Development of gating foils to inhibit ion feedback for ILC-TPC

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Positive Ion feedback in ILC TPC

- **Positive Ion Feedback in ILC TPC**
- 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 (~2m) @3.5T
- Simulation result shows we need the gating device.

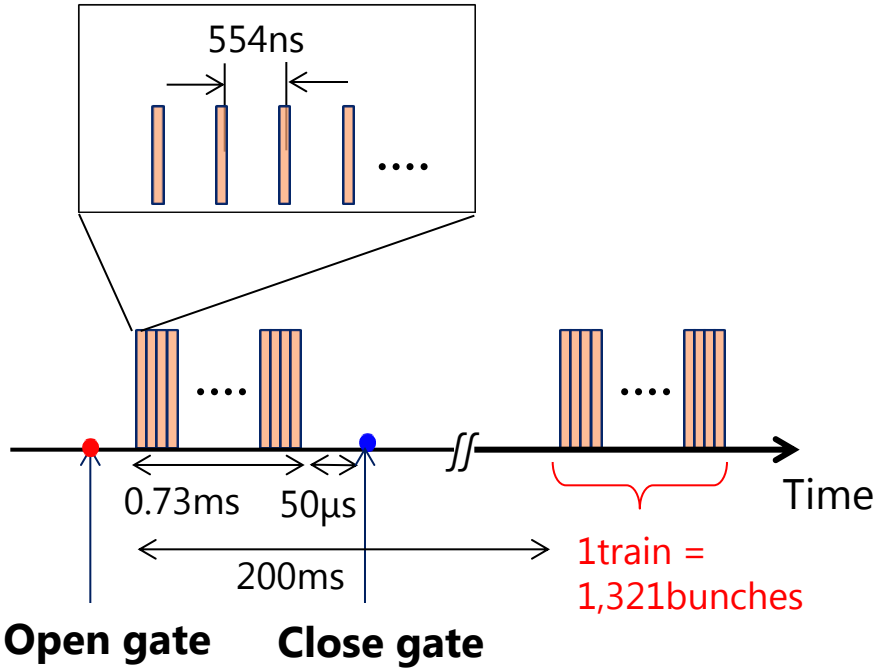


Fig 1-1. ILC beam structure

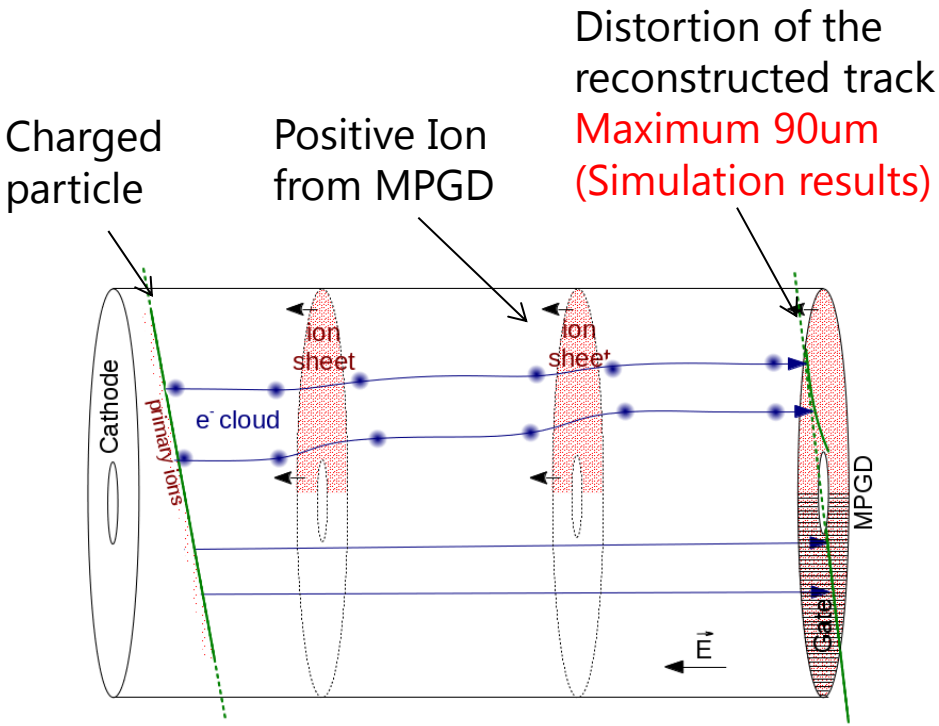


Fig 1-2. Positive ion feedback in ILC TPC

Gating device

- **Gating device for ILC TPC**

- Mounting the gating device having a foil structure near the MPGD to stop the feedback of positive ions.

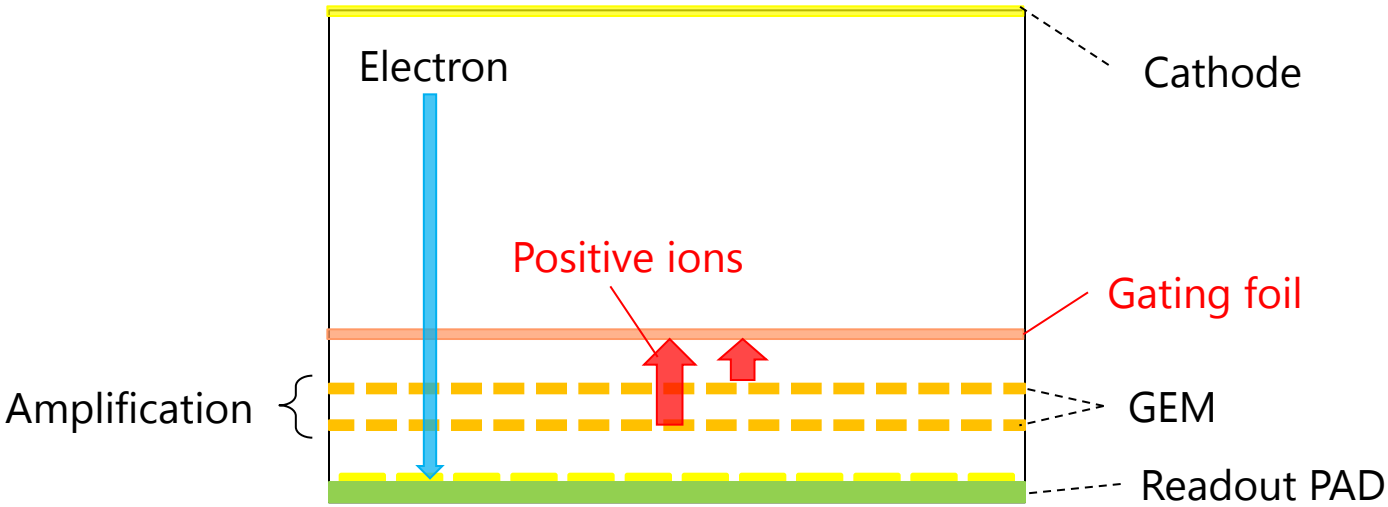


Fig 2. Mounting image of gating foil on the amplification module

■ **What is 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.

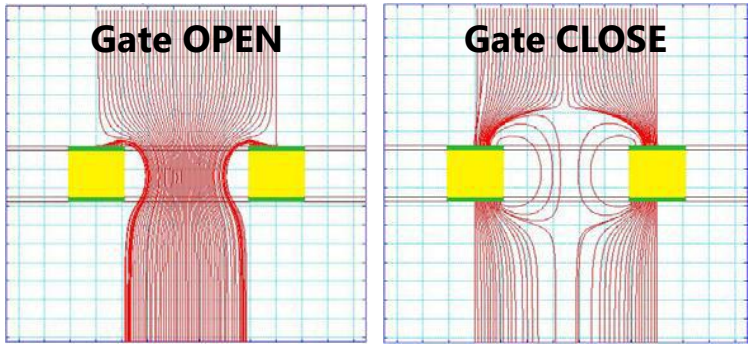


Fig 3. Electric field of gating foil

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 electron transmission is closely related to optical aperture of the gating foil.

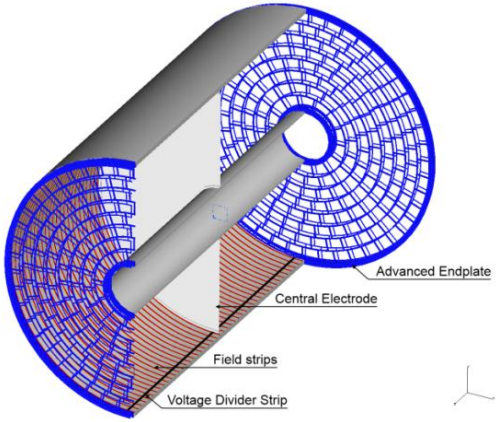


Fig 4. Image of ILC-TPC
(model with 8 rows of modules)

■ **Requirement spec for Gating foil and Amplification GEM**

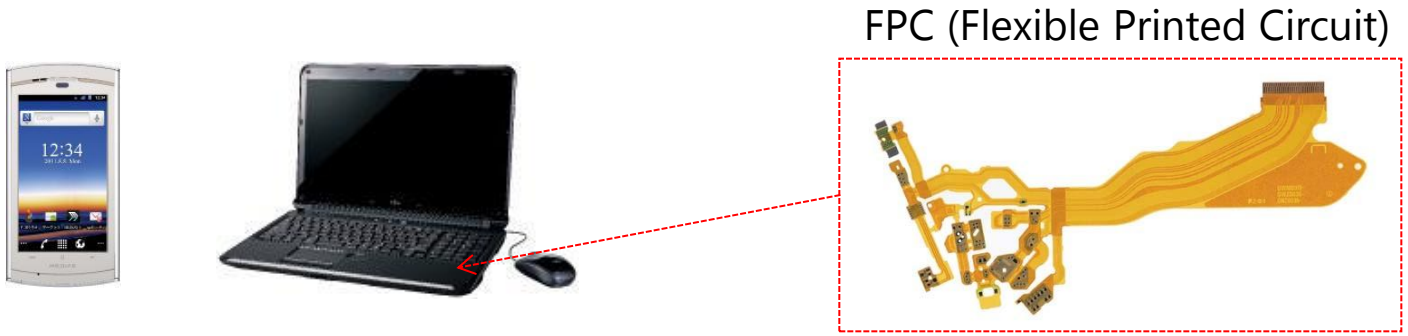
Item	Gating foil	Amplification GEM
Optical aperture ratio	≧80%	22.7%
Hole size	≦ 300μm	70μm
Hole pitch	≦335μm	140μm
Rim width (Hole pitch - Hole size)	≦35μm	70μm
Insulator thickness	≦25μm	50μm or 100μm
Foil size	170mm x 220mm	170mm x 220mm

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.



