Manufacturing techniques for PCB and Detectors:

- Base materials
- Photolithography
- Multilayer structures
- Drilling/milling
- Plating
- Test
- Example of productions

Tuesday December 3, 2024

Rigid /Flex materials

- Rigid
- Glass epoxy
  - G10 , FR4, High TG, Low loss , low Dk , anti CAF , low CTE etc..
- Aramid Epoxy
  - Low CTE
- Glass polyimide
  - G30 ,High temperature , high reliability
- Glass Teflon , ceramic Teflon
  - High frequencies
- Bakelite
  - Low cost
- Flex
- Polyimide
  - General flex application
  - Low intrinsic radiation
  - Low outgassing
- LCP , PEEK
  - High reliability flex application
  - low moisture absorption , low outgassing
  - High frequencies
- PET , PEN
  - Low cost

Elite Material Co., Ltd. *Technical Data*

http://www.emctw.com

Lead-free , Halogen-free Material

EM-370(5) / EM-37B(5)

- Superior thermal resistance for lead-free process
- Halogen, antimony and red phosphorus free
- For LCD, memory module and mobile device application

Basic Laminate Property

Item		IPC-TM-650	Test condition	Unit	Typical Value
Glass transition temp.		2.4.25	DSC	℃	155
CTE, X-, Y-axis		2.4.24	Pre-Tg, TMA	ppm/℃	12/15
CTE, Z-axis		2.4.24	Alpha 1, TMA	ppm/℃	40
			Alpha 2, TMA	ppm/℃	190
Z-axis Expansion		2.4.24	50~260℃, TMA	%	2.60
Decomposition temp.		2.4.24.26	TGA	℃	385
Thermal stress 10sec 288℃		2.4.13.1	Clad	—	Pass Visual
			Etched	—	Pass Visual
Water absorption		2.6.2.1	E-1/105+D-24/23	%	0.11
Peel strength	0.5 oz	2.4.8	as received	lb/in	7.4
			[illegible]	[illegible]	7.4
	1.[illegible]	[illegible]	[illegible]	[illegible]	8.6
			after thermal stress	lb/in	8.4
Permittivity (RC 50%)	1 MHz	2.5.5.9	C-24/23/50	—	4.8
	1 GHz			—	4.3
Loss tangent (RC 50%)	1 MHz	2.5.5.9	C-24/23/50	—	0.009
	1 GHz			—	0.013
Volume resistivity		2.5.17.1	C-96/35/90	MΩ-cm	$>10^{10}$
Surface resistivity		2.5.17.1	C-96/35/90	MΩ	$>10^{8}$
Flexural strength	Warp	2.4.4	as received	MPa	560~600
	Fill		as received	MPa	470~510
Flame resistance		UL-94	A&E-24/125	—	V-0

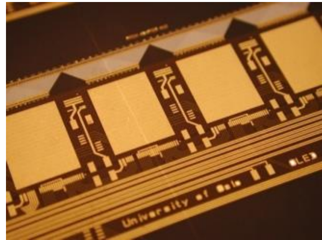
Specification Sheet : IPC-4101C / 127 · 128

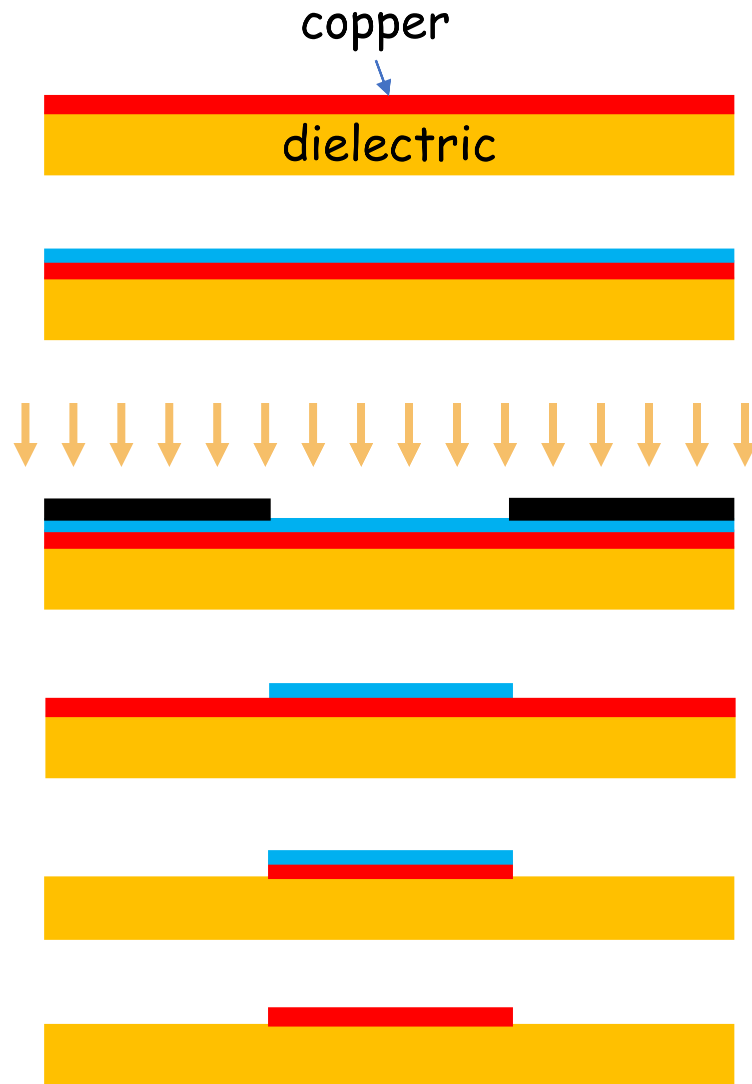
Example of data sheet

Photolithography

- Basic process steps
- Photo-imageable materials
- Resist deposition
- Masks
- Resist exposure
- Resist development

Photolithography basics (substrative)





Base material with copper

Photoresist deposition

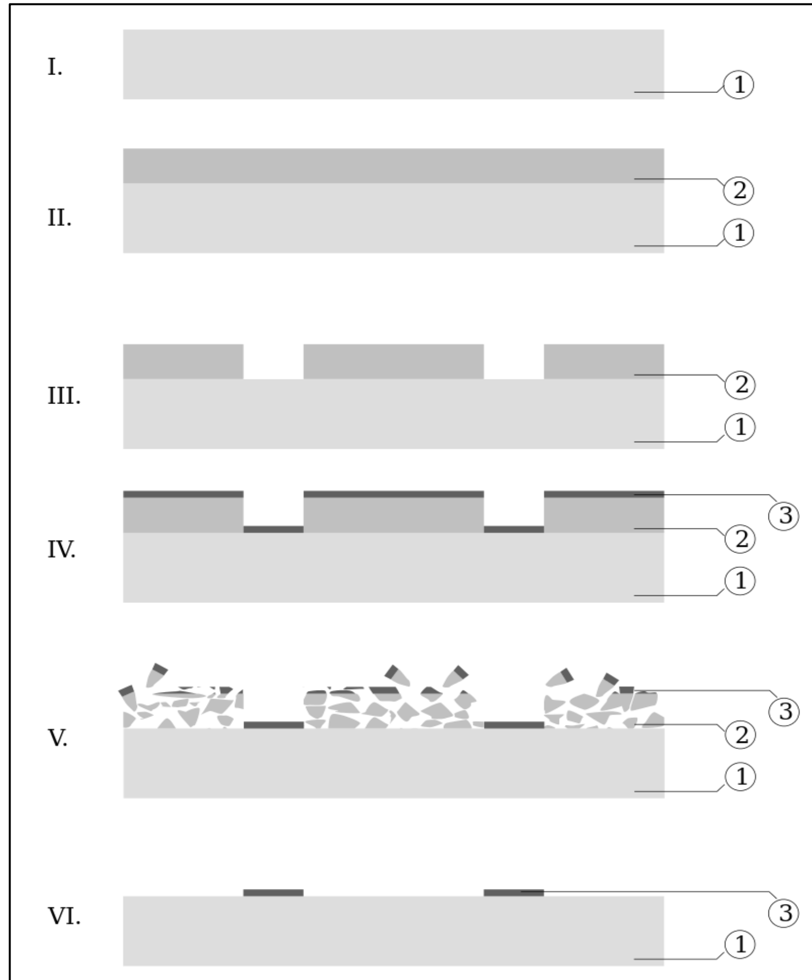
UV exposure through a mask

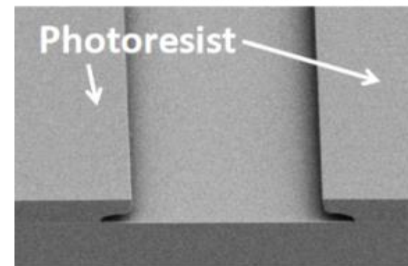
Resist development (negative resist)

Copper Etching

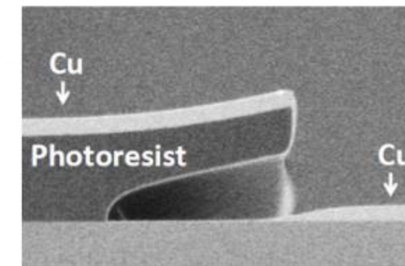
Resist Stripping

Lift Off patterning (additive)

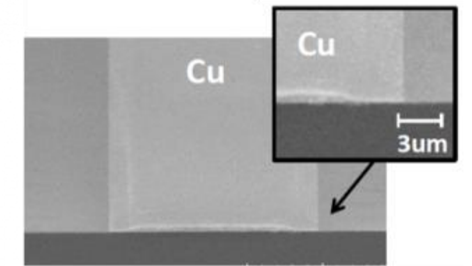




Post lithography



Post sputtering



Post stripping

Photo-imageable materials

- Liquid resist (sacrificial)
  - Pattern lines
  - Thickness : 1um to 5um
  - L/S: sub micro-meter
- Solid resist (sacrificial)
  - Pattern lines
  - Thickness: 15um to 200um
  - L/S : 20-30um
- Solder-mask (not sacrificial)
  - Protect external lines on rigid boards
  - Typical thickness : 30um
  - L/S: 50um
- Photo-imageable Cover-layer (not sacrificial)
  - Protect lines on flexible boards
  - Thickness 30um
  - L/S: 50um
- Legend inks (not sacrificial)
- Liquid Polyimide (usually not sacrificial)
  - Make 3D shapes , protect Chips
  - Thickness :from 1 to 30um
  - L/S : 20um
- Liquid Epoxy (usually not sacrificial)
  - Make 3D shapes , used for MEMs , Gridpix
  - Thickness :1 to 100um
  - L/S: 20um

Resist deposition

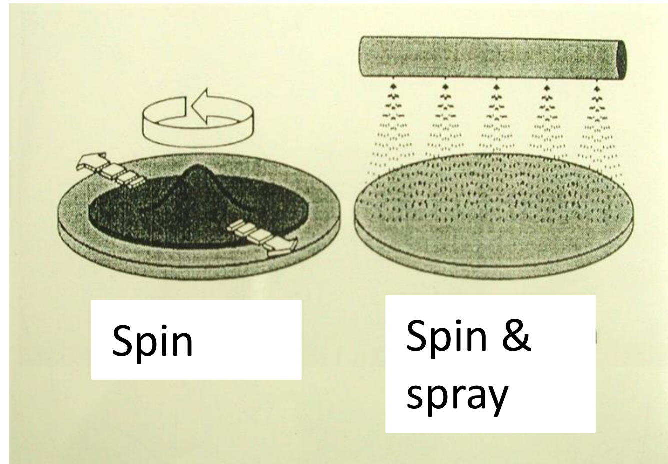
liquid

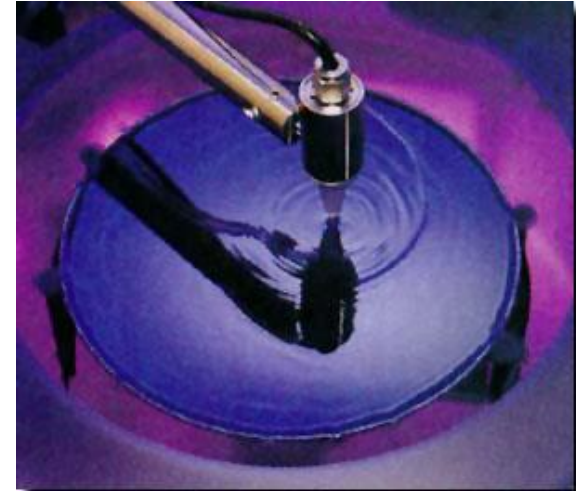
- Spinning - semiconductor production
- Dip coating - fine lines for PCBs or 3D objects
- Curtain coating - solder mask deposition
- Spray – solder mask- cover layer
- Screen printing - solder mask deposition

Solid

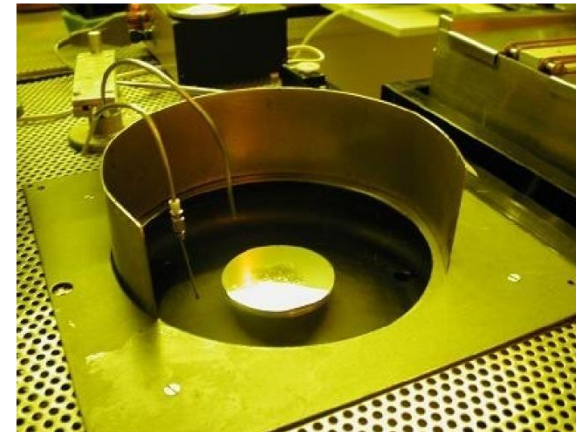
- Dry film lamination- PCB production

Spin Coating

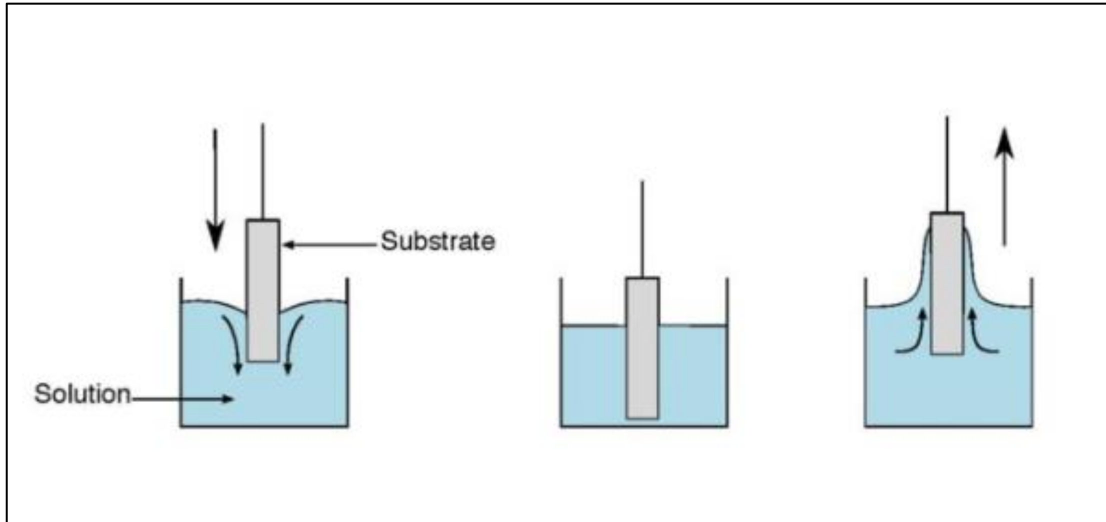




Deposition by centrifugation
Uniform thickness
Ultra-thin : down to 1 µm thickness
Excellent repeatability
Clean room mandatory

