simulation results, we can get over 80% electorn tronsimission in the magnetic field 3.5T.

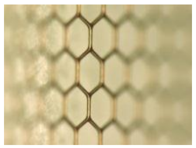
(2-1) Circle structure Gating foil
(Optical aperture ratio : 75.8%)



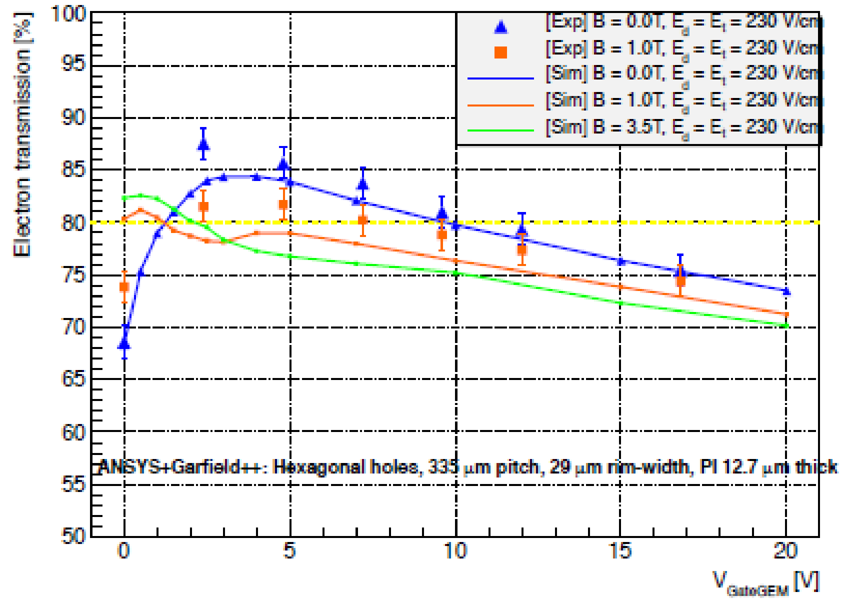
Exp vs Sim (Fujikura Type 0)



(2-2) Honey comb structure Gating foil
(Optical aperture ratio : 82.3%)



Exp vs Sim (Fujikura Type 3)



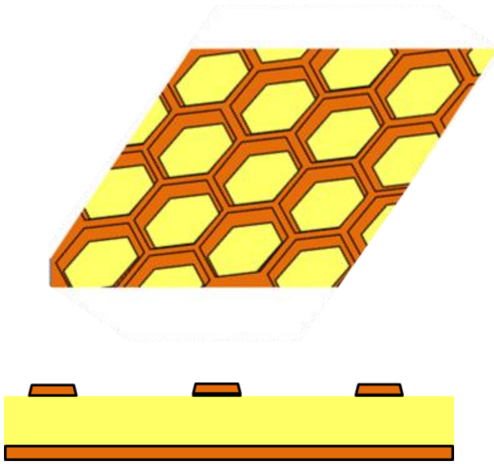
Preliminary

Refer from "Development of Large-Aperture GEMs as a Gating Device of ILC-TPC for Blocking Positive Ion Feedback"
Katsumasa Ikematsu (Saga Uni.)