■ 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

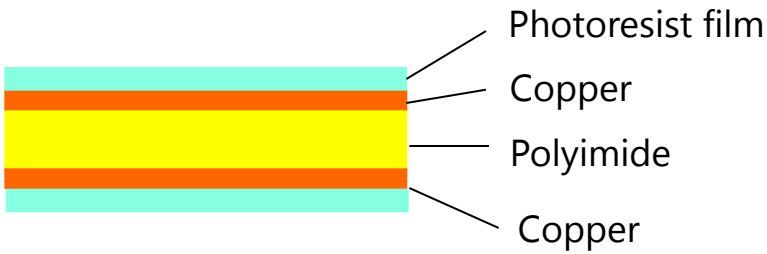
Table 2. Relationship between GEM and FPC

Key techniques of FPC and GEM production

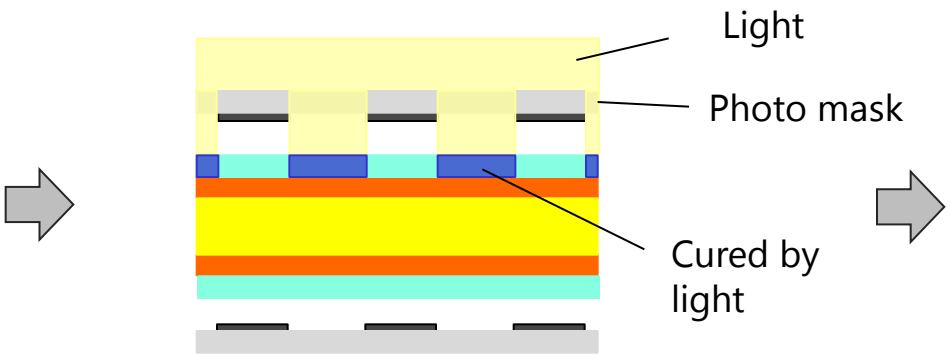
- **Key techniques of Gating foil production**

■ Production method of Double Layer FPC

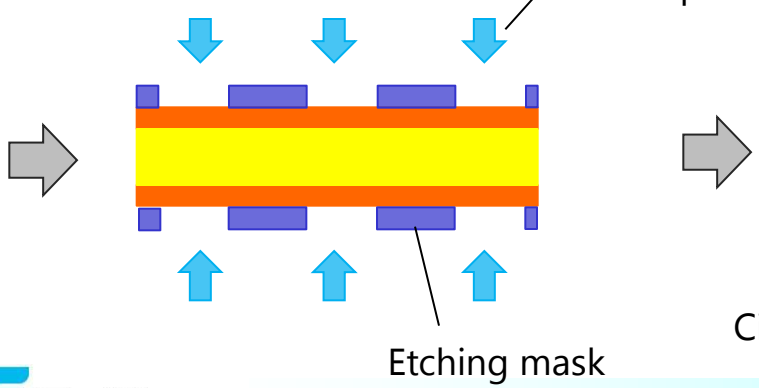
(1) Laminate the photoresist film on the CCL (Copper Clad Laminate)



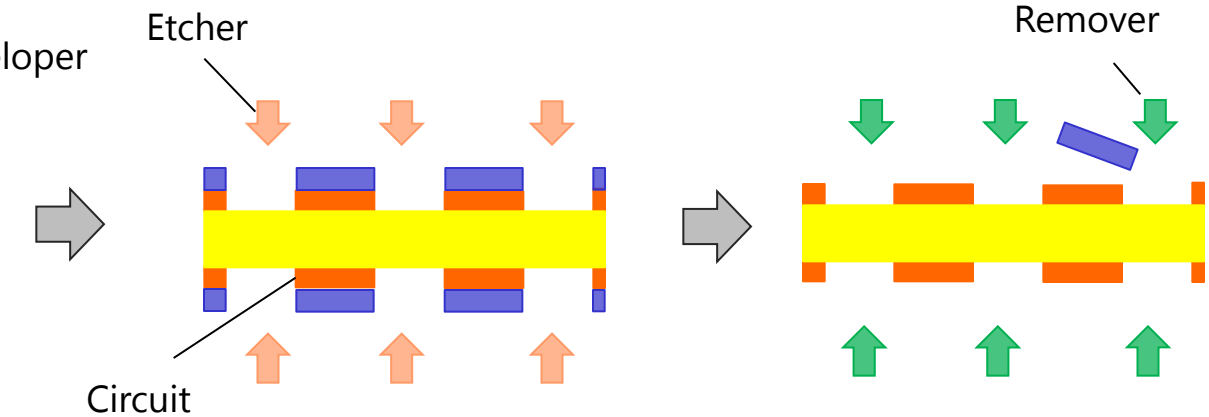
(2) Expose the film using the photo mask



(3) Photoresist development



(4) Etching and remove the photoresist



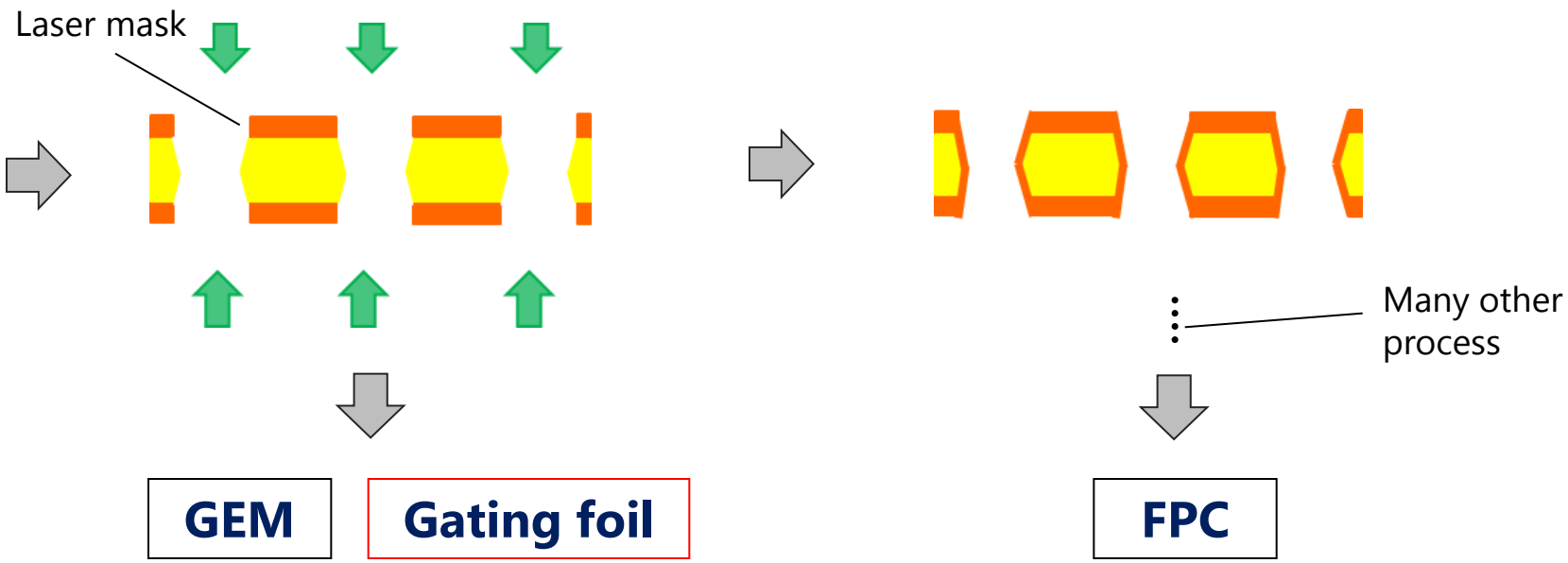
Our Goal

- **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 FPC production techniques.

Difficulty of Gating foil processing

■ What is a difficulty of Gating foil processing

- Gating foil has very fine structure. (Narrow rim and thin thickness insulator)
- The size of the gating foil (170mm x 220mm) is so larger than FPC products (a few of tens mm).
- Processing of the gating foil is so challenging even for FPC manufacturers.

Item	Gating foil
Optical aperture ratio	≧80%
Hole size	≦ 300μm
Hole pitch	≦335μm
Rim width (Hole pitch - Hole size)	≦35μm
Insulator thickness	≦25μm
Foil size	170mm x 220mm

Table 3. GEM production methods

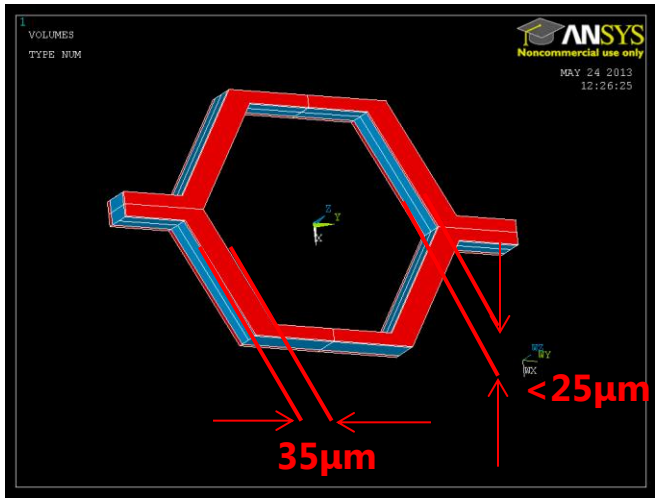


Fig5. Hole image of the gating foil

We don't know how can we process the gating foil…

Gating foil processing : Double mask

■ Production methods for gating foil processing

- We tried to study about 3 production methods.

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

Table 4. 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.