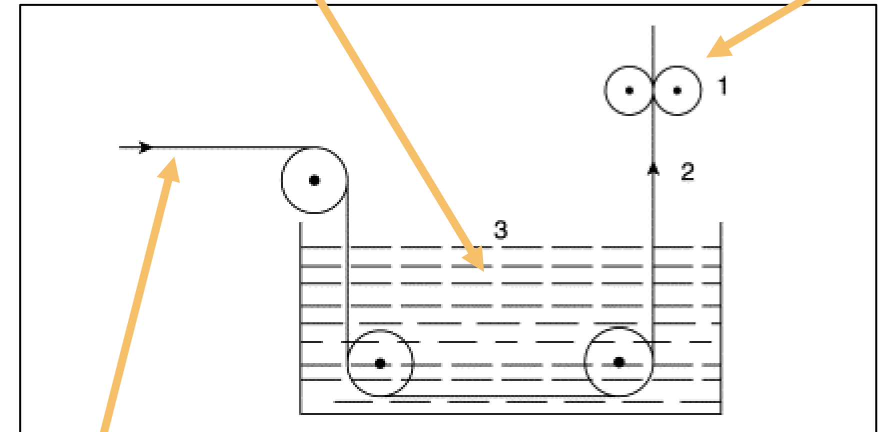


Dip Coating



tank with liquid resist

vertical dryer



base material

Rigid board deep
- -Simple
- -Difficult to maintain repeatability
- -Thin depositions
- -Fine patterns

Continuous flex mass production
- -Good repeatability
- -Fast deposition
- -Perfect uniformity

Curtain coating

Reservoir with
Liquid resist

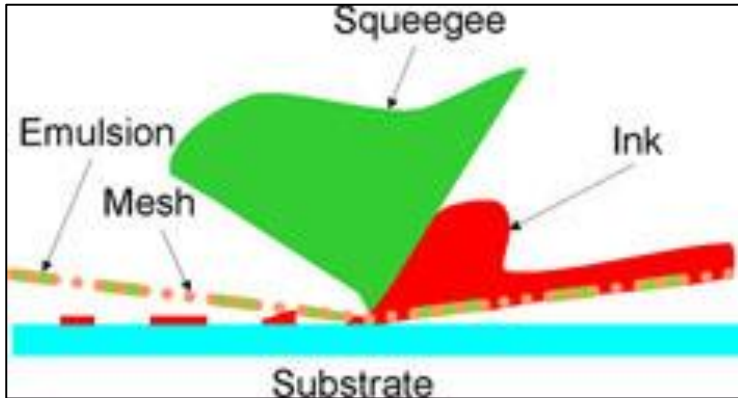
Resist layer

PCB 2

PCB 1

Good for solder-mask deposition
-fast deposition
-but thickness not accurate

Screen printing



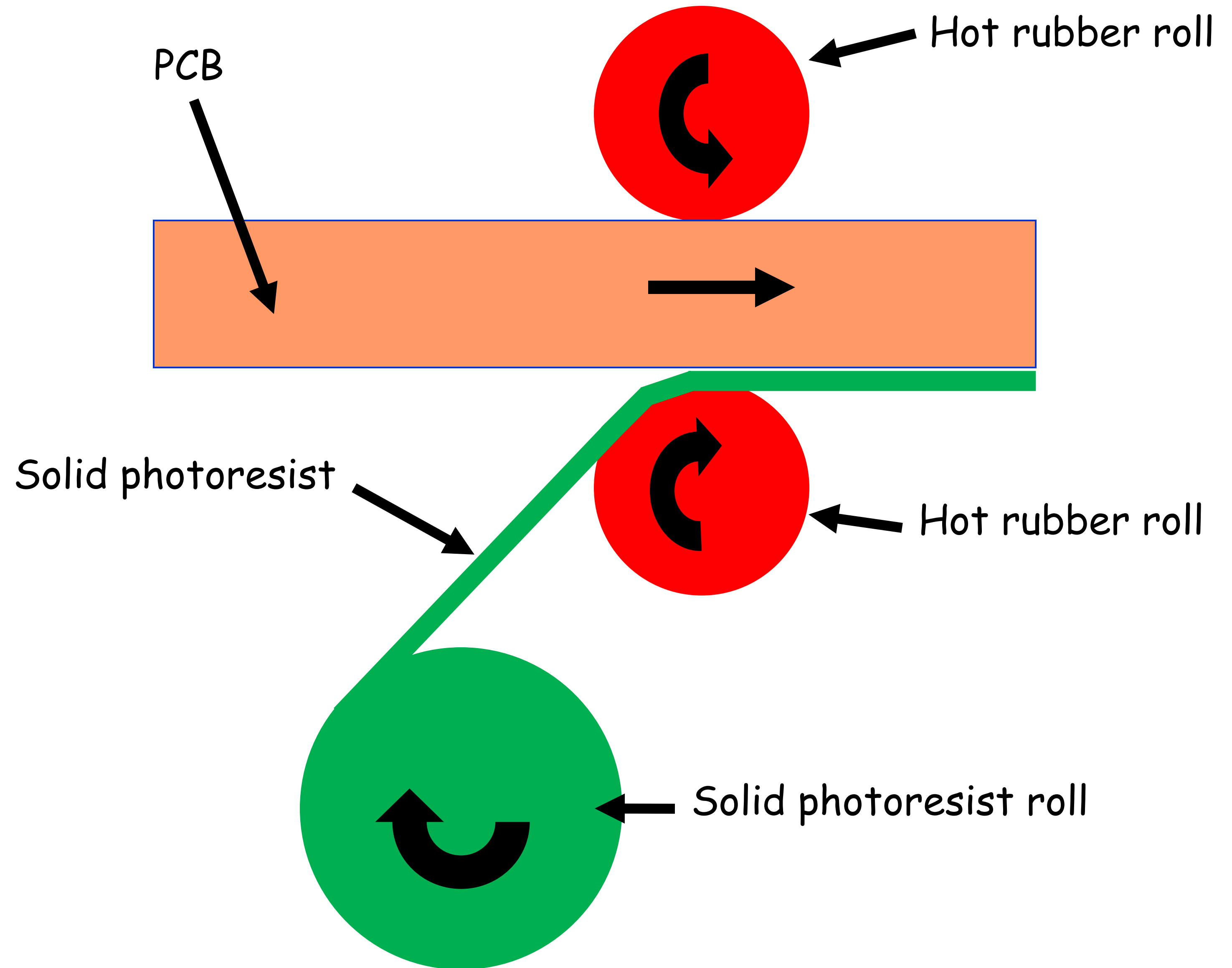
Good for solder-mask deposition
- -fast deposition
- -thickness not really accurate
- -direct pattern printing

CERN precise machine
20cm x20cm deposition

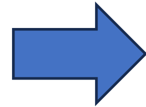
CERN Semi automatic machine 1.5m x 2m
General purpose

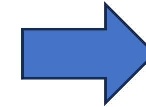
Hot roll lamination

Dry process
Medium class clean room
Large size
Precise thickness
Easy to process
Down to 20µm line/space
Not compatible with 3D shapes

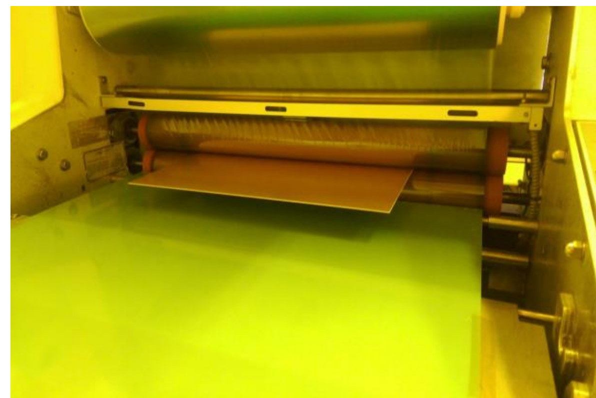


Hot roll lamination deposition





Cu/Glass-Epoxy/Cu plate
Or flex



Resist deposition by Lamination

Plate + Photoresist

Masks

Precise mask : few mm of Glass or Quartz

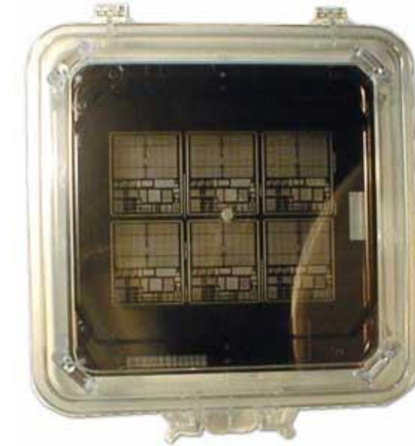
- -Chromium on thick soda lime glass
- -Sub-micron resolution
- -up to 1m x 0.6m (15 000 CHF for a 1m x 0.6m mask)

Polyester mask : 100um thick

- -Minimum line and space around 20um
- -up to 2m x 1.5m (400 CHF for 2m x 1.5m mask)

Laser direct imaging : no mask

- -Minimum 20um line and space
- -up to 80cm x 60cm



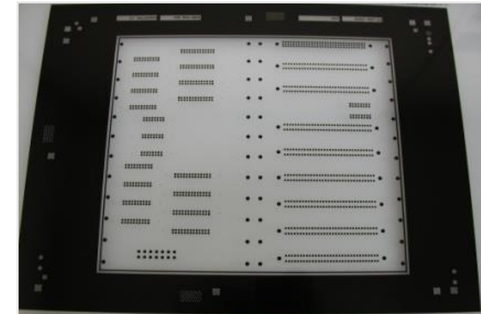


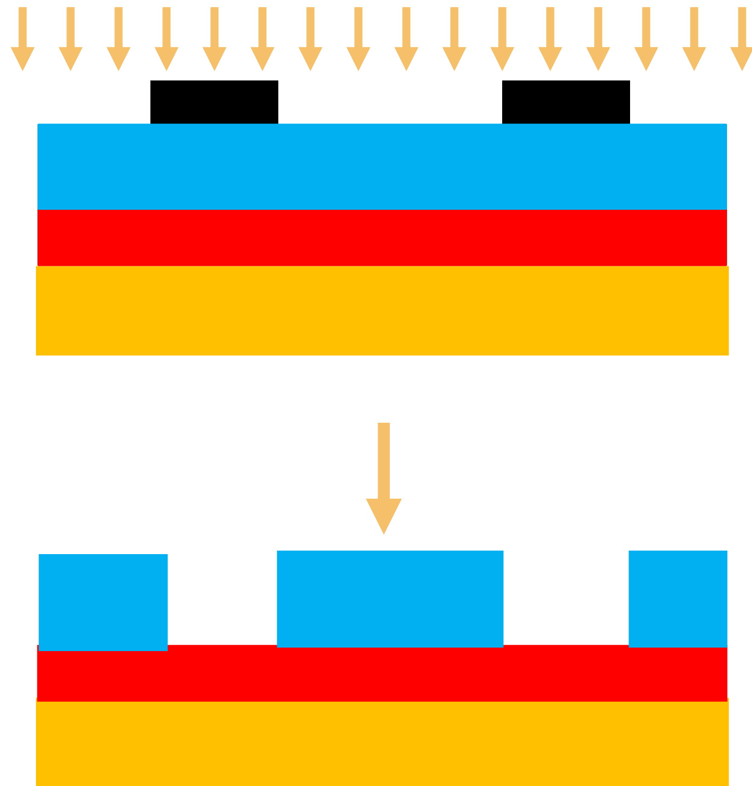
Figure 2 e 3 – The Paragon-8000 Laser Direct Imaging system (above) and 25 µm features exposed using this system (below)

Photolithography problems

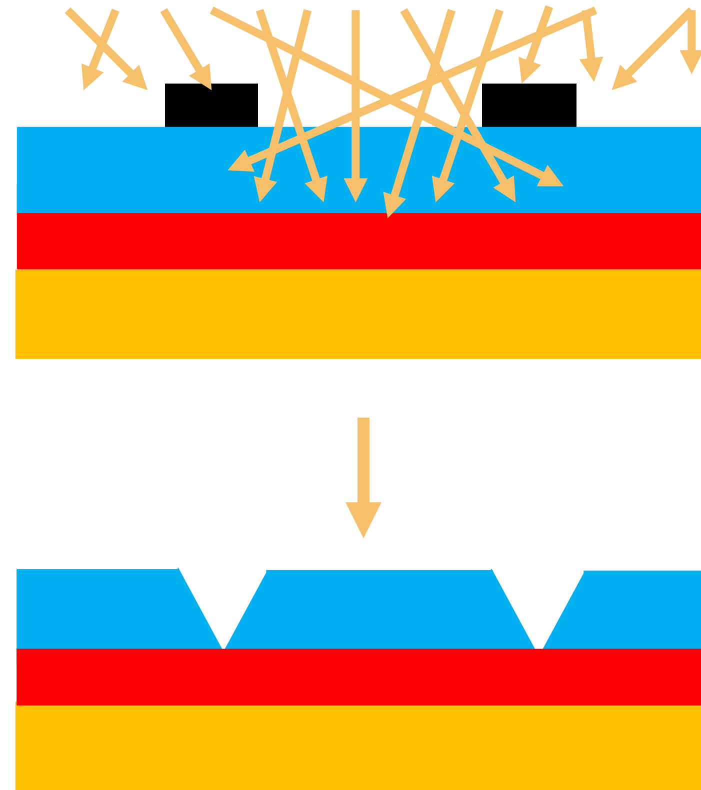
- Light diffusion
- Light absorption
- Light diffraction