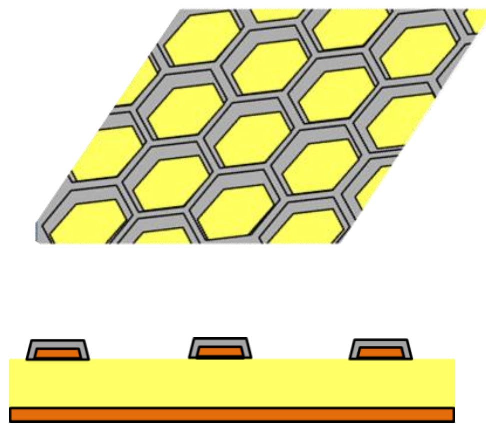
2. Ni-plating Single mask process

(1) Process

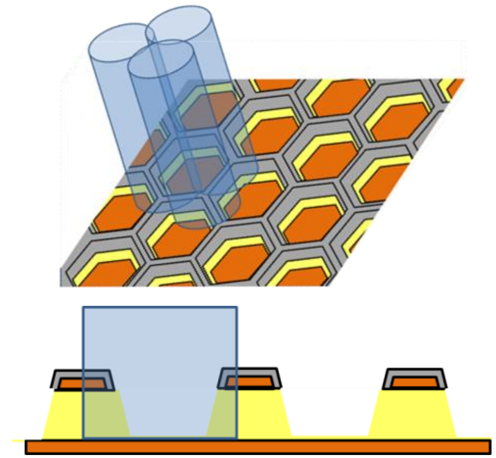
(1) Form the honeycomb circuit



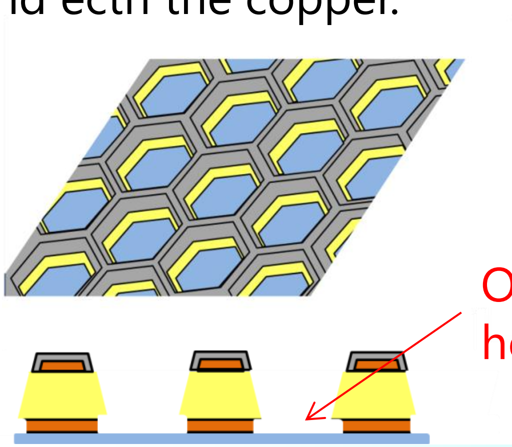
(2) Plating Ni on the circuit of F-side



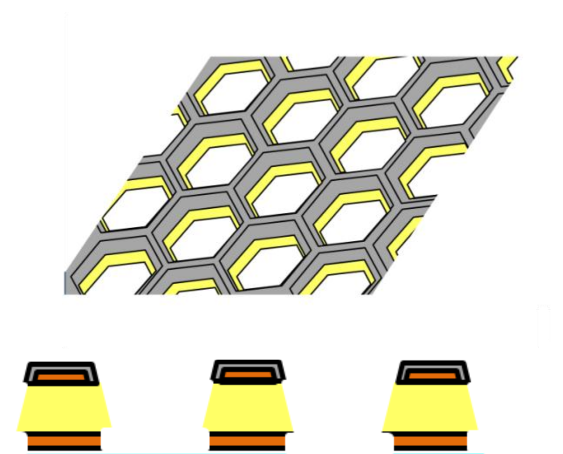
(3) Remove the polyimide by UV-YAG Laser



(4) Laminate the cover film on B-side, and ecth the copper.