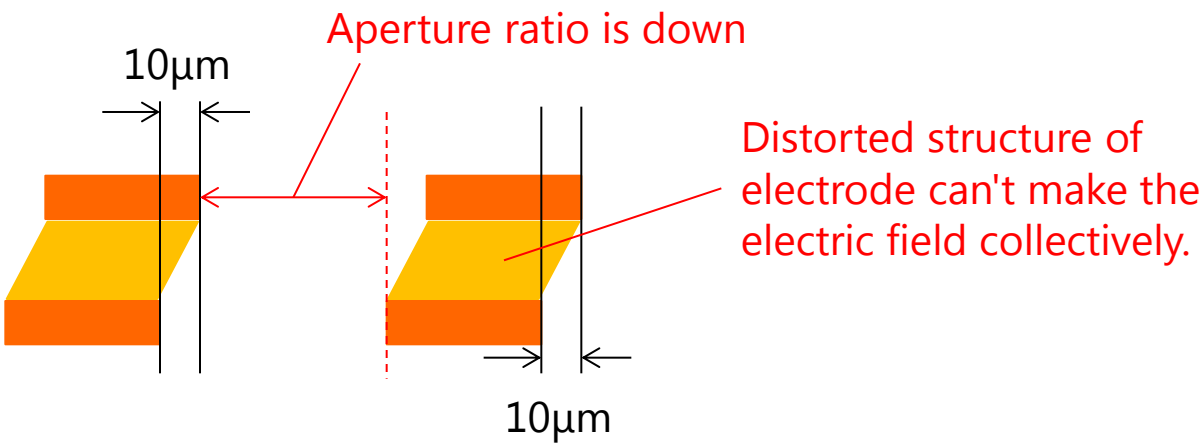


Fig 6. Image of rim (Double mask process)

Laser drilling process - 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.

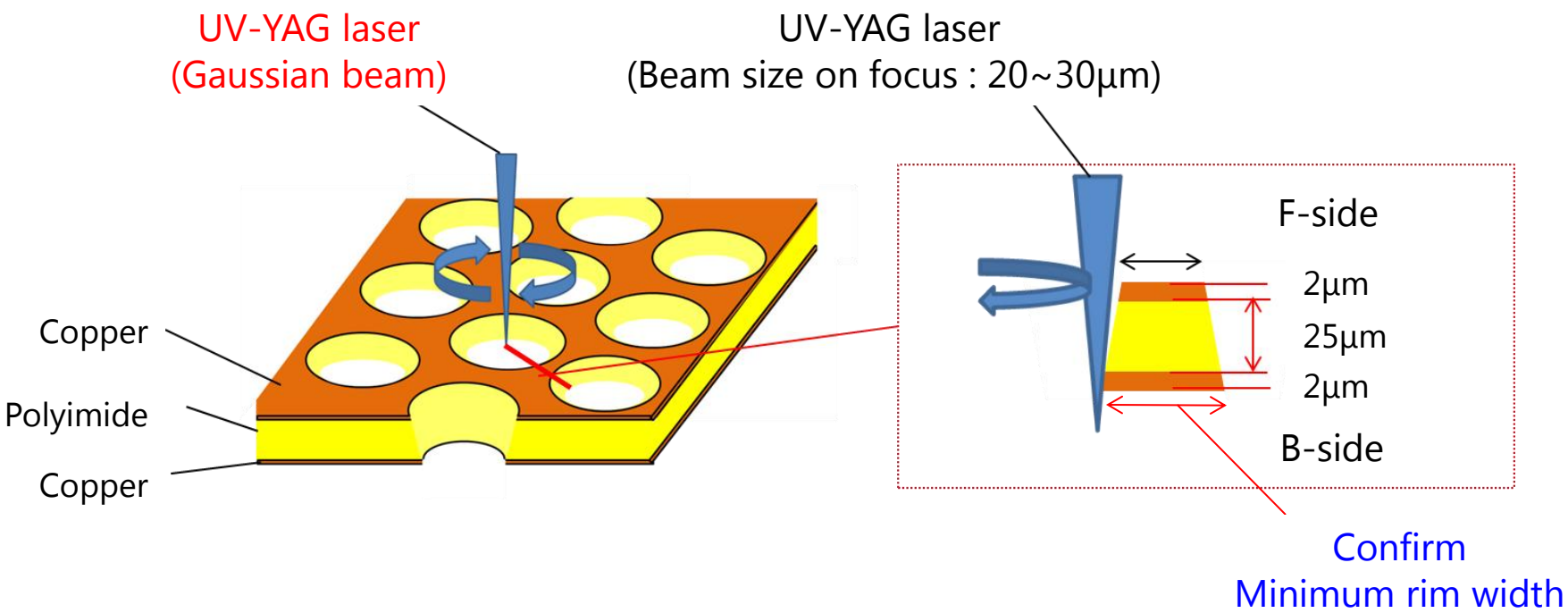


Fig 7. Image of Laser drilling process

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%

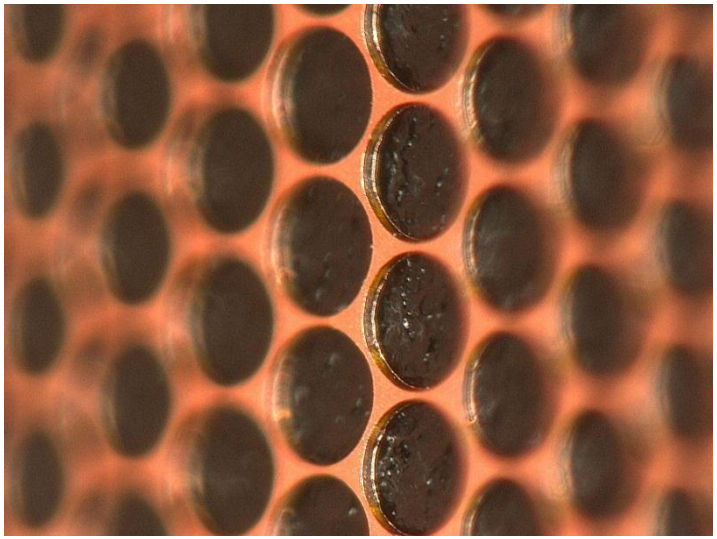


Fig 8. Surface of F-side

- Minimum rim width is 28μm. (Under 35μm)
- The rim didn't break and maintained the fine structure. (Fig.8)
- 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…

Laser drilling process - Problem

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.

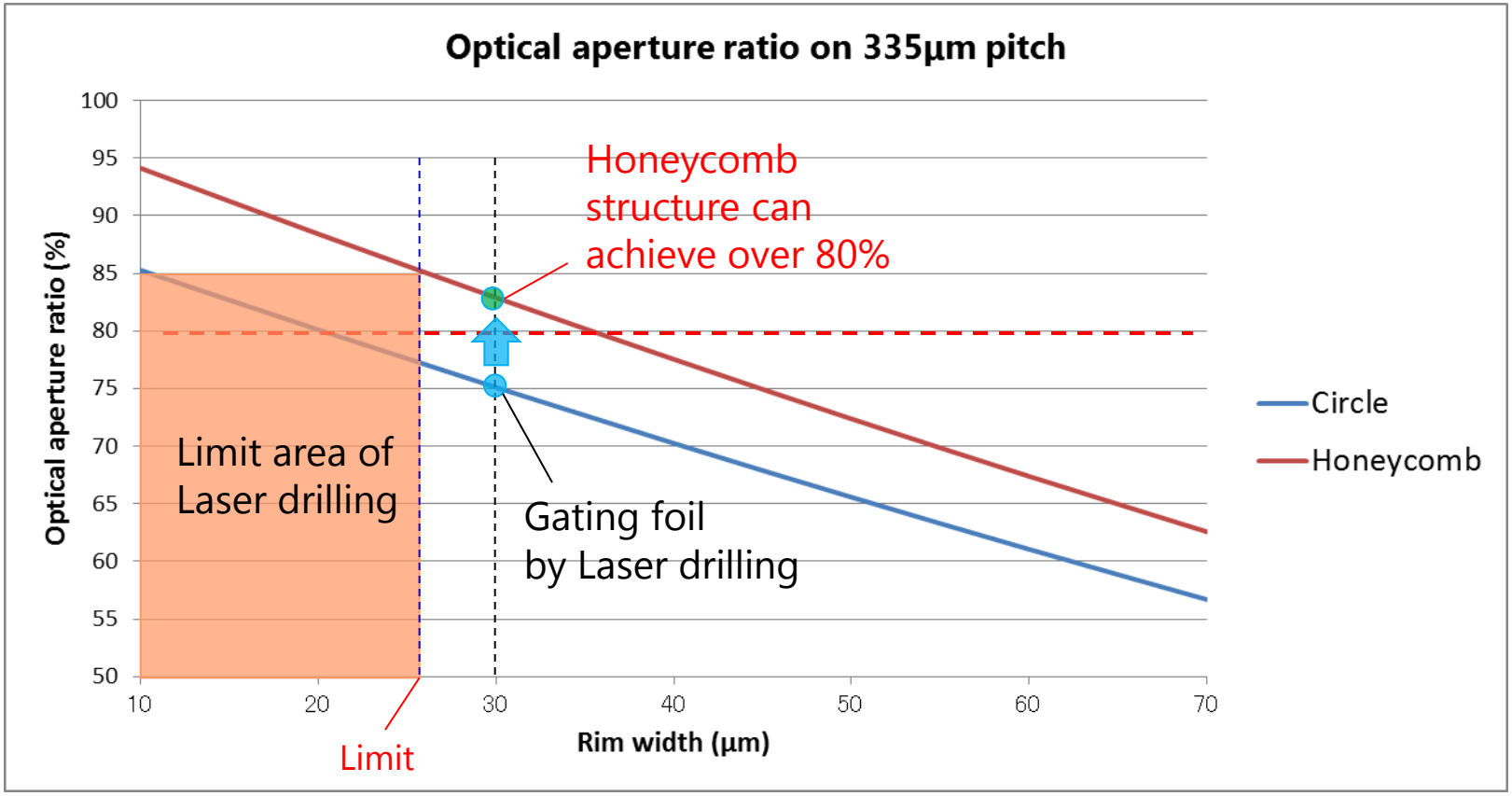


Fig 9. Relationship between Rim size and Optical aperture ratio on 335µm hole pitch

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

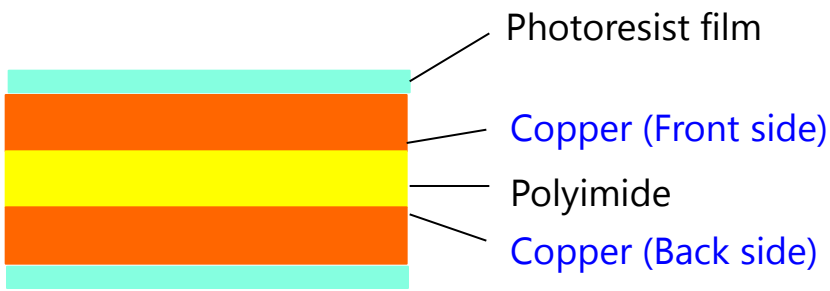
Single mask process with Ni-plating : Process

3. Single mask process

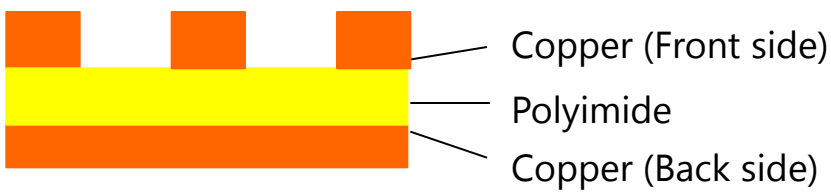
- Single mask process don't need photomask alignment.
- We need to consider the etching method for back side copper
- Ni-plating is usually used as the etching mask for B-side copper etching.