light diffusion problem

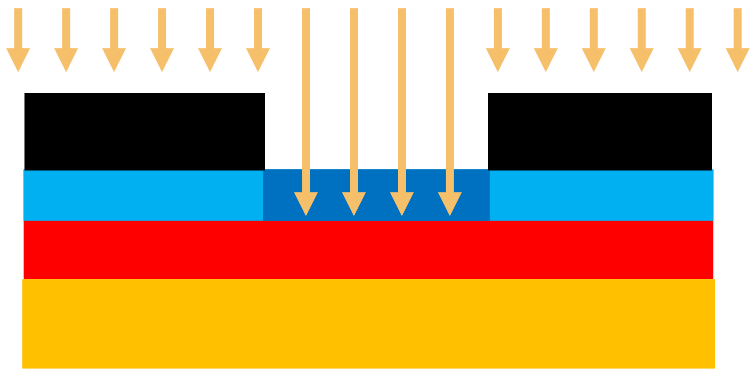
Collimated (polarized) UV light



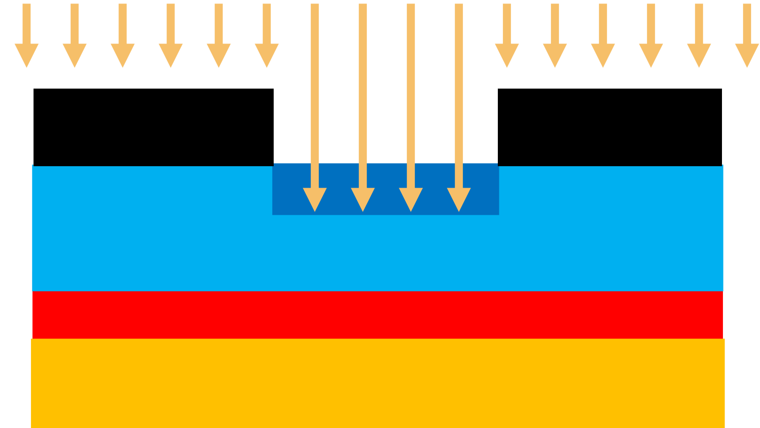
Diffuse UV light
Ex: a neon tube



light absorption problem

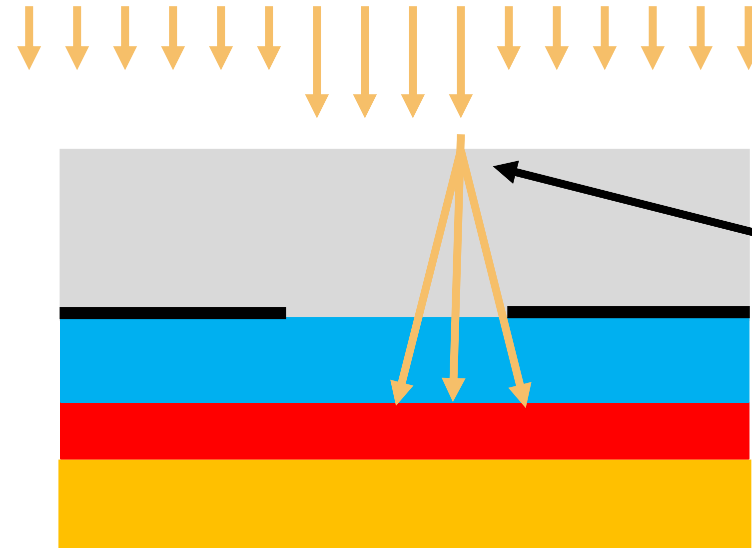


Thin layers ok



Problem with thick layers

light diffraction problem

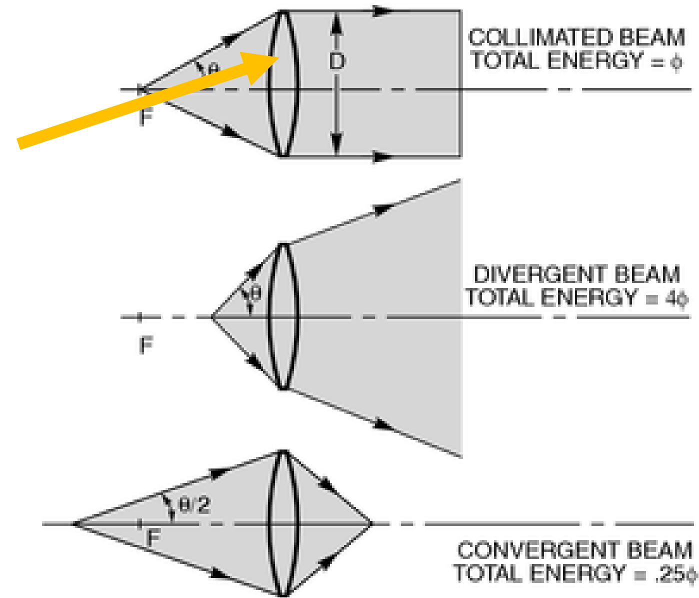


Diffraction in glass or polyester
Less with quartz

Problems appear with small pattern below the um

Collimated UV lamps

Precise large size lens
up to 12 inches

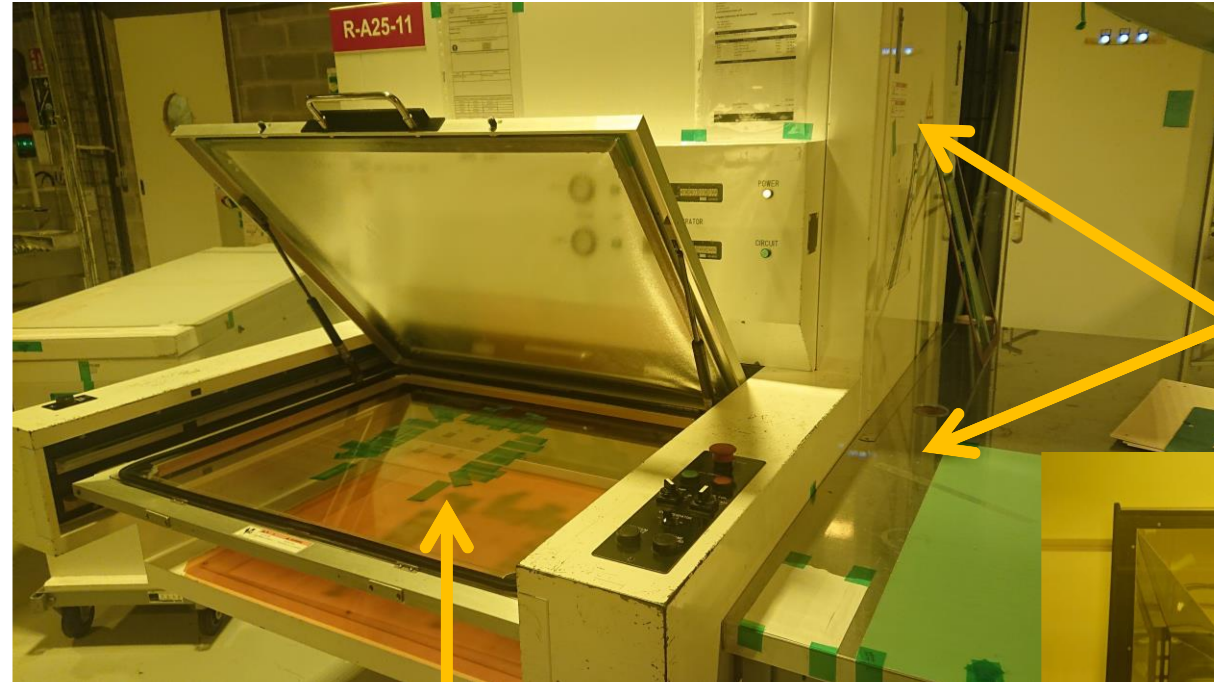


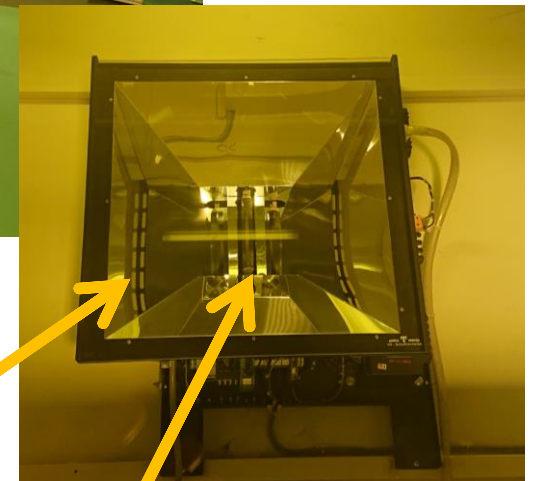
-Perfect Collimated light
-Low local energy → absorption problem → only thin resist
-Diffraction→ quartz mask
-Working size : 20 cm diameter
-Good enough for 1um line and space

Classical UV exposure machine for PCB production

-Semi Collimated light
-Low local energy → absorption pb
-Diffraction → thin polyester mask
-Working size up to 2.5m x 1.5m
-Good enough for 30um line and space

Stack up:
-Polyester foil
-Mask → manual alignment
-PCB with resist to be patterned
-Glass plate (Chassis)





Two UV bulbs

Vacuum Drawer (open)
Sliding in the machine.

Deflectors to
Improve collimation

UV bulbs

LDI: laser Direct Imaging

-Collimated light

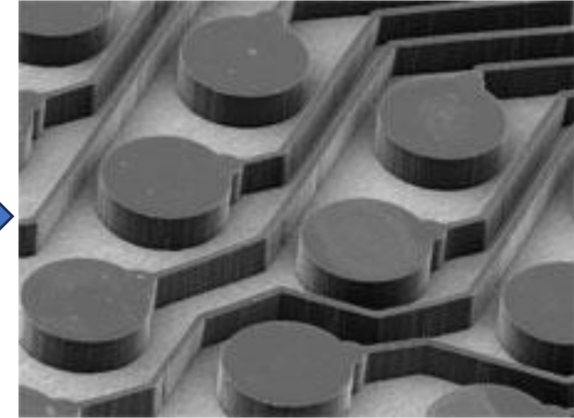
-High local energy better for absorption but not perfect

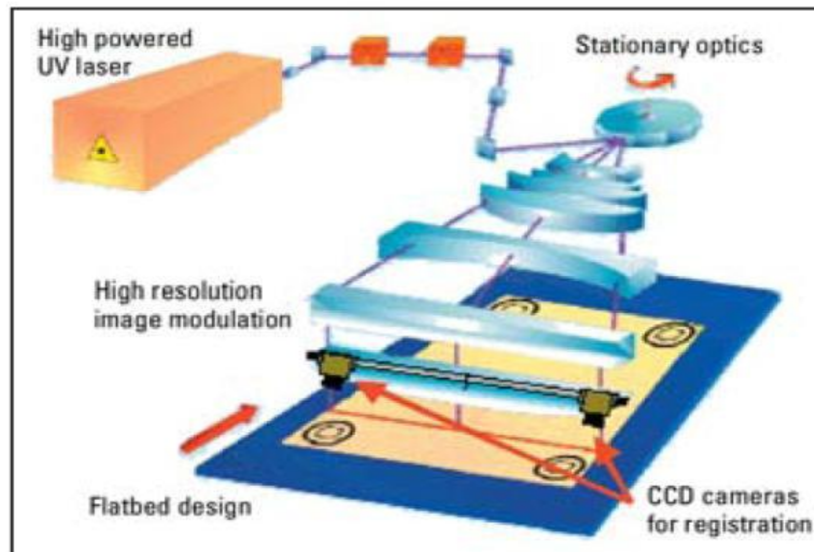
-No mask→ no diffraction

-Working size 80cm x 70cm

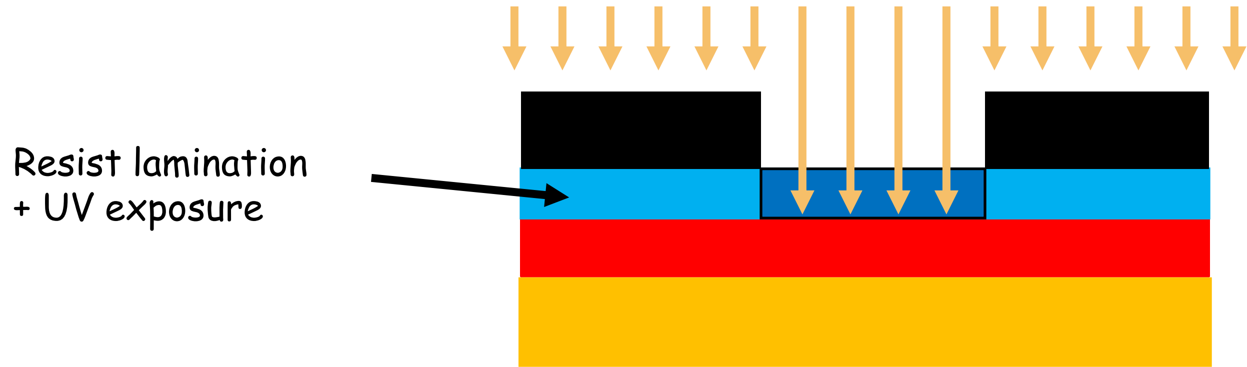
-Good enough for 20um line and space

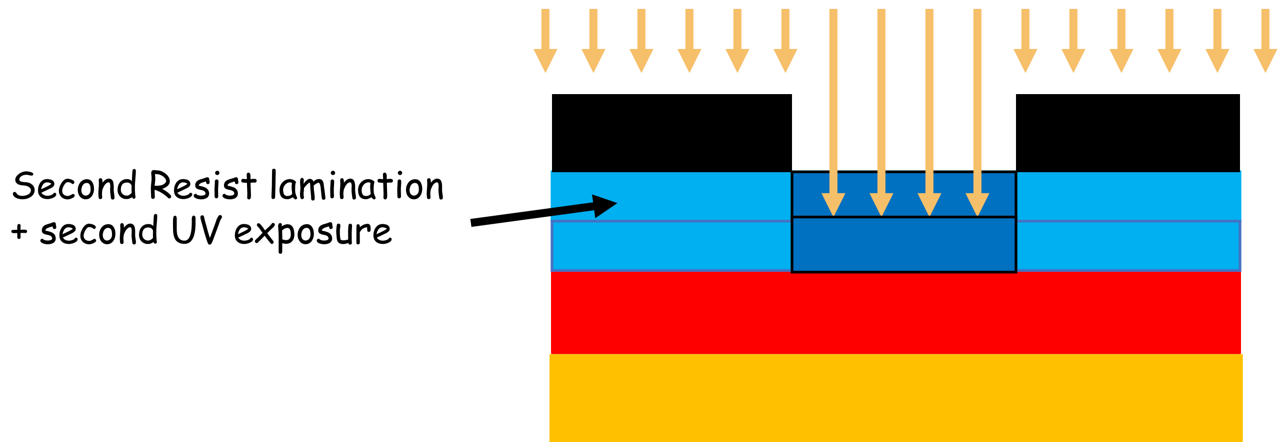
X Y steps: 0.5 μm to 2 μm (depending on machine type)

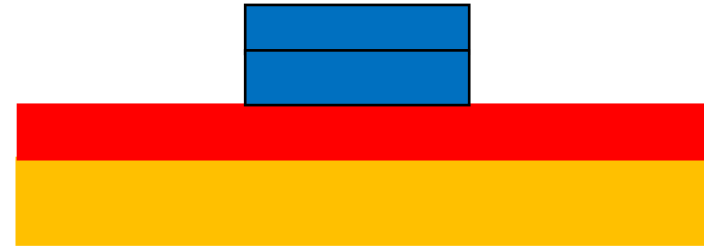




Cheap way to avoid light absorption with thick patterns (above 100um)







After development

That's how the Micromegas pillars are produced.

Wet development

<u>After Exposure:</u>

UV exposure change slightly the resist color.

The UV light have initiated a crosslink in the polymer

Sodium carbonate
NA2CO3 development
With spray nozzles

<u>After Development:</u>

All the areas exposed to UV stays.

Everywhere else the resist is dissolved.