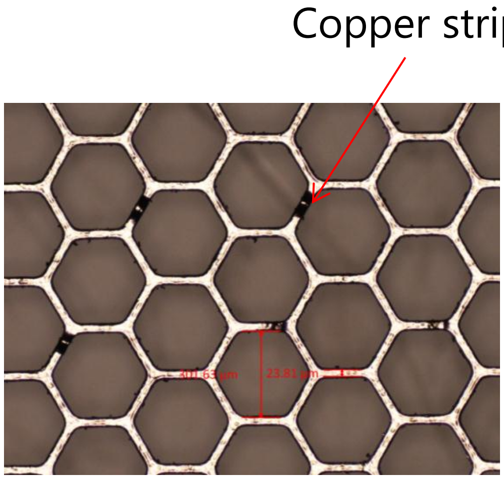
(5) Remove the cover film



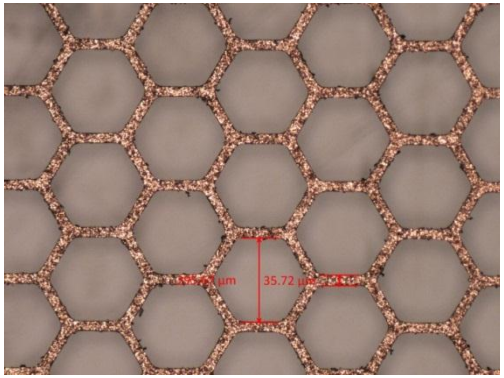
2. Ni-plating Single mask process

(2) Results

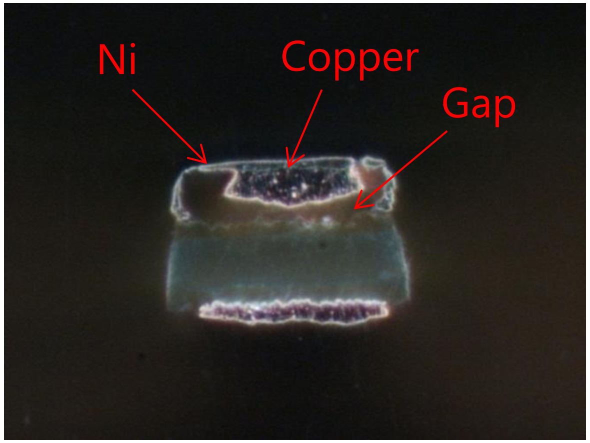
Item	Gating foil
Hole size	295μm
Hole pitch	330μm
Rim width : F-side	25μm
Rim width : B-side	35um
Insulator thickness	12.5μm
size	30mm x 30mm
Processing time	10min (only laser)
Optical aperture ratio	80.0%



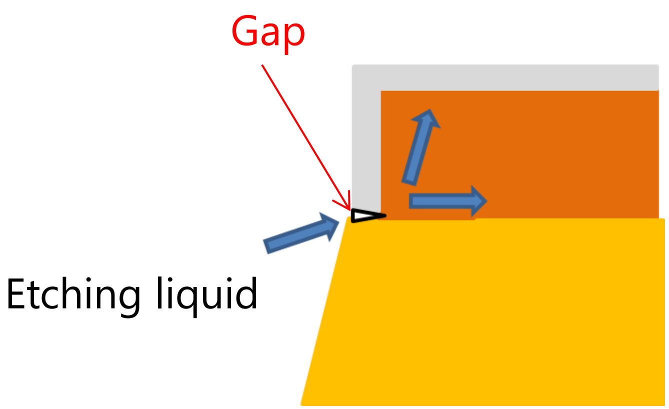
Pic11-1. F-side

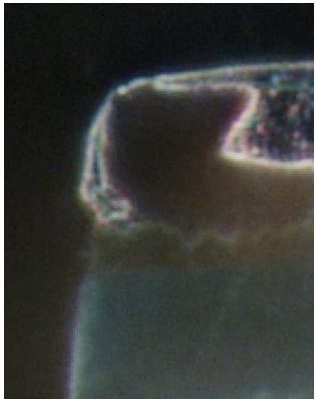


Pic11-2. B-side



Pic11-3. Cross section



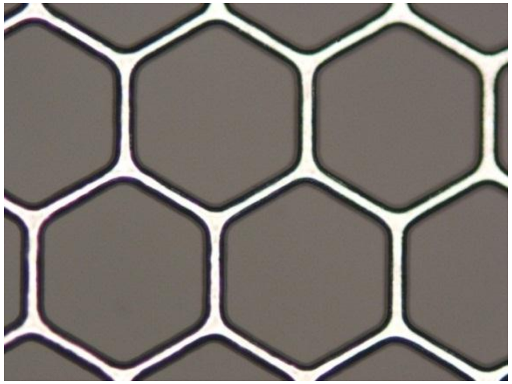


- Etching liquid ecth the copper under the Ni
- Copper stripped from the surface of polyimide