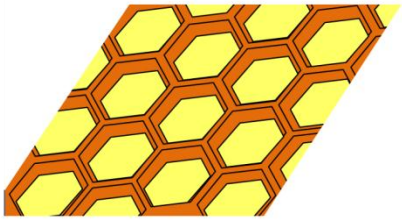
■ Single mask process with Ni plating

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



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

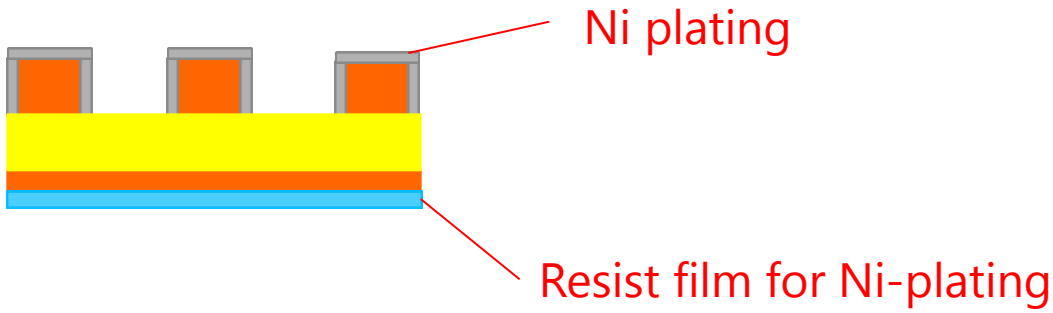


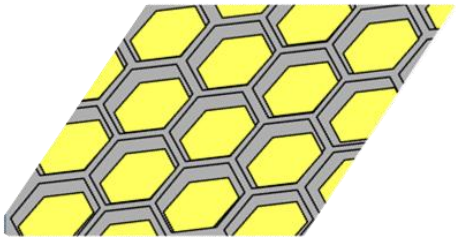


Single mask process with Ni-plating : Process

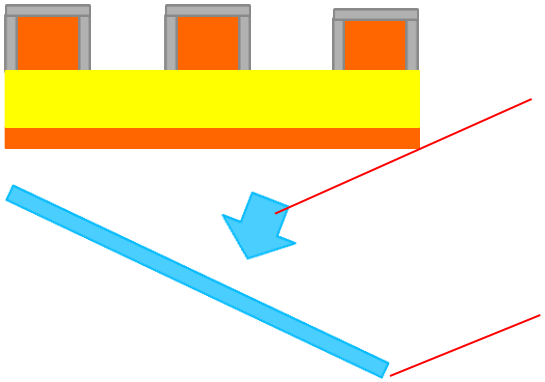
3. Single mask process

(3) Plate Ni on the front side copper





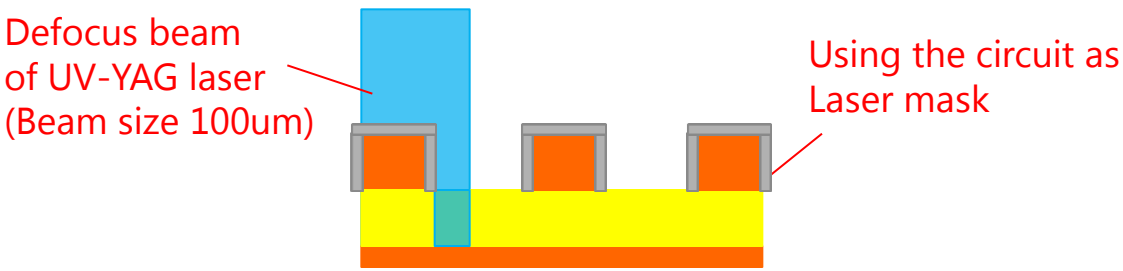
(4) Remove the resist film

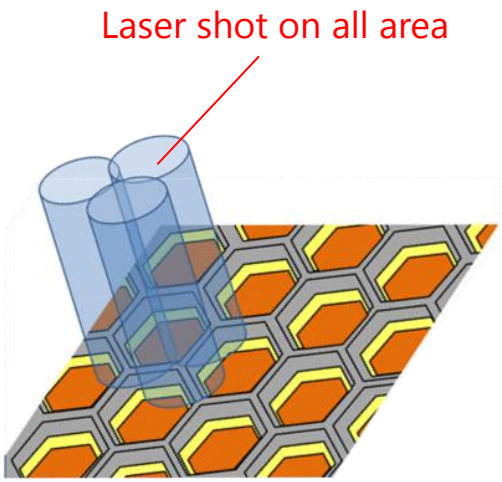


Single mask process with Ni-plating : Process

3. Single mask process

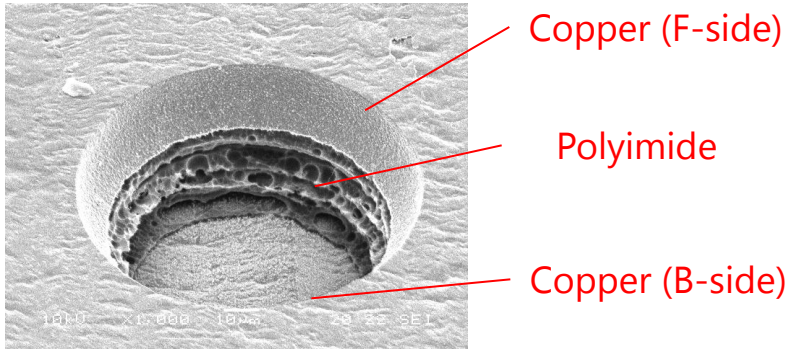
(3) Remove the polyimide by UV-YAG Laser





■ 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)



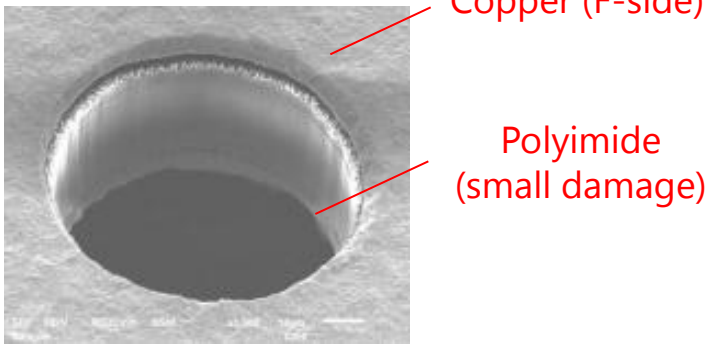
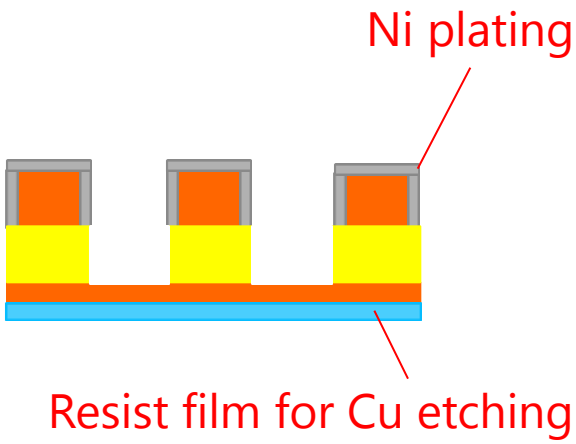


Fig10. Damage of polyimide by UV-YAG Laser and CO2 Laser

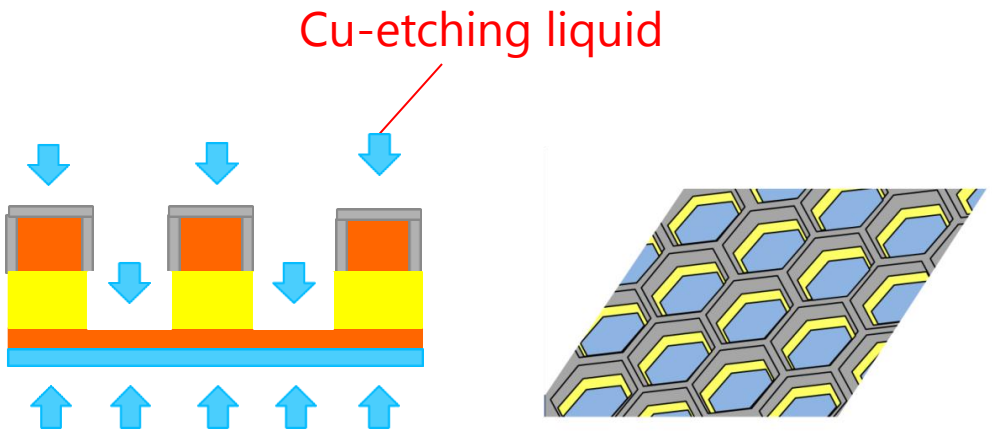
Single mask process with Ni-plating : Process