Etching

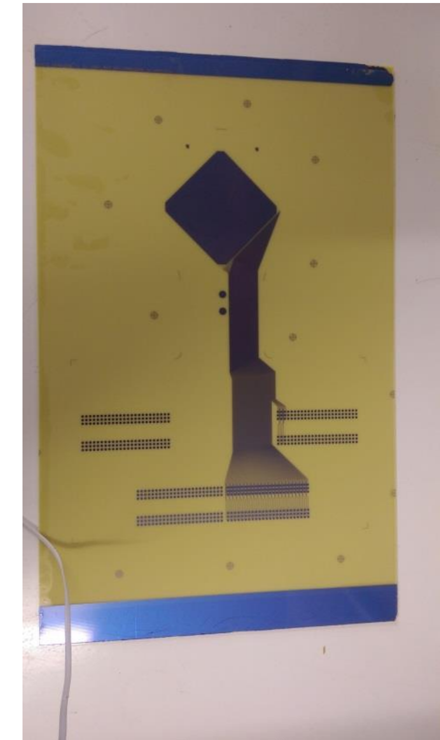
- Wet etching
- Anisotropic /isotropic
- Laser ablation
- Electroforming to reach high aspect ratio patterns
- Resist stripping

Wet spray Etching

Resist Image

Wet spray horizontal etching
Some examples of chemistries:

- -Ferric Perchloride for: Copper/SS/Aluminium
- -Phosphoric/sulphuric/Fluoridric acid for: Niobium
- -Fluoridric acid for: Titanium
- -Potassium Ferrocyanide for: Tungsten
- -Iode/Iodine for: Gold
- -Iron nitrate for: Silver
- -etc.. etc..

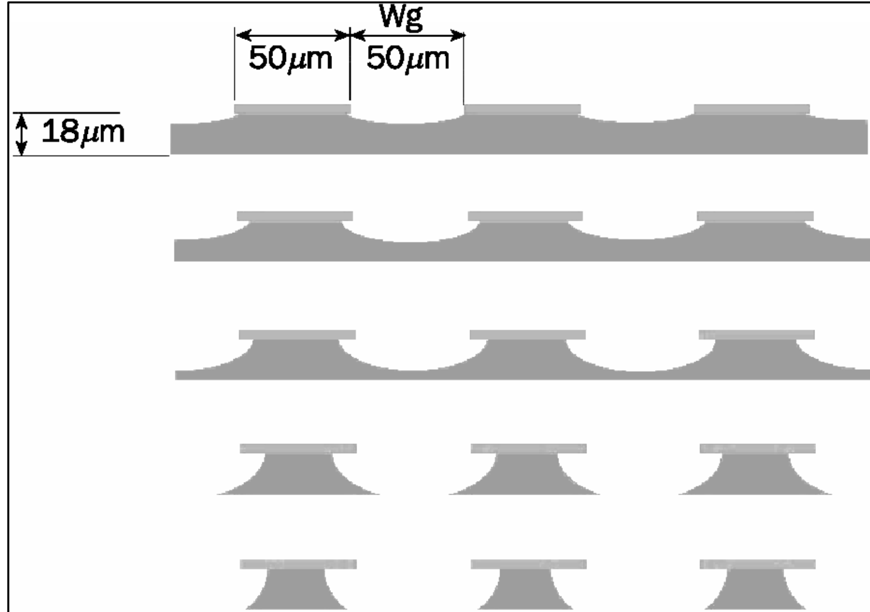


After Etching

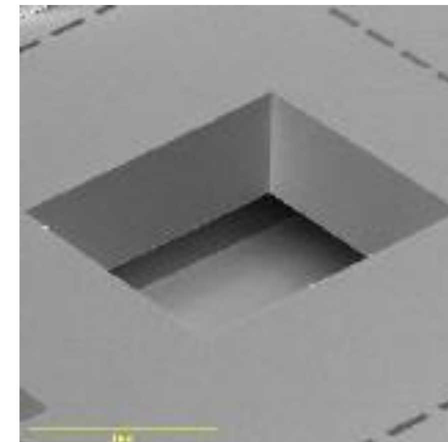
Wet etch , anisotropic or isotropic ?

- Wet etching is isotropic for nearly all materials

- Some exceptions
  - Silicon etching is anisotropic due to its crystalline structure
  - Polyimide etching can also be anisotropic



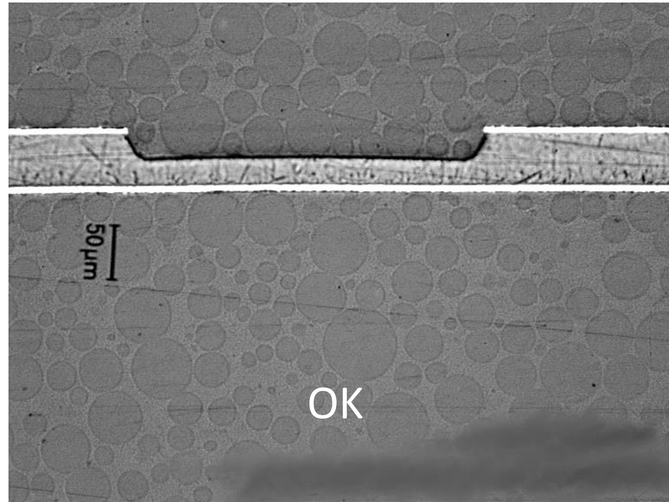
Minimum line spacing → 3 to 4 time the metal thickness.
Big limitation for thick layers !

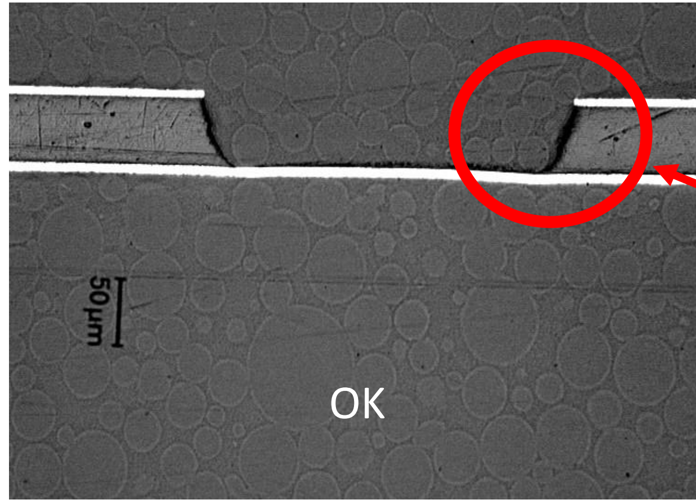


Patterned silicon

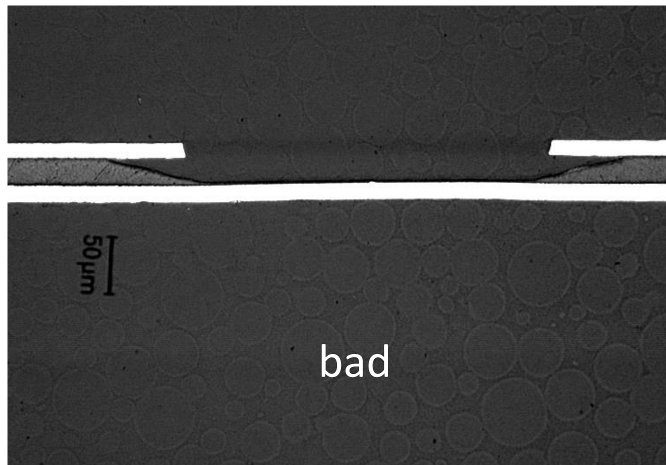
Anisotropic etching

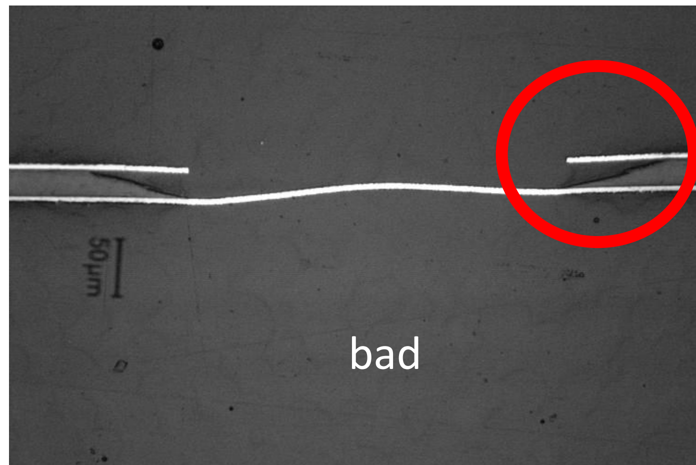
Polyimide wet etching , isotropic and anisotropic





First type of polyimide:
Perfect anisotropic etching
No under etch
Perfect to make small holes





Second type of polyimide:
Fully isotropic etching
Not satisfactory

Les than 10% of PIs available on the market have an anisotropic behavior.

Laser etching

-Laser direct patterning is anisotropic , but not commonly used to make lines in PCBs.

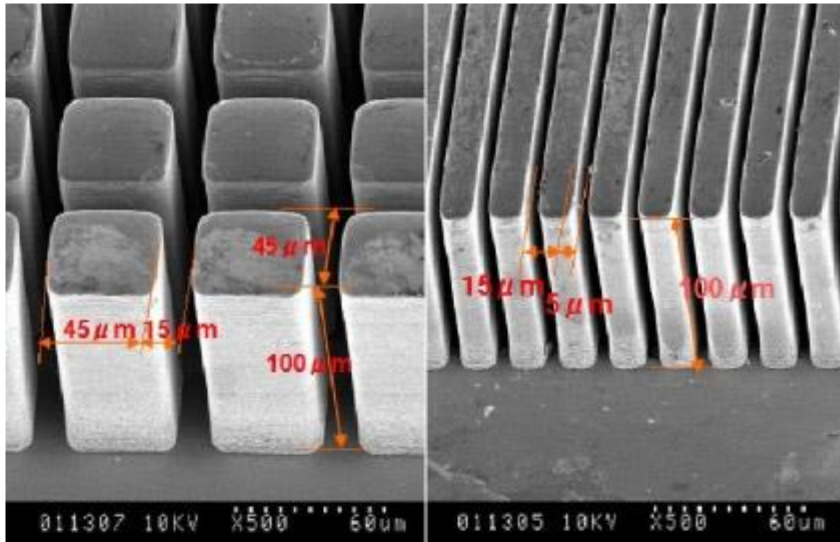
-But lasers are nice for repairs .

Full of shorts

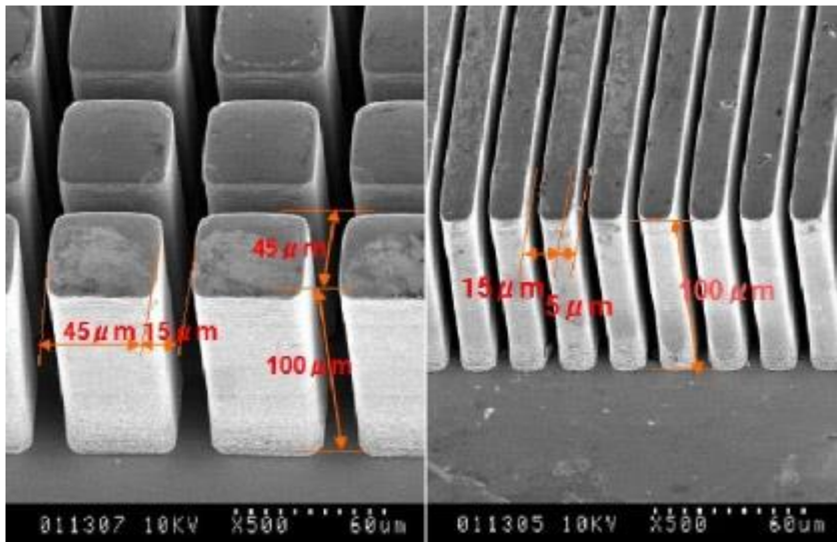
Cleaned up

Seems simple but the process to get this result is highly complex , only lasers can achieve this result.