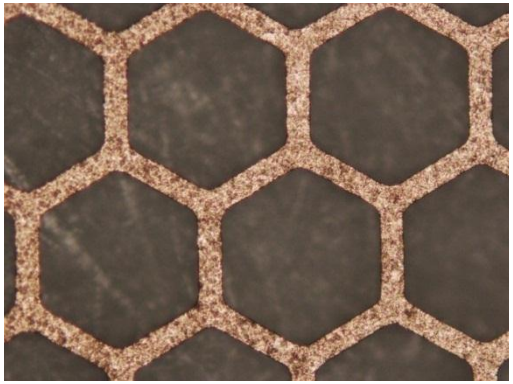
2. Ni-plating Single mask process

(2) Results

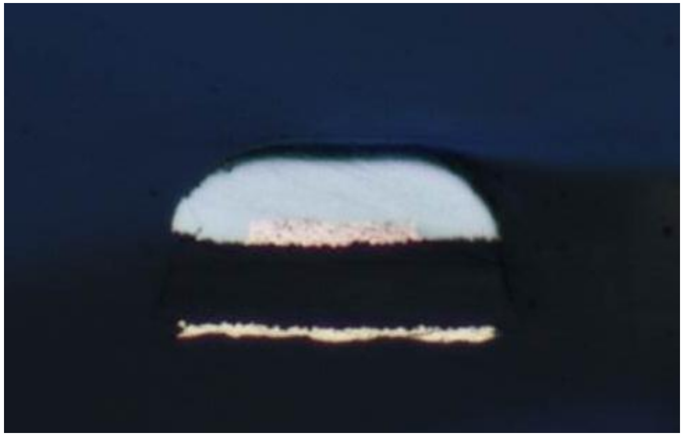
Item	Gating foil
Hole size	275μm
Hole pitch	315μm
Rim width : F-side	30μm
Rim width : B-side	40um
Insulator thickness	12.5μm
size	90mm x 90mm
Optical aperture ratio	76.0%



Pic12-1. F-side



Pic12-2. B-side



Pic12-3. Cross section

- We need to plate thick-Ni to protect the copper circuit.
- ILC-TPC is used in the high magnetic field 3.5T, so we don't use the Ni.
- Polyimide expose when we strip the Ni. (we can't make the collective electric field)
- Ni-plating Single mask isn't suitable for the Gating foil processing.

3. CO2 Laser and UV-YAG Laser

- Processing method of CO_2 laser is "Thermal processing" and UV-YAG laser is "Ablation".
- Ablation is Non-thermal processing, so we can process the polyimide with small damege.

Laser sourse	Wave length	Processing
CO_2	10.6μm	Thermal processing
UV-YAG	355nm	Ablation

■Laser ablation

Laser ablation is the process of removing material from a solid (or occasionally liquid) surface by irradiating it with a laser beam. At low laser flux, the material is heated by the absorbed laser energy and evaporates or sublimates. At high laser flux, the material is typically converted to a plasma. Usually, laser ablation refers to removing material with a pulsed laser, but it is possible to ablate material with a continuous wave laser beam if the laser intensity is high enough.

Measurement results

- We confirmed the processing accuracy of electrodes on the No Ni-plating Single mask process.
- We measured the rim width on 5 position (center and 4 corners) in 3 samples.