3. Single mask process

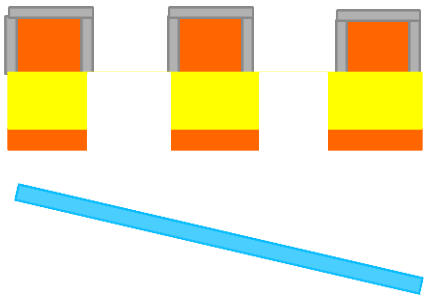
(4) Laminate the etching resist

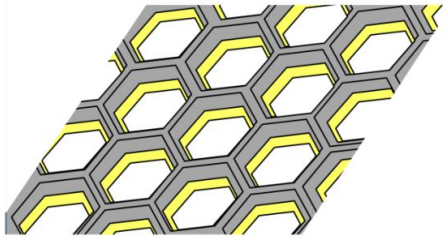


(5) Etch the copper from both side



(6) Remove the resist film



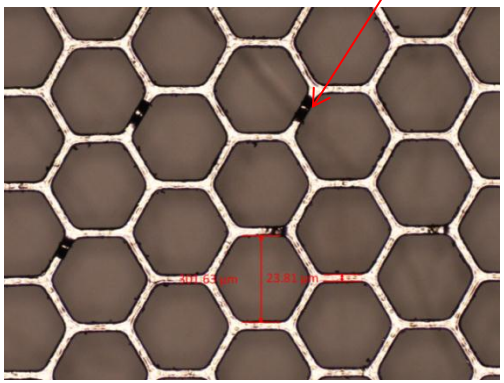


Single mask process with Ni-plating : Results

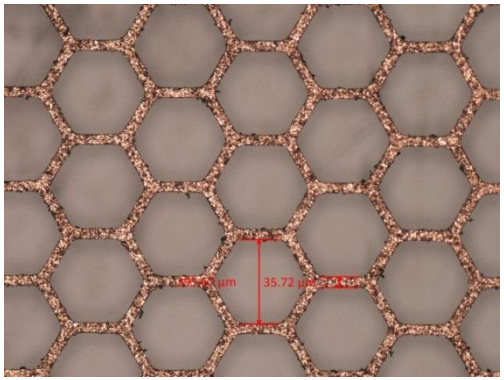
■ Results

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%

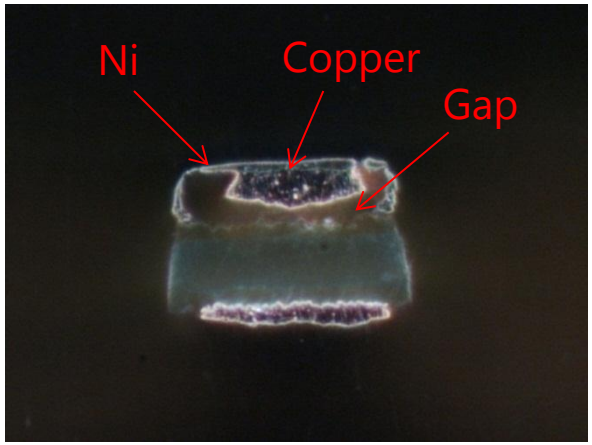
Copper stripped



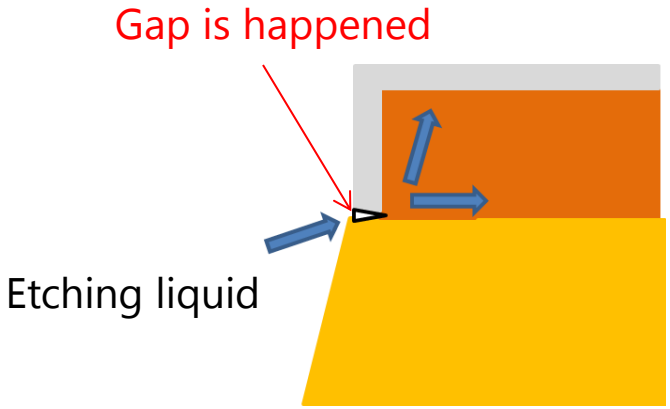
Pic11-1. F-side

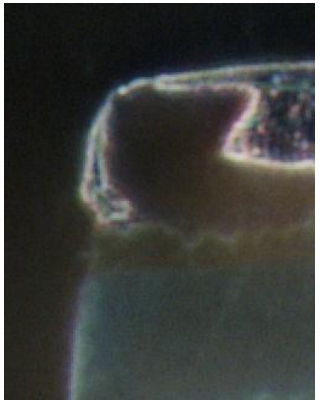


Pic11-2. B-side



Pic11-3. Cross section



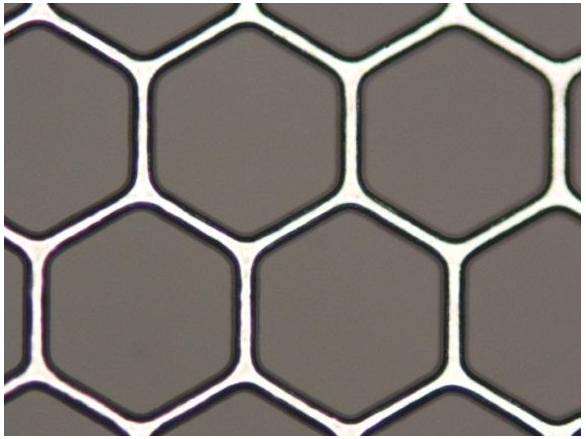


- Etching liquid etch the copper under the Ni
- Gap between Ni and Polyimide is happened when insulator removing process by Laser.

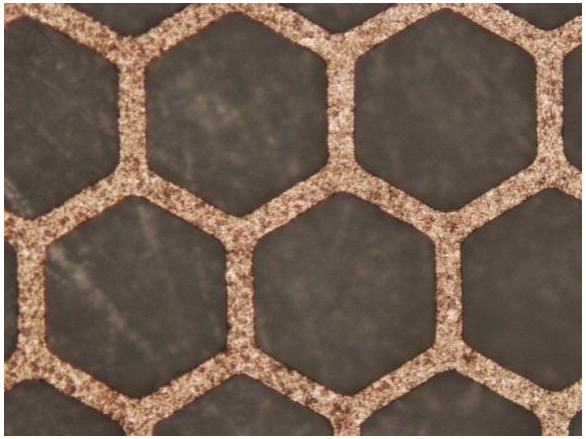
Single mask process with Ni-plating : Results

Solution for the stripping electrodes

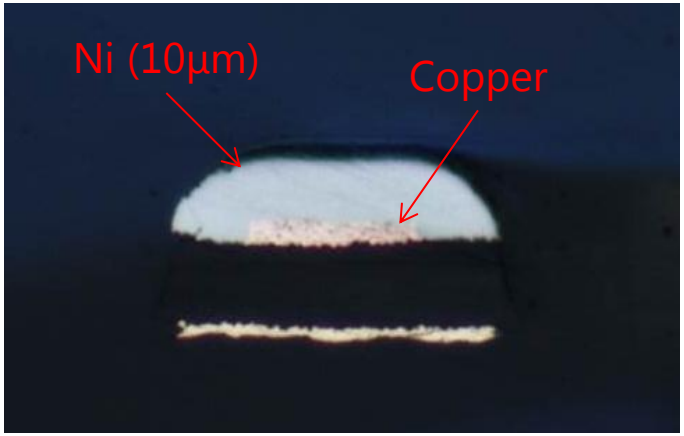
- Plating thick Ni (thickness : 10μm) on the front side copper can prevent the copper etching, and can solve the electrode stripping problem.



Pic12-1. F-side



Pic12-2. B-side



Pic12-3. Cross section

■ Problem of Single mask process with Ni-plating

1. Ni is magnetic material (We don't want to use Ni in high magnetic field 3.5T)
2. Process is complex (not good for large size processing)

➡ **We need to invent new single mask process without Ni plating**

Single mask process without Ni-plating : Process

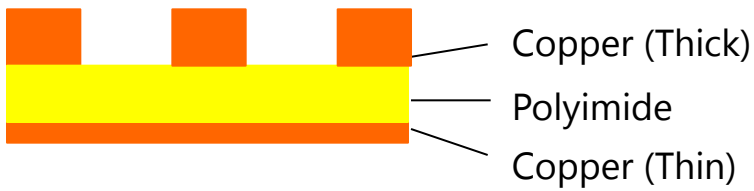
3. Single mask process

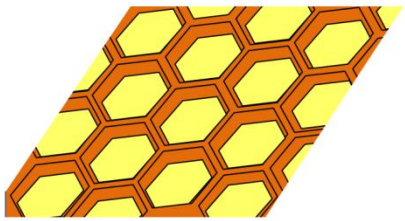
- We invented new single mask process which is more simple and don't use Ni-plating.