Electroforming to beat wet etching isotropy



Electroforming to beat wet etching isotropy



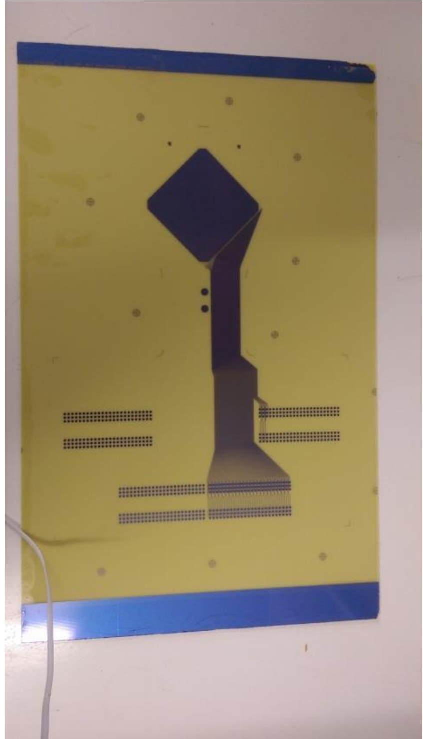
Thick resist

Electro plating

Resist stripping

Seed layer removal by wet etching

After wet etching → wet resist Stripping



After copper Etching

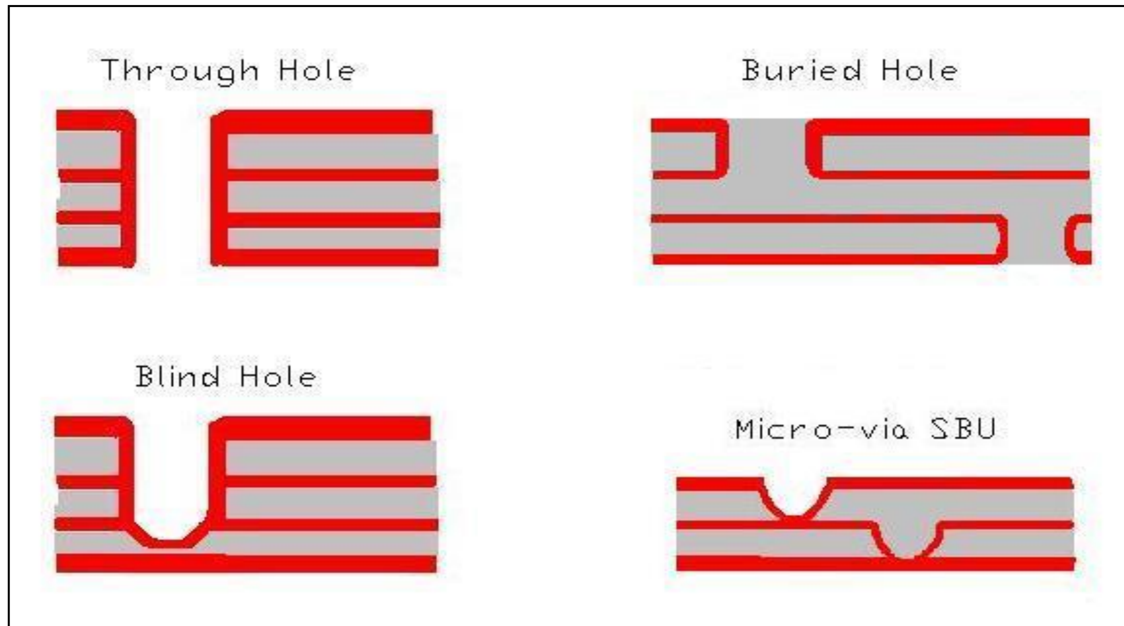
Stripping with:
NAOH
KOH
Solvents

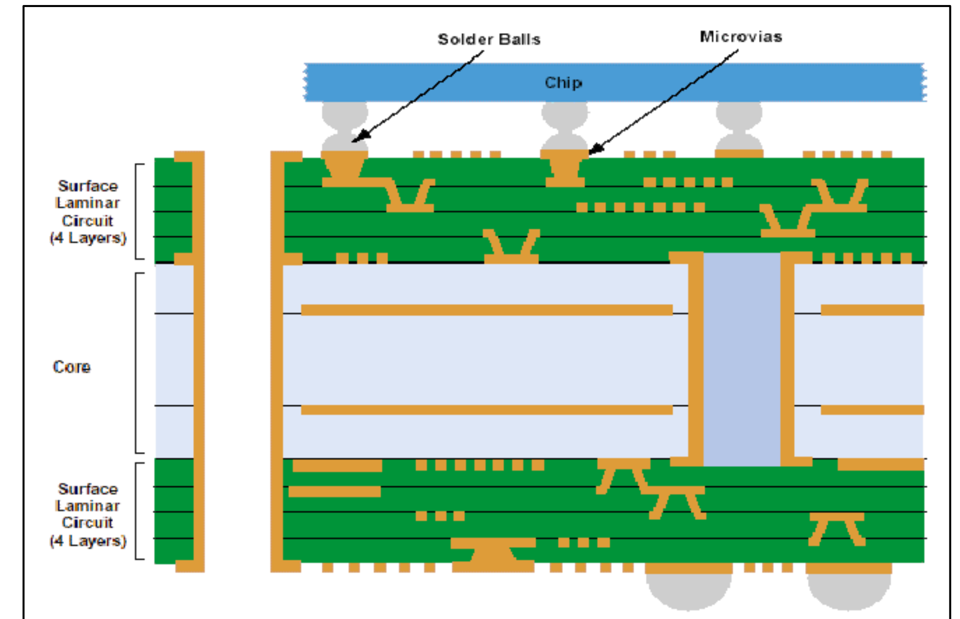
After stripping

Multilayer structures

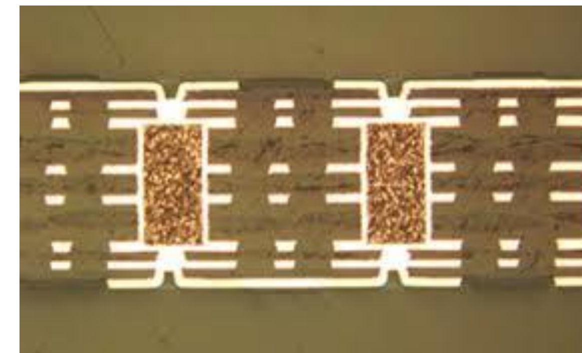
- Parallel layers production
  - Produce all the layers in parallel
  - Stack and glue them
  - Drill and plate the full stack
- Sequential build-up
  - Produce layer 1
  - Glue layer 2 on top
  - Drill and plate layer 2
  - Pattern layer 2
  - Etc..
- Mix structure
  - Core done with parallel production (power supplies)
  - Sequential build up for high density interconnect

Different interconnection strategies and corresponding holes





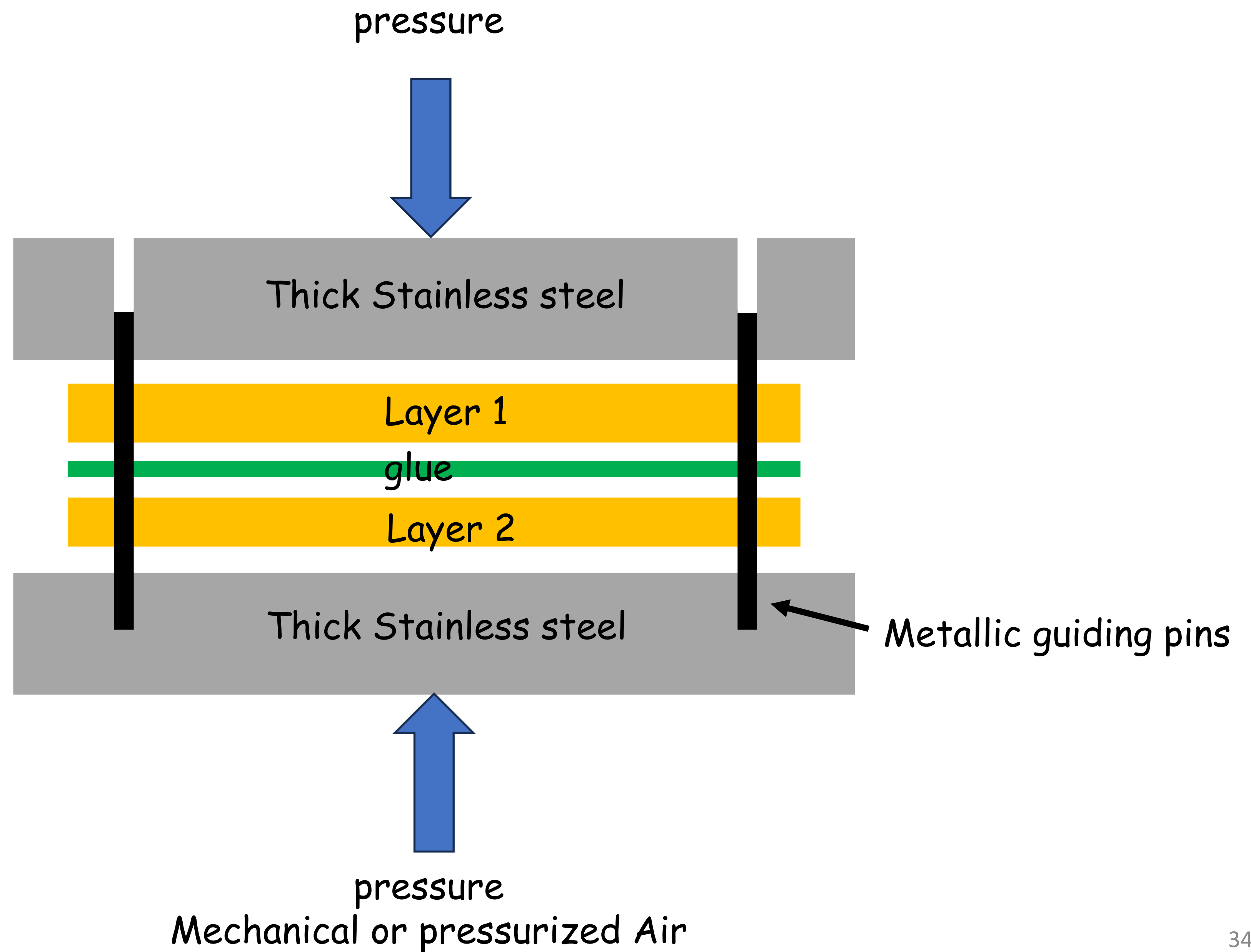
Staggered micro vias, buried and through holes



Buried holes and stacked micro vias

Gluing

Stack under vacuum
And then heat the stack



Glue

- Liquid
  - Difficult to apply , impossible to clean , thicknesses not accurate
  - Impossible to remove bubbles
- Prepregs
  - Woven glass impregnated with a bi-stage glue
  - Few um precision thickness
- Cast
  - Thin solid bi-stage glue layer without glass fiber
  - Epoxy, epoxy-acrylic
  - Few um precision thickness
- Bond-ply
  - Polyimide foil with a cast layer on both sides
  - Polyimide foil with a thin thermoplastic polyimide layer on both sides

Elite Material Co., Ltd. *Technical Data*

http://www.emctw.com

Lead-free , Halogen-free Material

EM-370(5) / EM-37B(5)

Basic Available Prepreg

Type	Resin Content (%)	Unclad Laminate Thickness (mil)
1037	71.0±3.0	2.2
	75.0±3.0	2.5
106	71.0±3.0	2.2
	75.0±3.0	2.5
1067	71.0±3.0	2.6
	75.0±3.0	3.1
1080	64.0±3.0	3.0
	67.0±3.0	3.3
1086	64.0±3.0	3.4
	67.0±3.0	3.9
2113	56.0±3.0	3.9
2116	53.0±3.0	4.8
	57.0±3.0	5.4
1501	49.0±3.0	6.7
	53.0±3.0	7.5
7629	45.5±3.0	7.9
	49.0±3.0	8.6

Notice:

1. Table listed as above is basic property for reference only.
2. Lower resin content might be insufficient resin for lower copper residual or heavy copper of inner layer.
3. If you have any other requirement, please contact our sales or customer service representatives.

Curing cycle

Cast

Processing AKAFLEX® KDF HT

The following pressing cycle is recommended for processing AKAFLEX KDF HT in heated-plate presses:

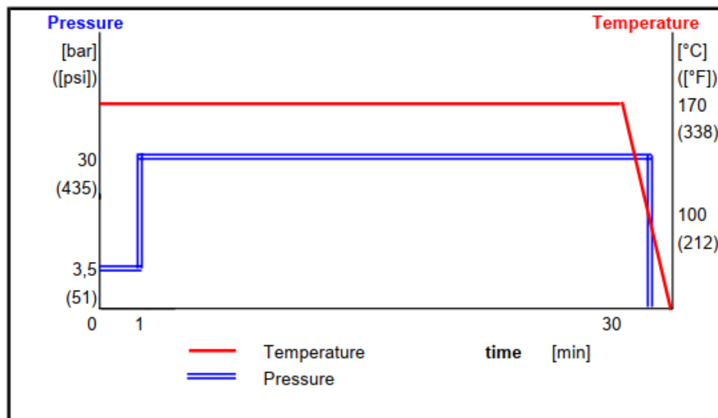


Plate temperature:
170 °C (338°F)

Contact pressure:
3.5 bar (51psi)(1 min)

Pressing pressure:
30 bar (435psi)

Pressing time:
30 minutes

Cooling:
< 100 °C (212°F) under pressure

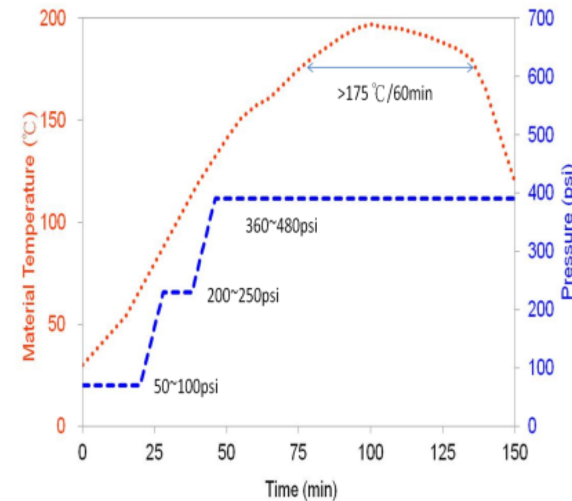
Conformal layer:
e.g. silicone

PrePreg

Lead-free , Halogen-free Material
EM-370(5) / EM-37B(5)

Press Cycle

Basic press cycle for normal construction of multilayer PWB:



Kiss pressure: 50~100psi(3.5~7kgf/cm²)

Middle pressure:200~250psi(14~18kgf/cm²)
Apply at 70~90°C
Heating rate:1.6~2.5°C/min(70~100°C)

Full pressure:360~480psi(25~34kgf/cm²)
Apply at 105~125°C
Heating rate:1.6~2.5°C/min(100~130°C)

Curing condition: >175°C / 60mins

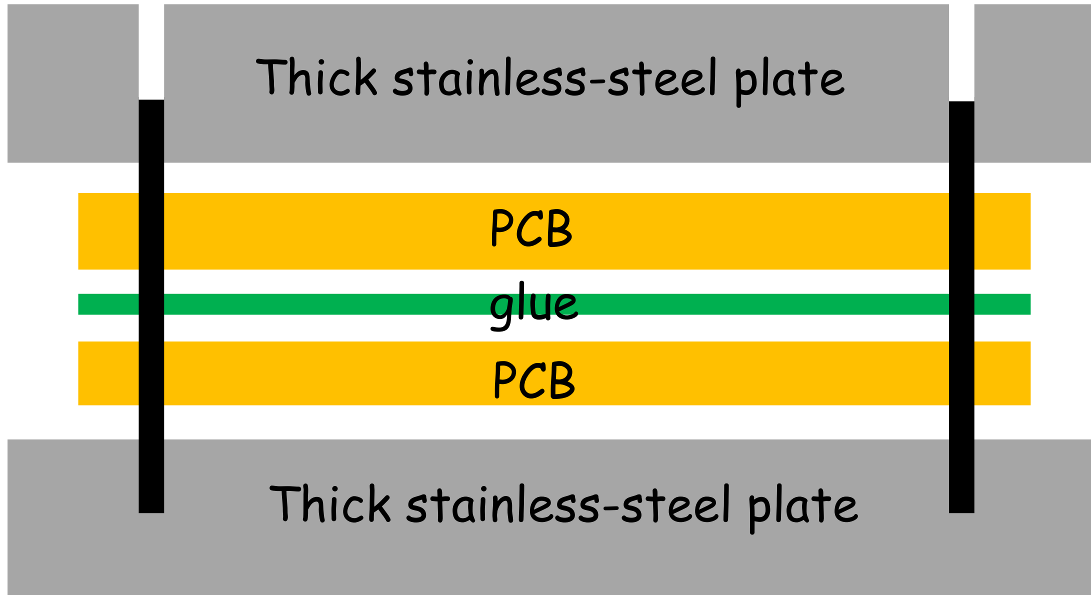
Peak temperature of material should be preferable achieved at 195°C

Gluing equipment

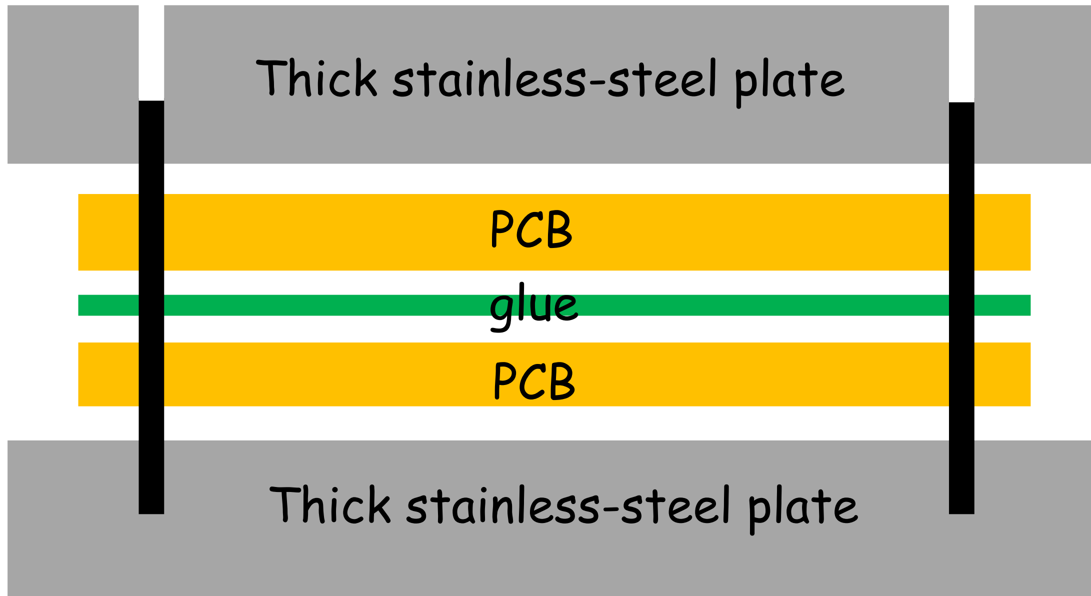
Isostatic press
- Vacuum chamber
- 5 heating platens , 4 daylights
- Mechanical Hydraulic pressure (170 Tons)
- Plate size 600mm x 700mm
- Presses with 3m x 1.5m platens exist
- Only used for flat circuits
- Perfect for mass production