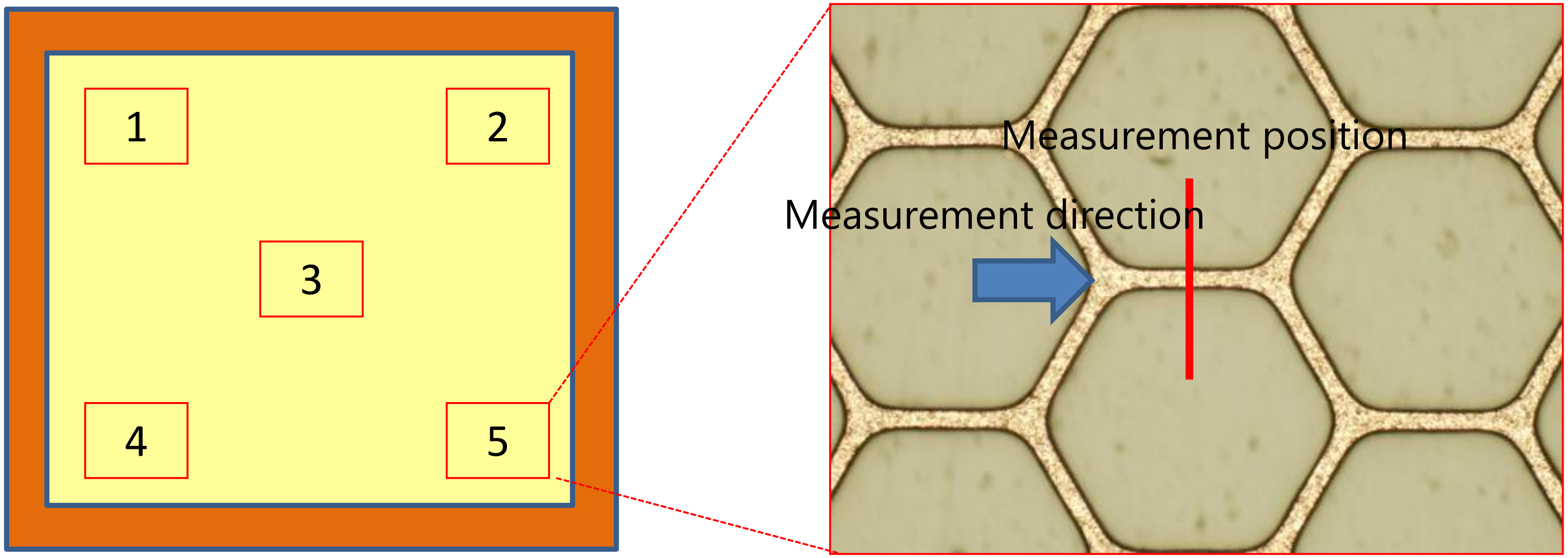
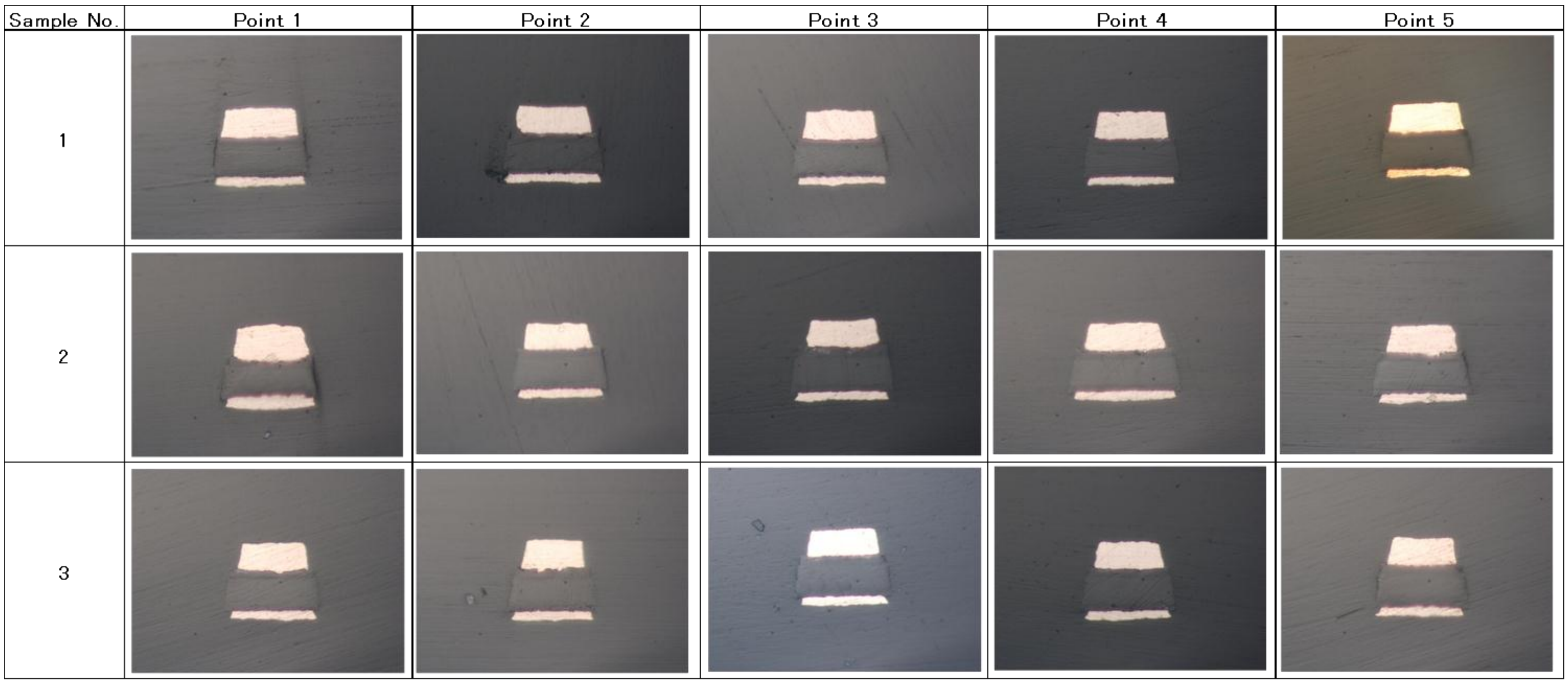