■ Single mask process without Ni plating

(1) Laminate the photoresist film on CCL

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

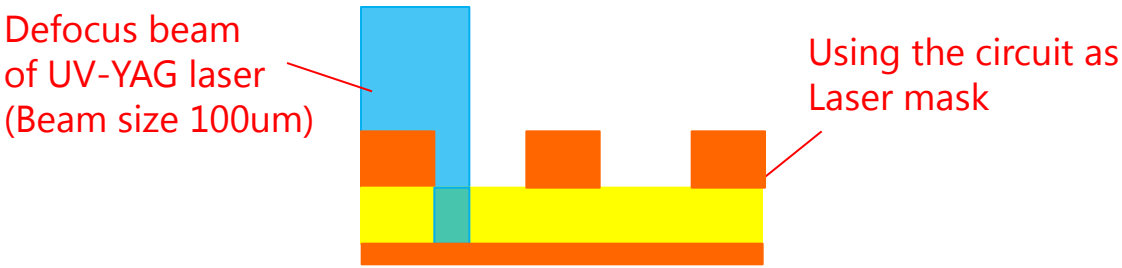


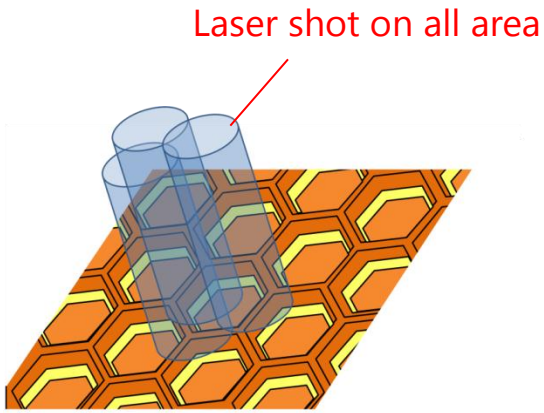


Single mask process without Ni-plating : Process

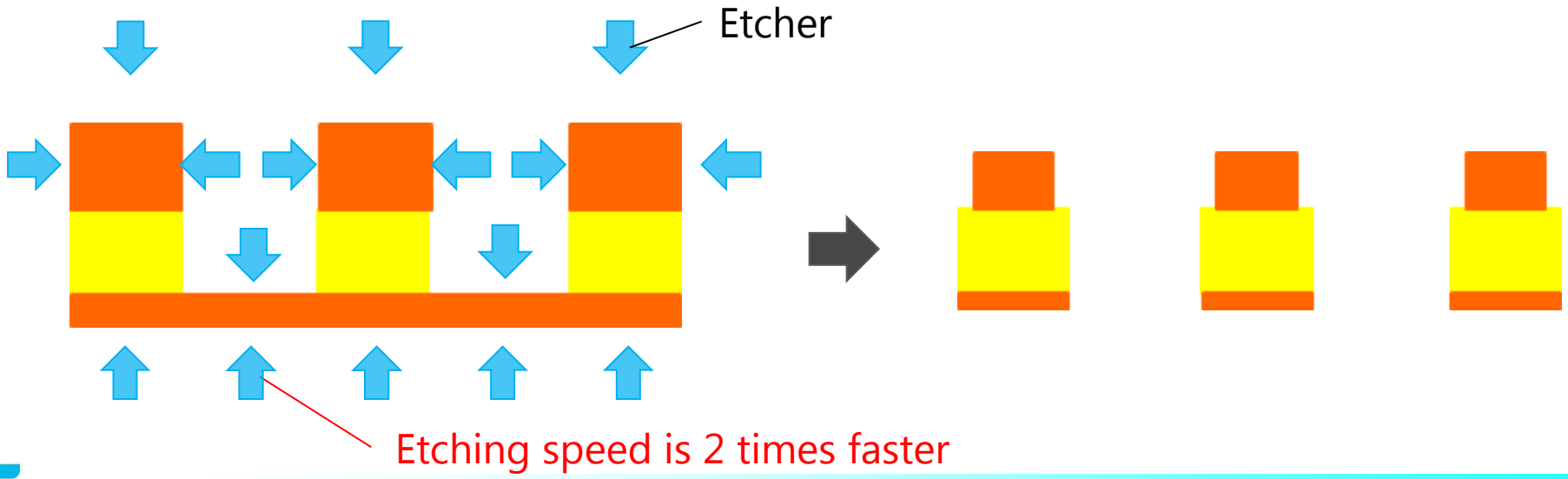
3. Single mask process

(3) Remove the polyimide by UV-YAG Laser





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



Single mask process without Ni-plating : Results

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...

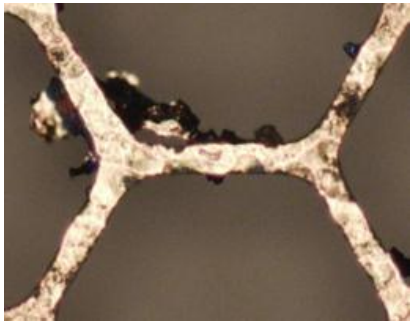


Fig13-1. Problem1 Effect of copper grain size

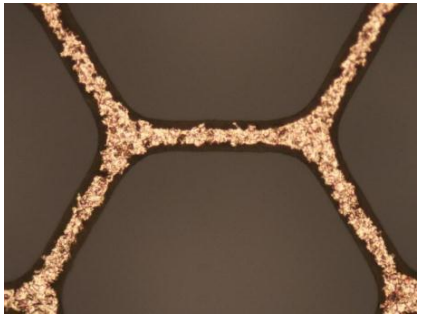


Fig13-2. Problem2 Effect of contact surface treatment on copper

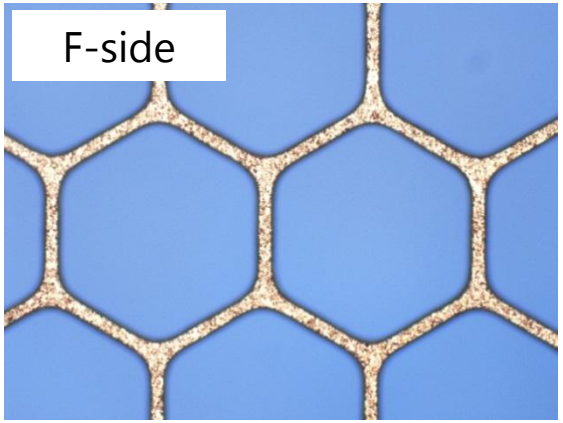


Fig13-3. Surface of F-side

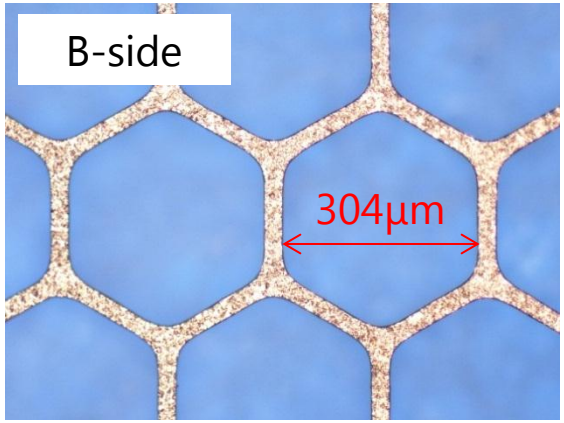


Fig13-4. Surface of F-side

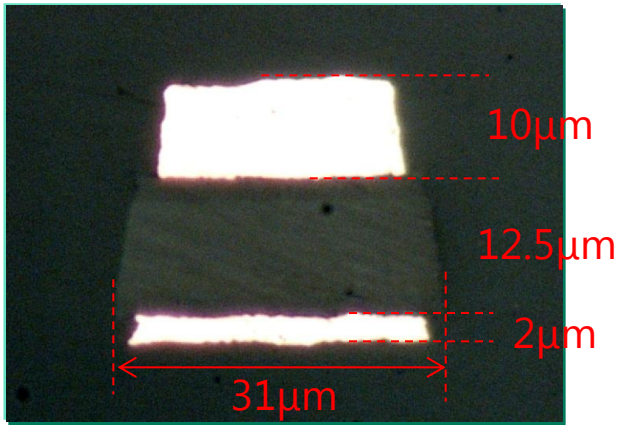


Fig13-5. Cross section of rim

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 !

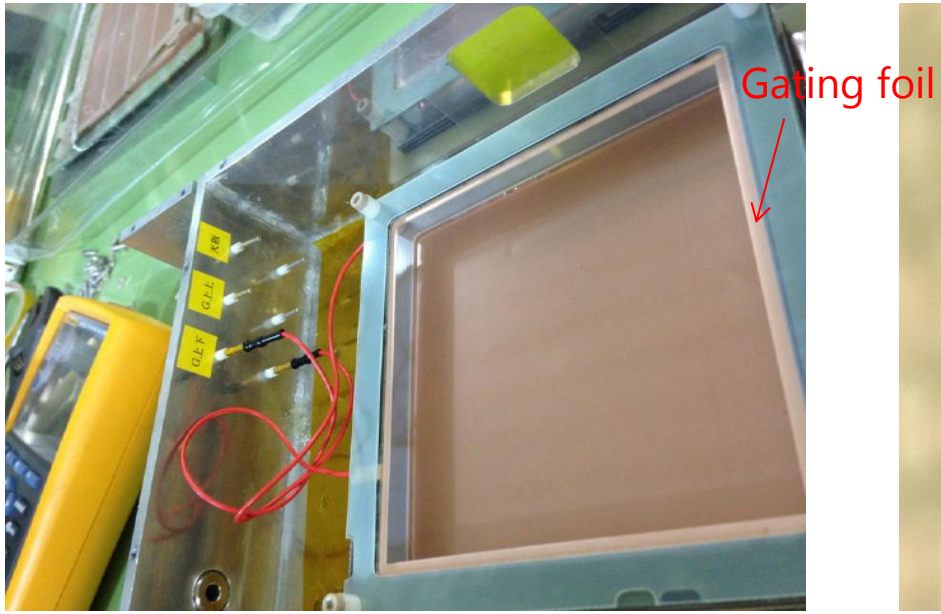


Fig14-1. Gating foil on the Test module
(Test by Saga Uni. and ILC-TPC Gr)

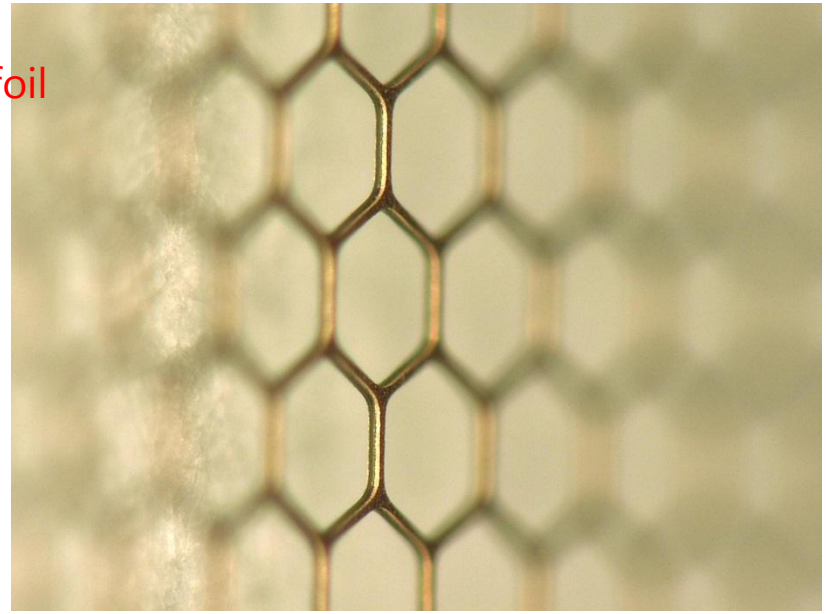


Fig14-2. Side view of Gating foil

We established the stable process for 100mm x 100mm size gating foil.

We tried to develop the LP1 size gating foil (170mm x 220mm)

Gating foil for Large Prototype1

- **Difficulty of LP1 size Gating foil production**

- LP1 size gating foil has other difficulties as below.