Autoclave
- The parts to be glued are in a vacuum bag
- Pressure comes from compressed air (7 Bars)
- STD size 2m x 1m
- Machine with a length of 20m are existing
- Long cycles
- 3D objects
- Need more handling than Isostatic

Problem : nothing is flat

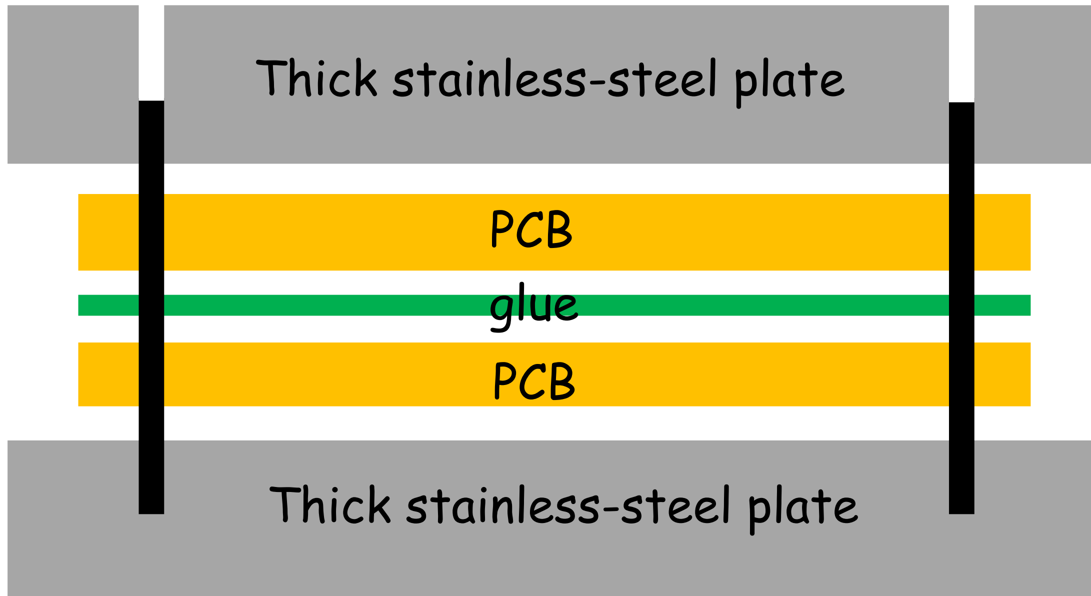


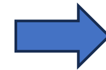
Problem : nothing is flat

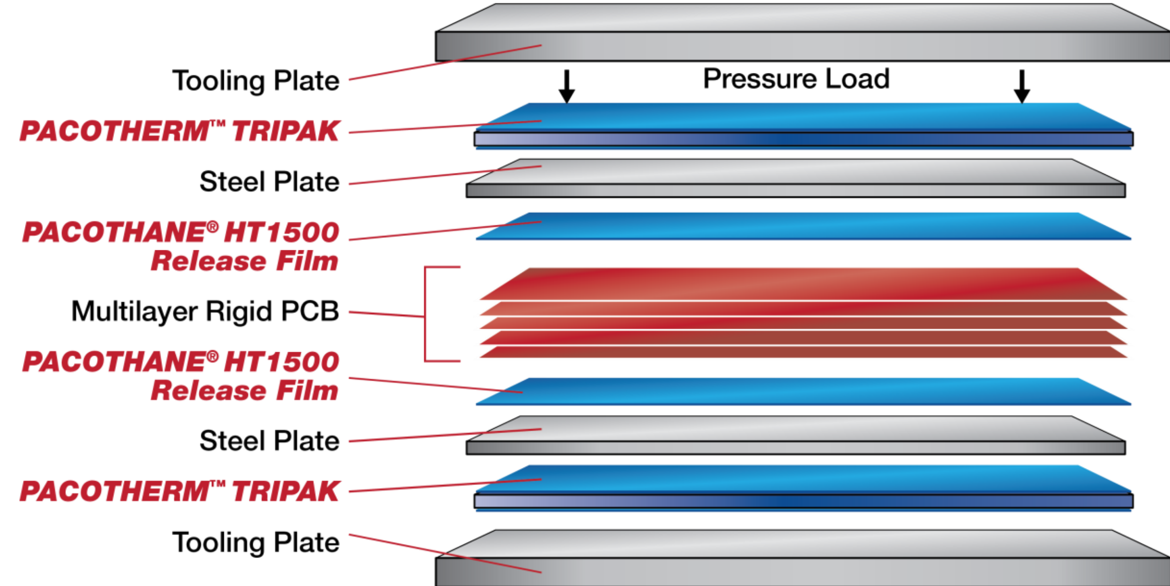


Machine platens →+/-150um error
SS plates →+/- 50um
PCB →+/- 10% of the thickness
Prepreg , Glues →+/-10um

Problem : nothing is flat





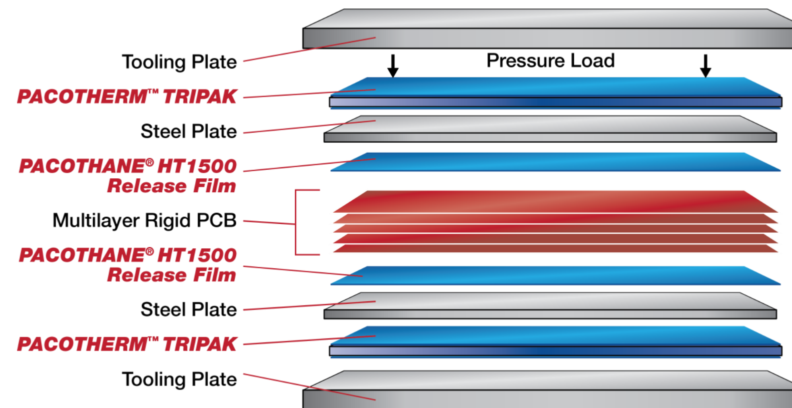


Machine platens →+/-150um error
SS plates →+/- 50um
PCB →+/- 10% of the thickness
Prepreg , Glues →+/-20um

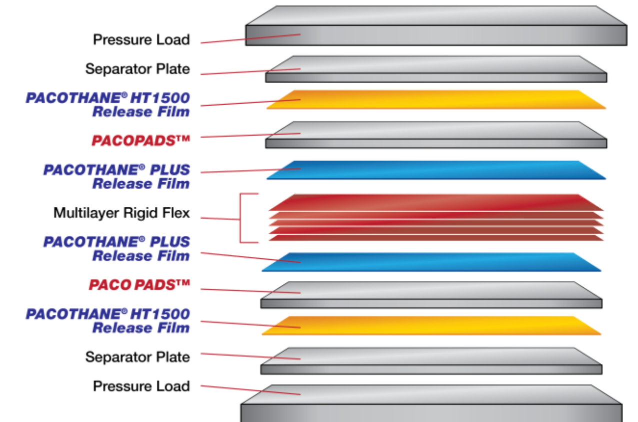
Introduction of conformal layers to correct all the errors

Release and conformal layers

- Release sheets
  - Pacotane
  - Pacolon → high temp
- Planarity correction
  - Pacopads→ 200um correction
  - Thermal activation
  - Pacoterms→ 1mm correction
  - Mechanical activation
- Hermetic layer
  - Pacovia→ Stop the glue flowing from buried holes
  - Thermal activation



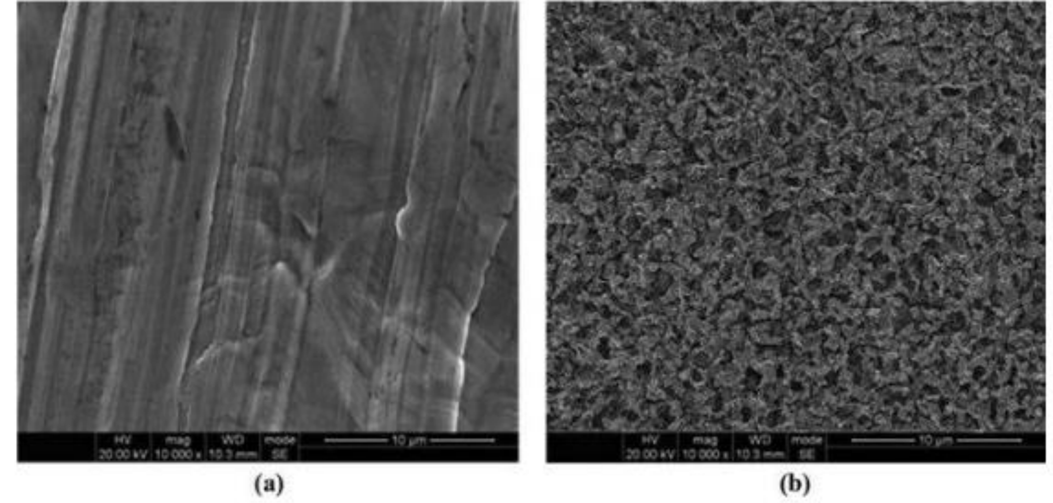
Typical 4-layer Rigid PCB stack



Typical 4-layer Flex stack

And not forget to prepare metals before gluing

1/Detergent Cleaner
2/Pre-conditioning
3/Micro structuring Chemistry
4/DI water Rinse
5/Dry



Copper before and after treatment

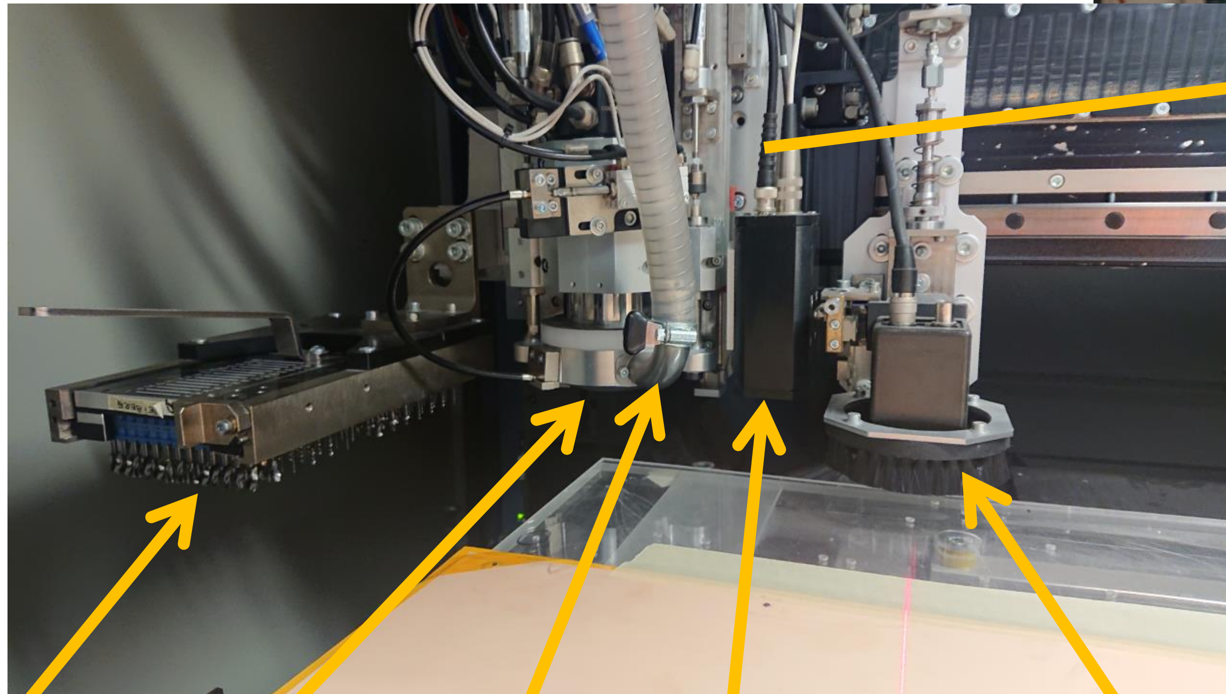
Drilling / Milling

- Mechanical
- Chemical
- Laser
- Plasma
- Sand blast

Mechanical drilling

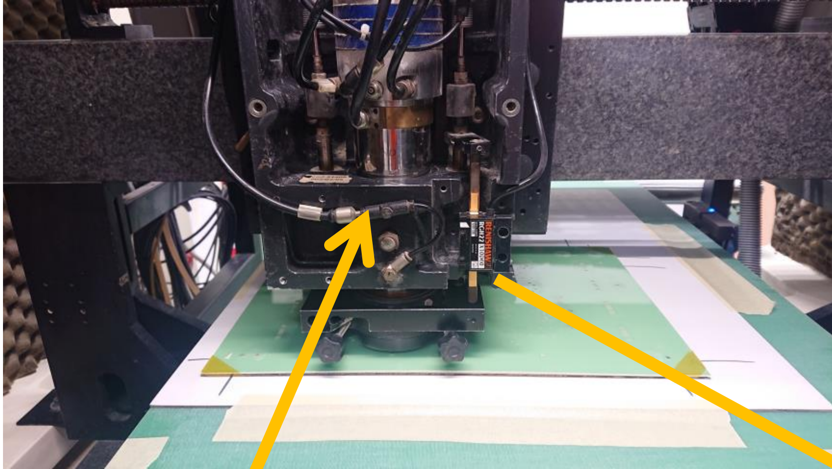
At CERN
Minimum tool diameter : 0.15mm
Spindle 180 000 RPM
Max rate 3Holes/s
1.4m x 0.6m drilling area

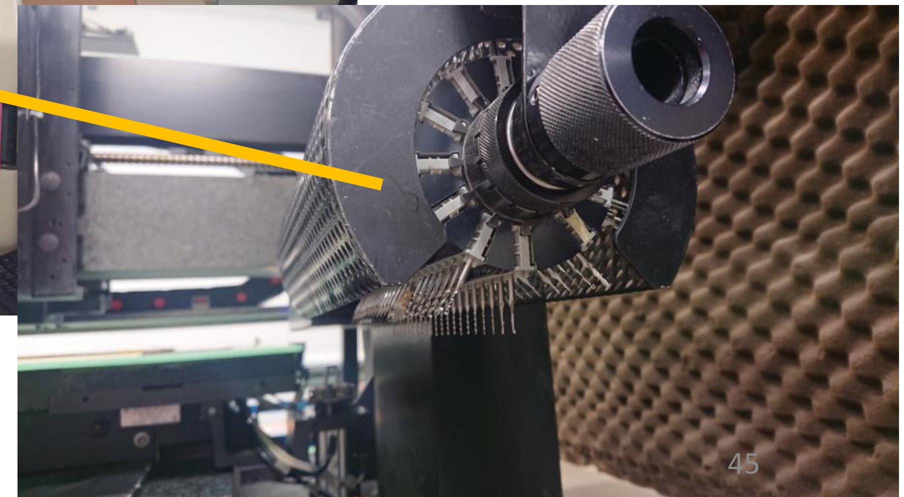
CERN Machine



In industry
- Up to 4m x 2m drilling area
- Max rate up to 10 holes/s
- Min tool diameter 0.05mm
- Spindle 300 000 RPM