Fig6. Measurement position

4. Accuracy of Single mask processing

Measurement results

	Rim width (um)		Copper thickness(um)	
	F-side	B-side	F-side	B-side
ave.	26.74	30.96	9.20	2.83
Max-Min	6.87	7.27	3.19	0.89
3σ	4.66	5.03	2.33	0.69



5. Distortion of Ion Feedback

Simulation results

- Distortion of the reconstructed track is Maximum 90um.

e^+e^- Pairs ➡ max 60μm $\gamma\gamma \rightarrow$ Hadrons ➡ max 30μm

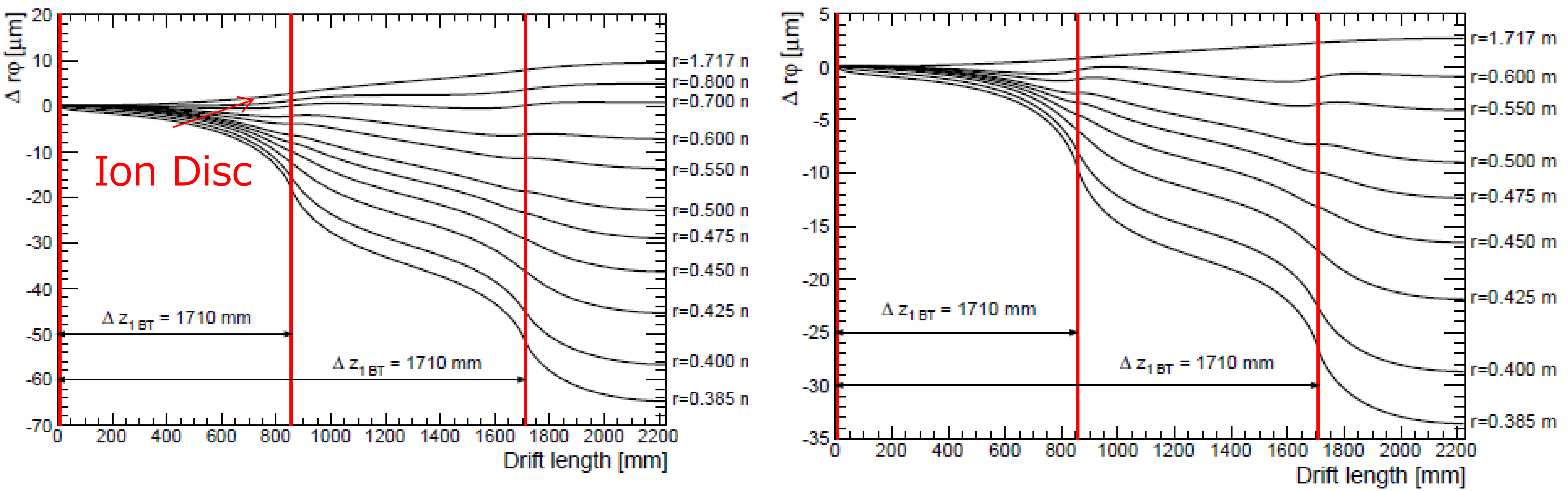
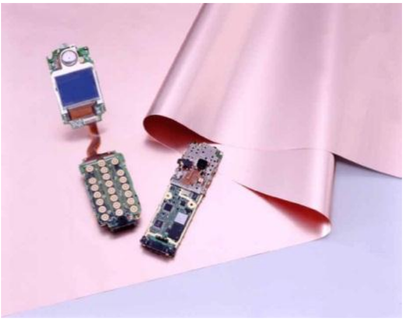


Fig7-1. Simulation results of disitortion fromIon Feedback

引用文献 "Simulation of Field Distortions because of Ion Back Drift" Thorsten Krautscheid

6. CCL : Copper Clad Laminate



Material for Gating Foil

- CCL is a basic material on the FPC production.
- We can select 3 types of CCL.
- We need to use the 2Layer CCL for Gating foil production, beacuse adhesive layer easily be damaged by Laser.
- Treatment on the contact surface of copper is very important for the B-side copper etching processing.

(1) 3 Layer CCL (2) 2 Layer CCL (3) Sputter CCL