  1. Side frame width : < 50μm
  2. No electrode breaks
  3. Resistance : >1GΩ

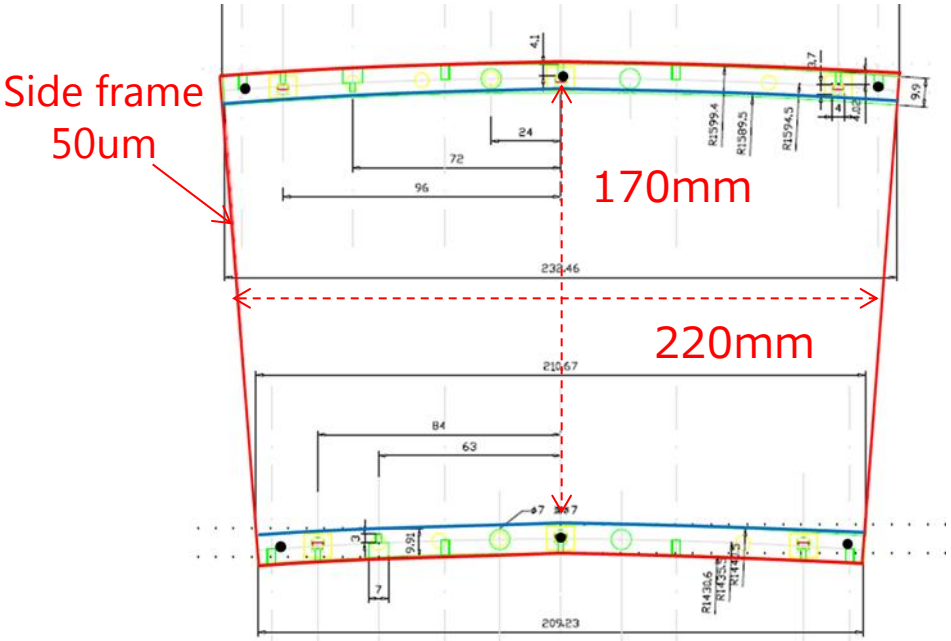


Fig 15-1. LP1 size gating foil design

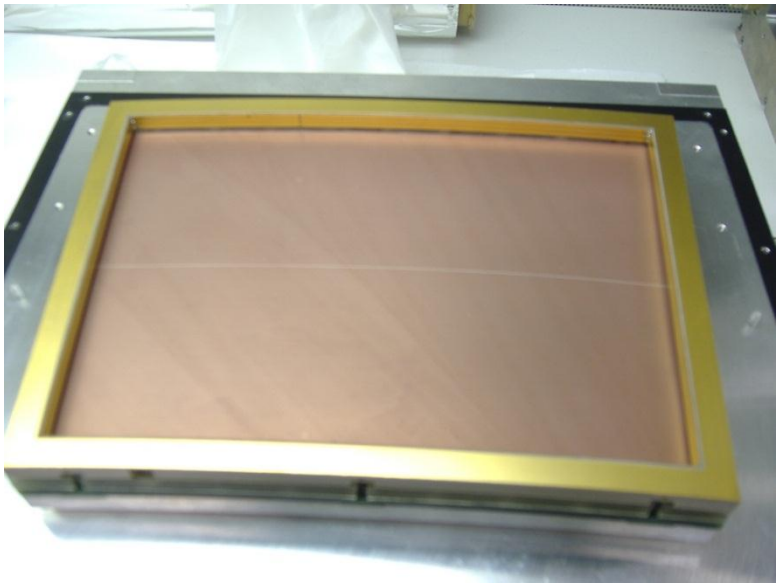


Fig 15-2. LP1 amplification module without gating foil

Gating foil for Large Prototype1 : Side frame

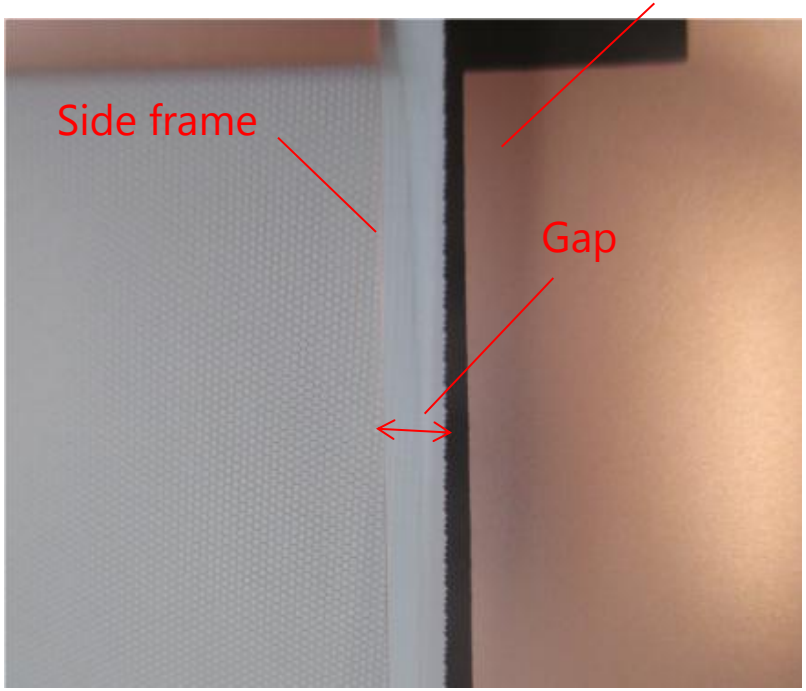
1. Side frame

- ILC-TPC has multi-module structure, so we need to form 50μm side frame.
- We tried to process the side frame.
- Improving the design and gap between side frame and CCL sheet.

We form the circuit on the CCL sheet

Fig 16-1. LP1 side gating foil after circuit formation

CCL sheet



Pic16-2. Side frame

we could process the 50μm side frame collectively.

Gating foil for Large Prototype1 : Electrode breaks

2. Electrode breaks

- No electrode breaks are required for the 170mm x 220mm size gating foil.
- But there are a few electrode breaks in the gating foil.

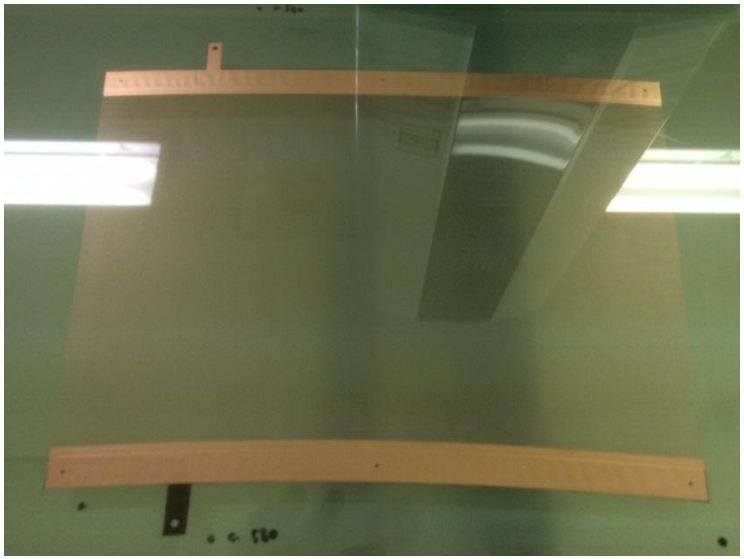


Fig17-1. Gating foil 170mm x 220mm size (include a few electrode breaks)

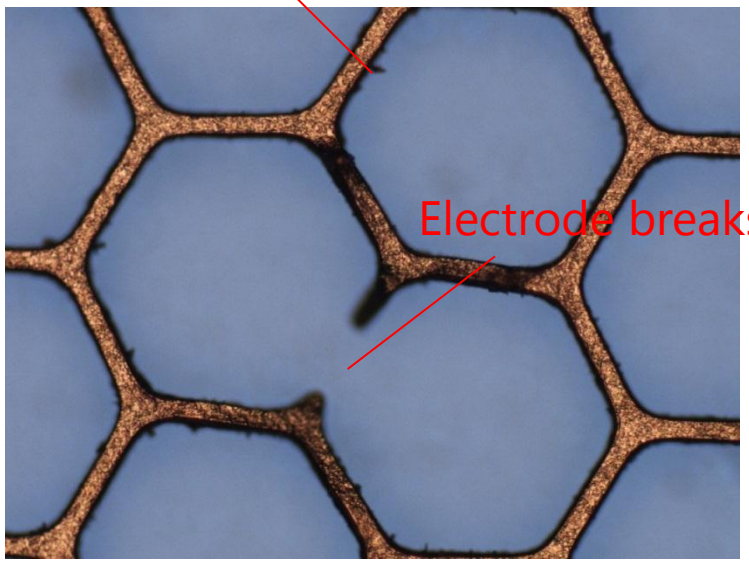


Fig17-2. electrode break after circuit formation (100mm x 100mm size gating foil before improvement)

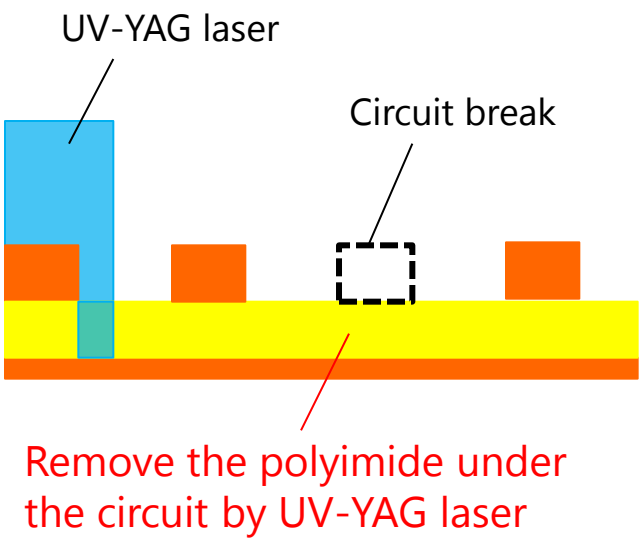
We tired to solve the electrode breaks !!