Mechanical Milling





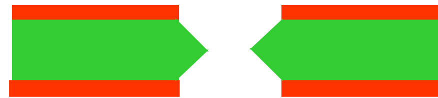
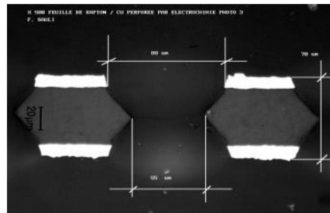
Spindle 80 000 RPM
0.5mm min milling tool

Tool store

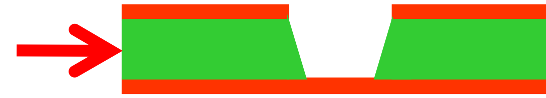
Chemical drilling → GEM

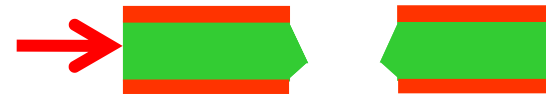
- Base material : Polyimide 50um + 5um on both sides

- Double mask

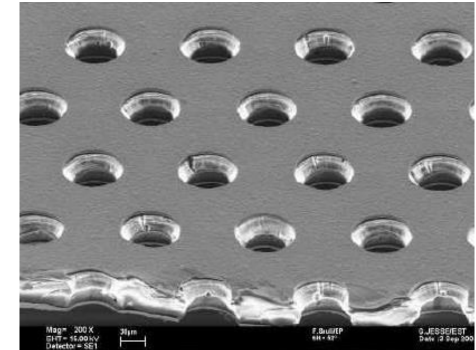



- Single mask

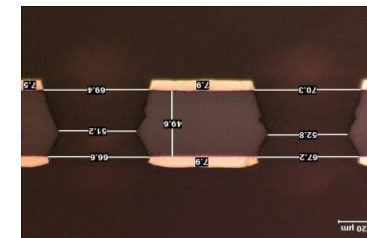




- Base material
- Hole patterning in Cu
- Polyimide etch
- Bottom electro etch
- Second Polyimide Etch



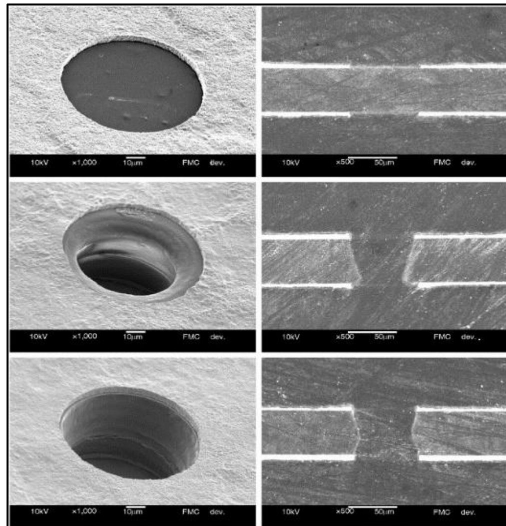
- Limited to 40cm x 40cm due to:
    - The masks alignment precision
    - And Glass mask cost



- Limited to 2m x 60cm due to:
    - Base material
    - Equipment

Laser or plasma drilling

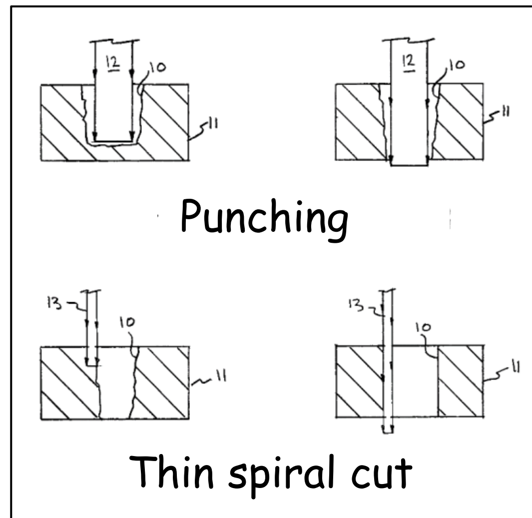
CO2 laser



-Many possible base Materials.
-Holes perfectly clean.
-Small patterns
-30um holes

-Not competitive with Wet drilling

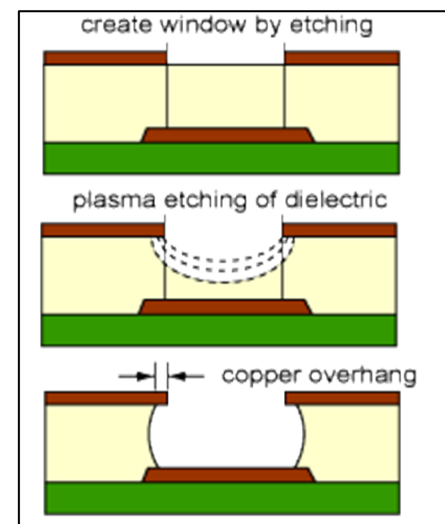
UV laser



-Many possible base Materials.
-Can drill both metals and polymers
-20um holes

-Not selective enough
-Not yet competitive with Wet drilling

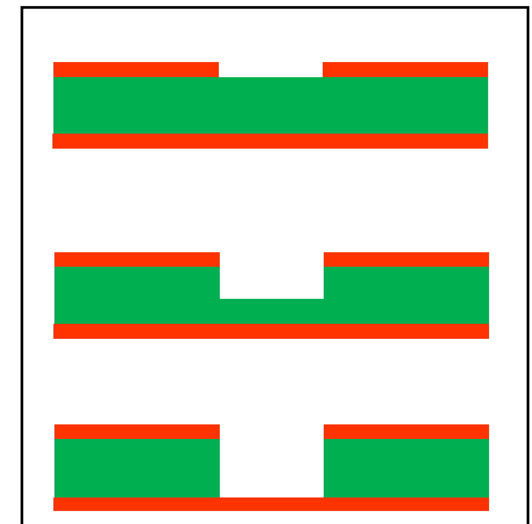
RIE Plasma



-Moderate machine cost .
-Holes perfectly clean
-50um holes

-Not uniform on large size.
-Etching too Isotropic

DRIE Plasma

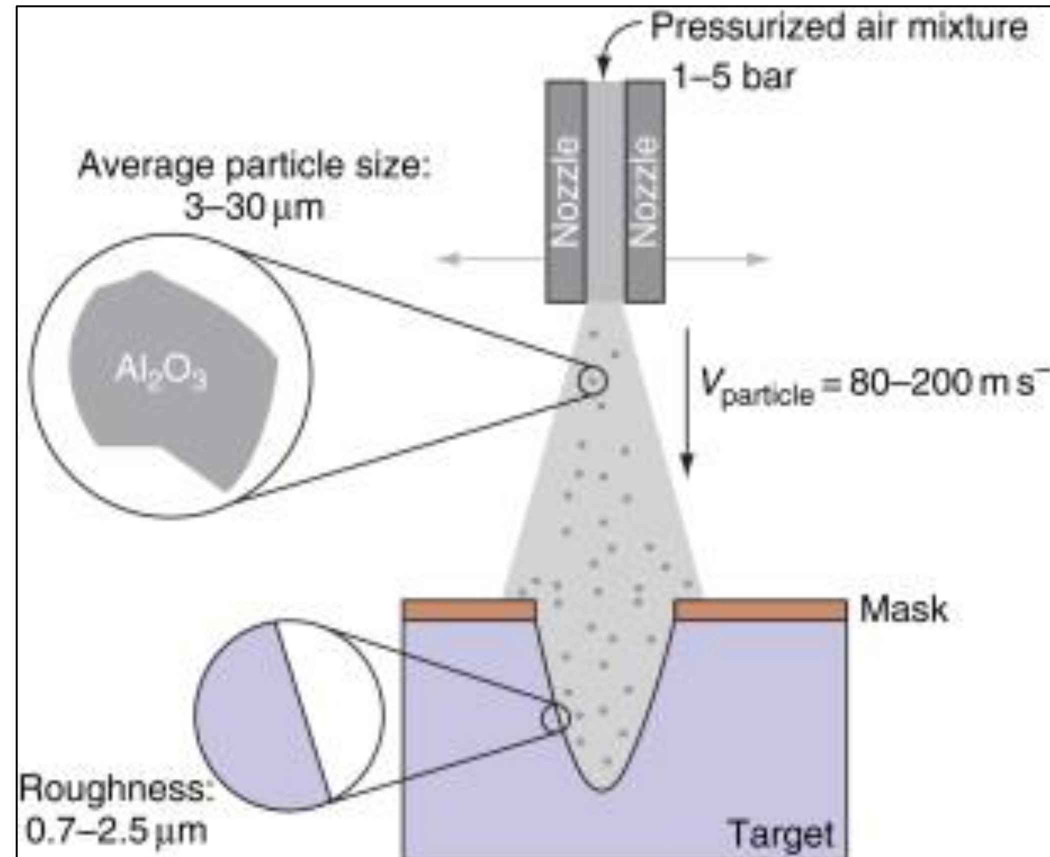


-Perfect cylindrical holes.
-Holes perfectly clean
-Ultra precise patterns
-20um holes

-Complex process
-limitation on size : dia 20cm max.

Sand blast drilling

- Anisotropic drilling
- Can drill nearly all materials
- Smooth walls
- Millimetric scale holes



Wet plating

- Black hole
- Electroplating
- Electroless plating
- Vacuum plating

Hole plating →Black hole

Drilled PCB

Carbon full coverage

Remove the carbon on copper

Electrolytic copper plating

Dielectric treatment before copper plating

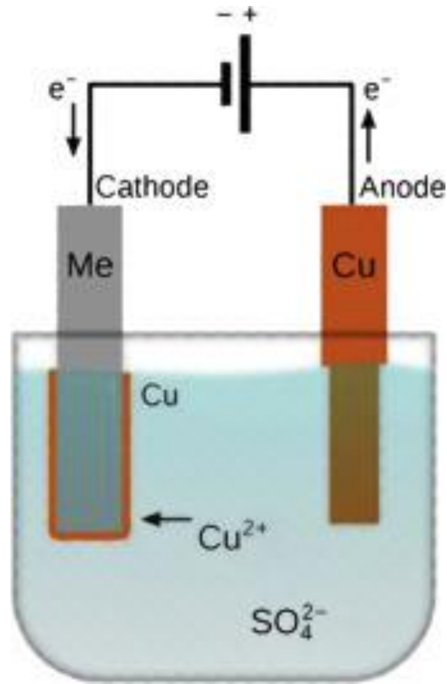
1/Deasmear line:

- Remove material burnt during drilling
- Come back to fresh dielectric
- Sequence:
  - 1/ Sweller
  - 2/ Potassium permanganate etching
  - 3/ Neutralizer

2/Carbon line:

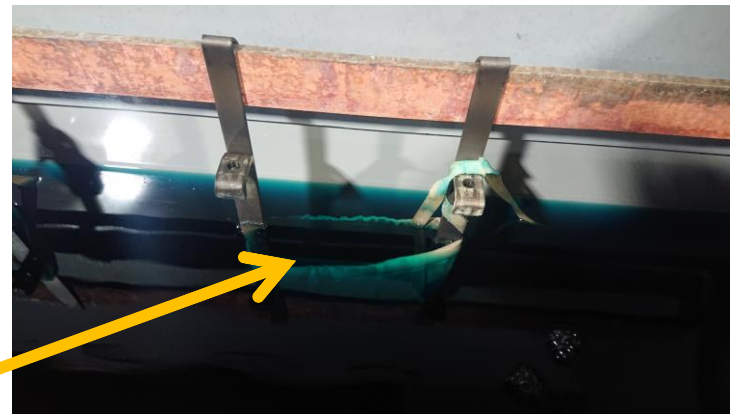
- Deposition of Nano Carbon on dielectric
- Sequence
  - 1/ Detergent cleaning
  - 2/ Nano carbon full coverage
  - 3/ Micro etch to remove carbon on copper

Electro plating

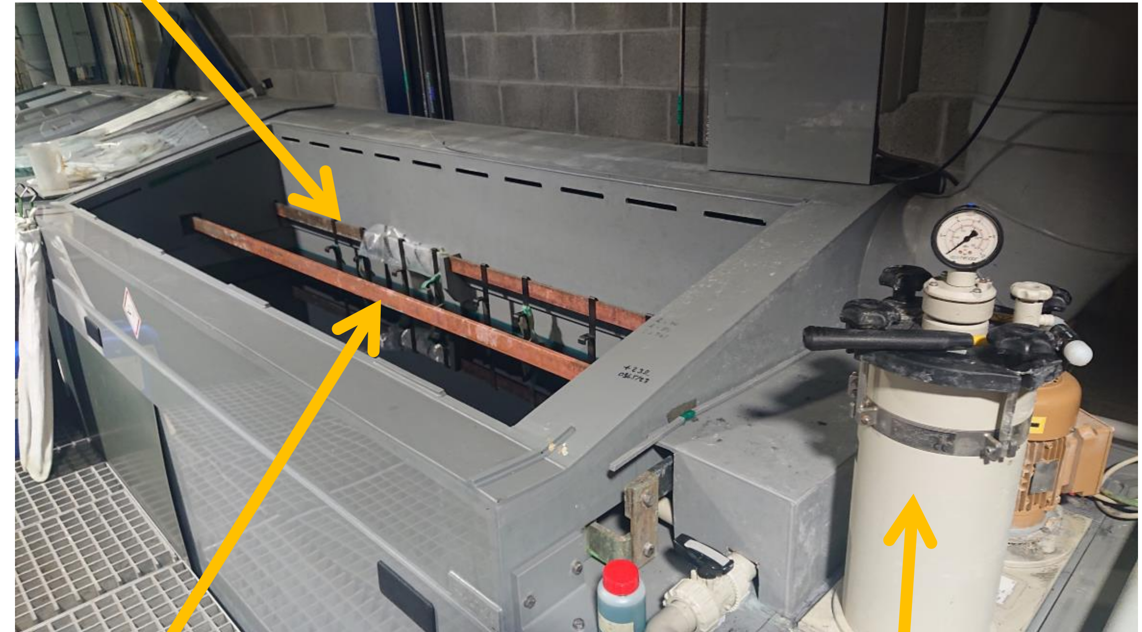


- CU
- NI
- Au

Anode



Basket with copper balls



Copper plating Bath
2m x 0.6m panels

Cathode

Filter/pump

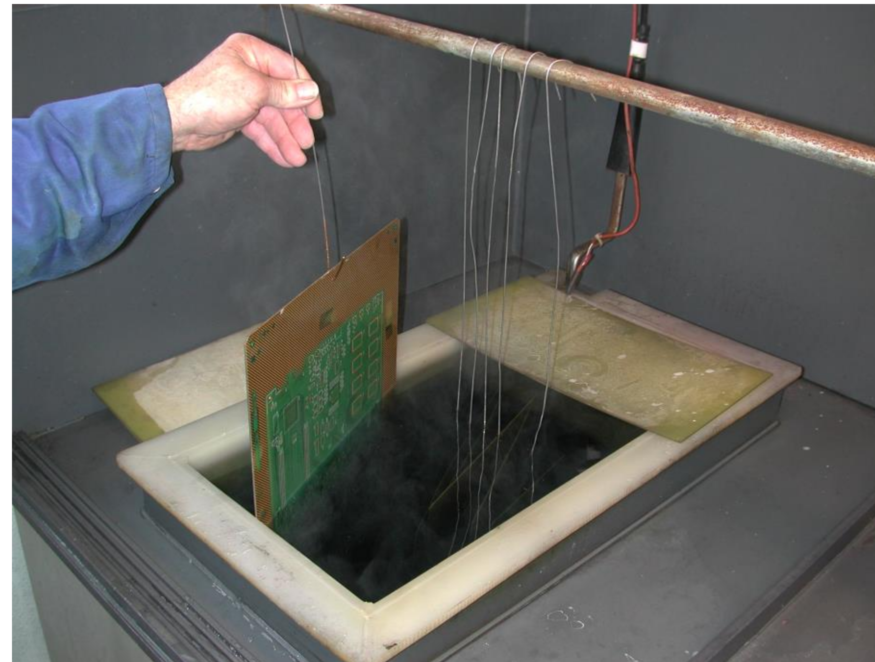
Electro-less plating

- Protect copper from oxidation
- Ease the components soldering
- Allow Aluminum or Gold wire Bonding