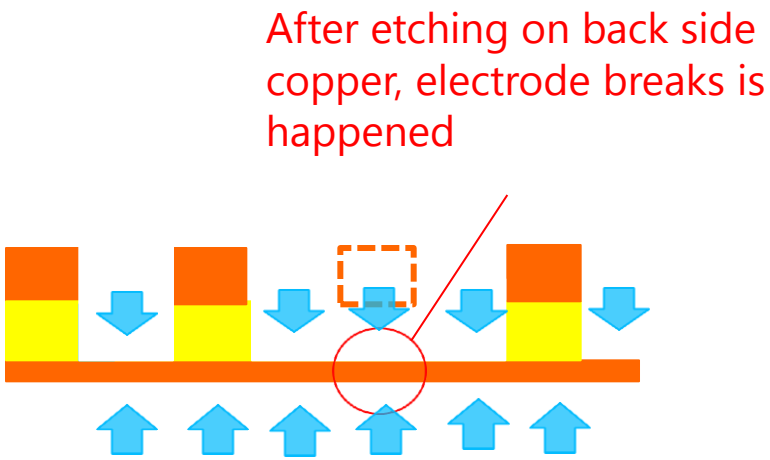
Gating foil for Large Prototype1 : Electrode breaks

2. Electrode breaks

■ **Why electrode breaks is happened ?**

- We understood the cause of electrode breaks is circuit breaks, because the circuit is used as a laser mask on the insulator removing process.





"Electrode breaks = Circuit breaks"

We need to form the 30um width circuit without breaks !!

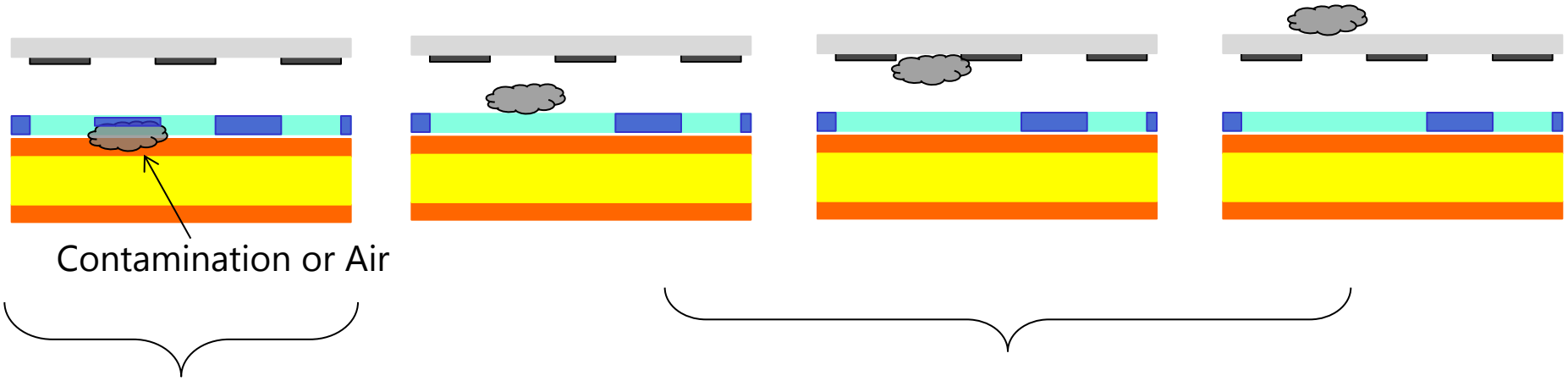
Gating foil for Large Prototype1 : Electrode breaks

2. Electrode breaks

- The cause of circuit breaks is due to contaminations on 4 possible places.
- We also understood the size of contamination is a few tens of μm.

■Cause and Solution of circuit breaks

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



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

Gating foil for Large Prototype1 : Electrode breaks

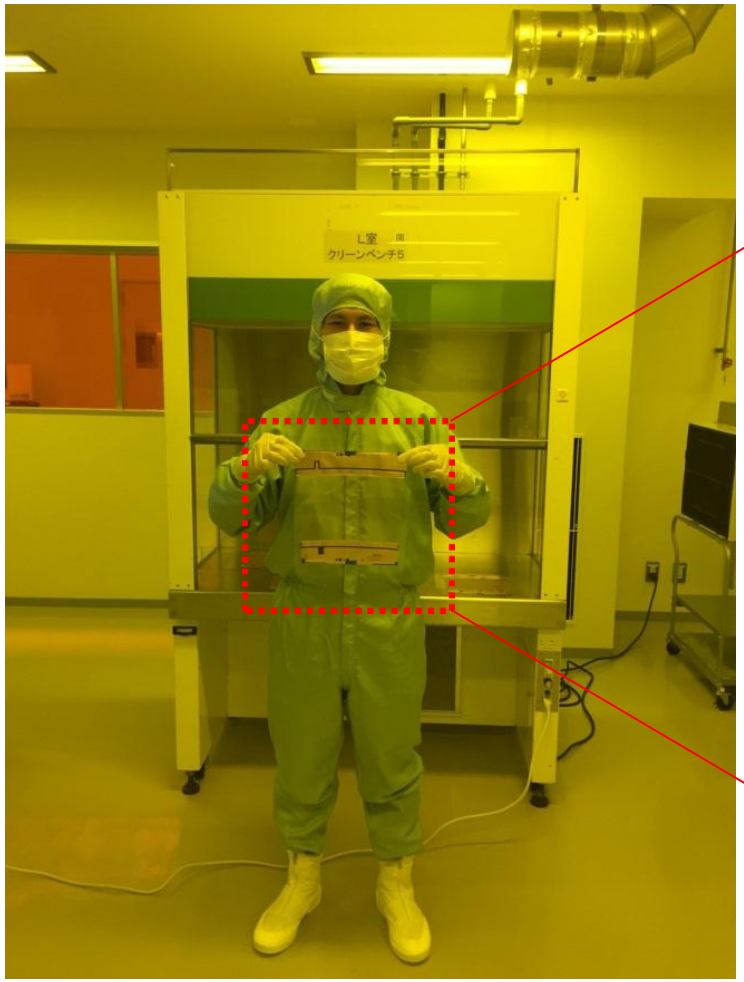


Fig18. LP1 module size gating foil without electrode breaks

We could develop the LP1 module size (170mm x 220mm) gating foil without electrode breaks !!

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 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 breaks, but we already solved this problem !!
- 170mm x 220mm size gating foil has over 1GΩ resistance was installed in LP1 module.

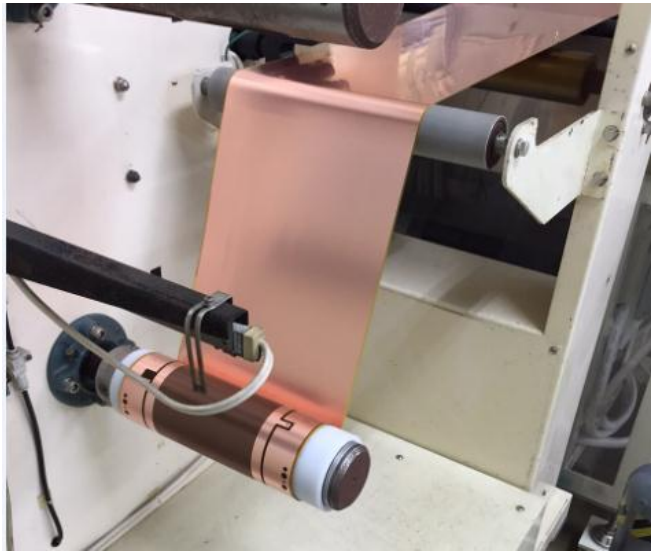


Fig20-1. Circuit formation process

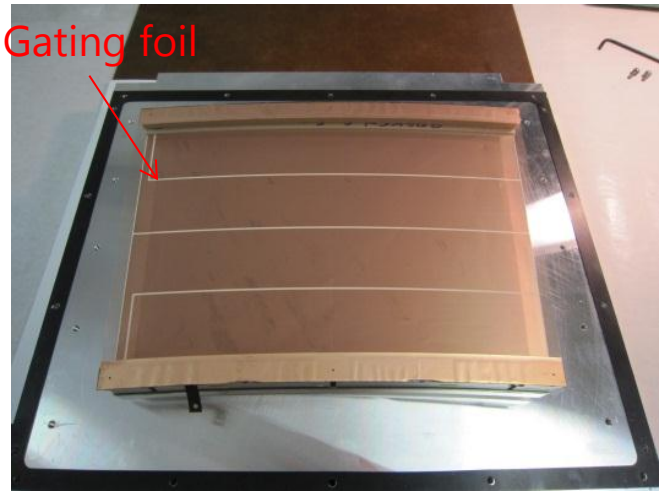


Fig20-2. Gating foil on the TPC module 170mm x 220mm size

Thank you for your attention

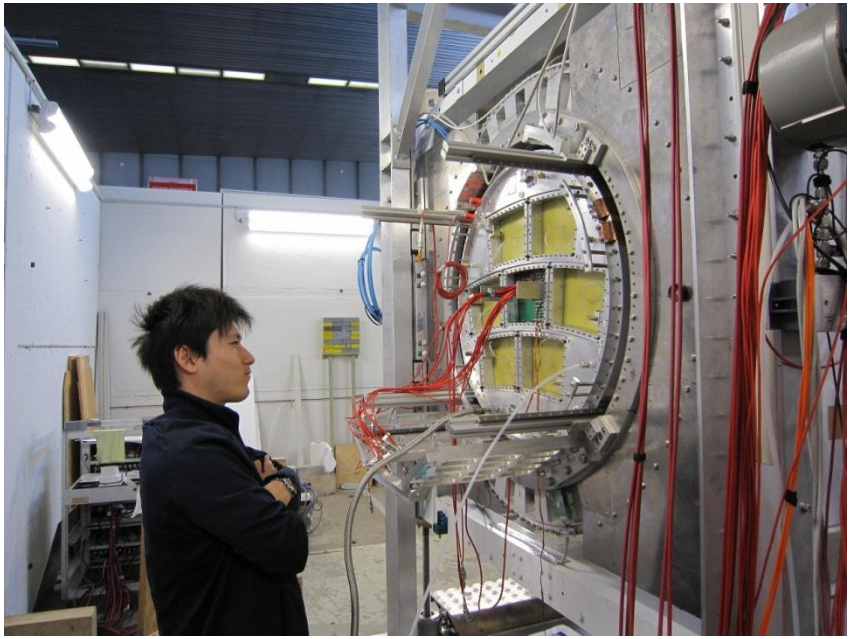


Fig21-1. LP1 module beam test
@DESY, ILC-TPC Group, 2010

5years

Fig21-2. Checking the circuit breaks
@ Fujikura Ltd. , 2015