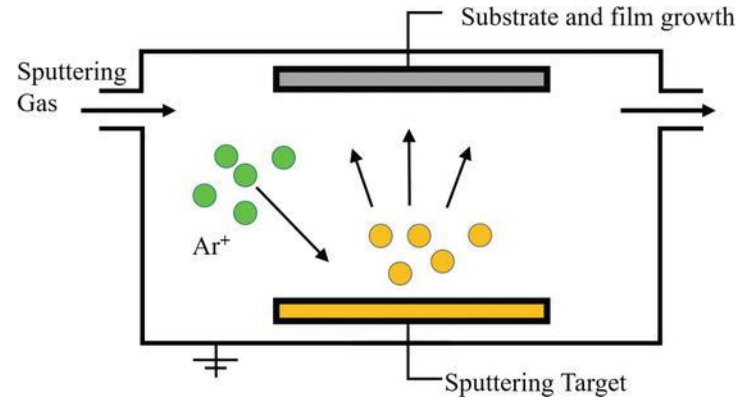
ENIG : Electroless nickel (5um) , Immersion Gold (0.07um)
ENEPIG: Electroless nickel , electroless Palladium , Immersion Gold
Ag: Chemical silver less than 1um
Tin: Chemical Tin

Immersion Au

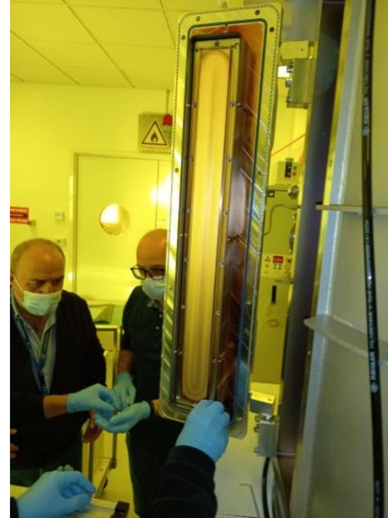
Electroless Ni



Vacuum deposition



Pulsed DC Magnetron vacuum deposition machine



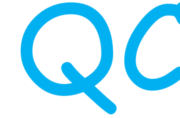
70cm targets

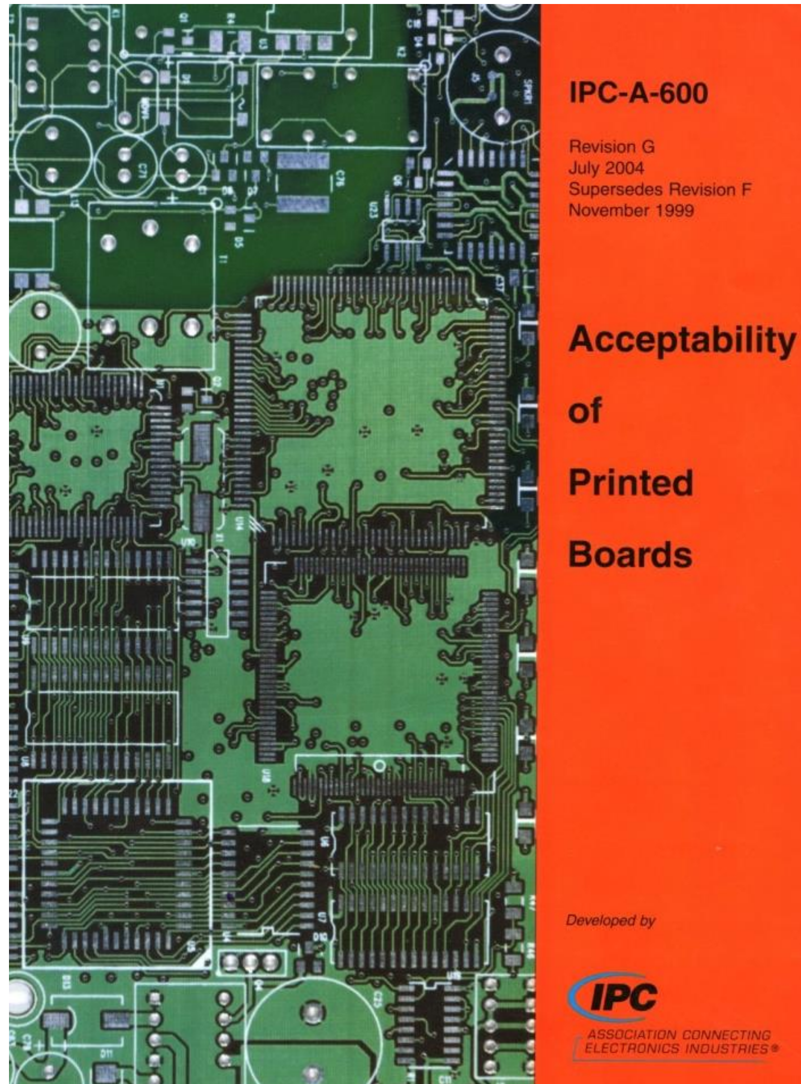
Cr
Cu
Al
Ti
Nb
B4C
DLC
ITO

Drum unloading after processing

Tests

- QC
- AOI
- Flying probe tester
- XRF





IPC standard define the parameters
to check and set 3 levels of quality.

Class 1: Consumer products
- It can fail without consequences
- exchange sometimes not necessary
- → radio , toy , microphone etc..

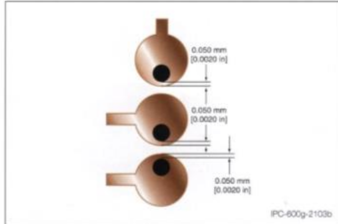
Class 2: Industrial products
- uninterrupted service is desired
- exchange is not critical.
- → CNC machines, Heat pumps etc..

Class 3: High reliability
- No possibility to exchange the product without serious problems.
- → Airplanes, trains , cars
- → President microphone.

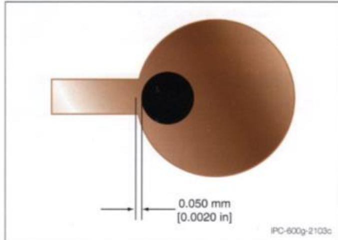
2.10 PATTERN DEFINITION – DIMENSIONAL

2.10.3 External Annular Ring - Supported Holes

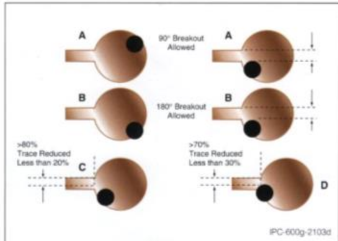
Target Condition – Class 1, 2, 3
- Holes are centered in the lands.



Acceptable – Class 3
- Holes are not centered in the lands, but the annular ring measures 0.050 mm [0.0020 in] or more.
- The minimum external annular ring may have 20% reduction of the minimum annular ring at the measurement area due to defects such as pits, dents, nicks, pinholes, or splay.



Acceptable – Class 2
- 90° breakout or less. (A)
- If breakout occurs at the conductor to land junction area, the conductor is not reduced by more than 20% of the minimum conductor width specified on the engineering drawing or the production master nominal. The conductor junction should never be less than 0.050 mm [0.0020 in] or the minimum line width, whichever is smaller. (C)
- Minimum lateral spacing between conductors is maintained.

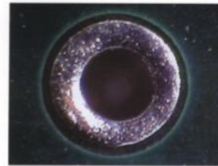


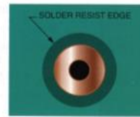
Acceptable – Class 1
- 180° breakout or less. (B)
- If breakout occurs at the conductor to land junction area, the conductor is not reduced by more than 30% of the minimum conductor width specified on the production master nominal. (D)
- Form, fit and function are not affected.
- Minimum lateral spacing between conductors is maintained.

Nonconforming - Class 1, 2, 3
- Defects either do not meet or exceed above criteria.

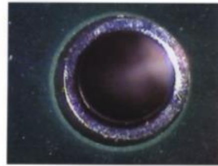
2.9 SOLDER RESIST (Solder Mask)

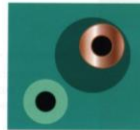
2.9.2 Registration to Holes (All Finishes)



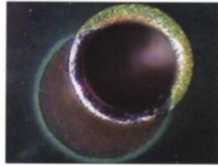


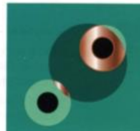
Target Condition – Class 1, 2, 3
- No solder resist misregistration. The solder resist is centered around the lands within the nominal registration spacings.





Acceptable – Class 1, 2, 3
- Misregistration of the resist to the land patterns but the resist does not violate minimum annular ring requirements.
- No solder resist in plated-through holes, except those not intended for soldering.
- Adjacent, electrically isolated lands or conductors are not exposed.

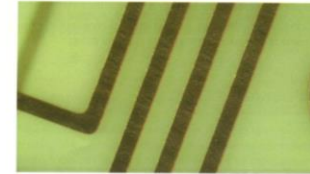




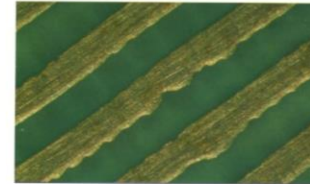
Nonconforming – Class 1, 2, 3
- Defects either do not meet or exceed above criteria.

2.10 PATTERN DEFINITION – DIMENSIONAL

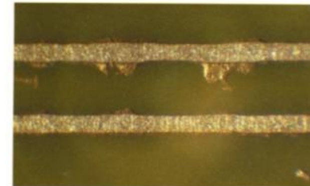
2.10.1.2 Conductor Spacing



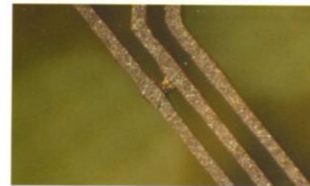
Target Condition – Class 1, 2, 3
- Conductor spacing meets dimensional requirements of the procurement documentation.



Acceptable – Class 3
- Any combination of edge roughness, copper spikes, etc., that does not reduce the specified minimum conductor spacing by more than 20% in isolated areas.



Acceptable – Class 1, 2
- Any combination of edge roughness, copper spikes, etc., that does not reduce the specified minimum conductor spacing by more than 30% in isolated areas.



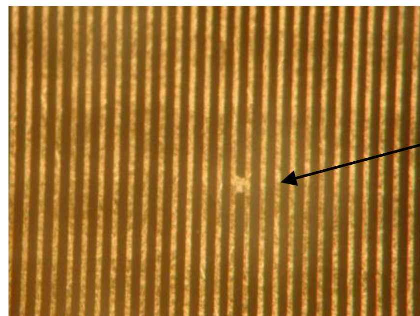
Nonconforming - Class 1, 2, 3
- Defects either do not meet or exceed above criteria.

50 July 2004 IPC-A-600G

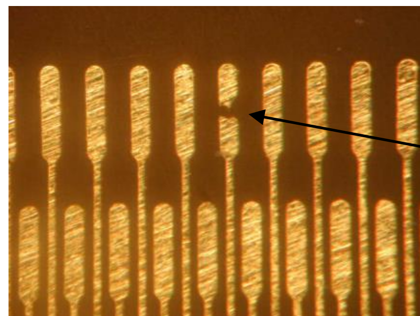
3 examples of parameters to be checked.
There are more than 150 parameters to check in IPC-A-600.

Automatic Optical Inspection (AOI)

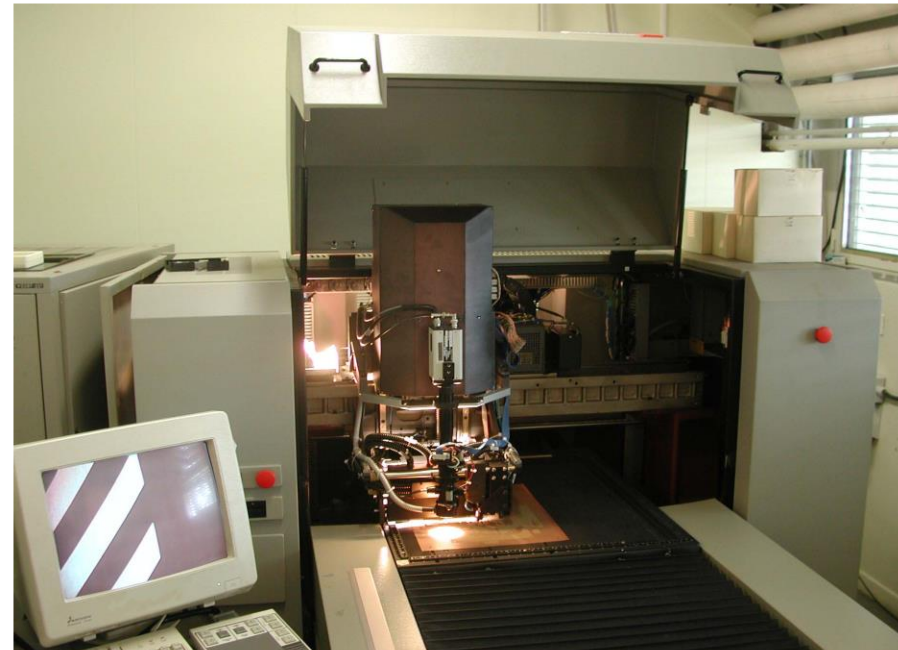
-Compare the scanned image with the CAD file
-Minimum track or space 20um
-Minimum detectable defect around 5 um (pixel 2.5um)
-Cannot detect defect in holes



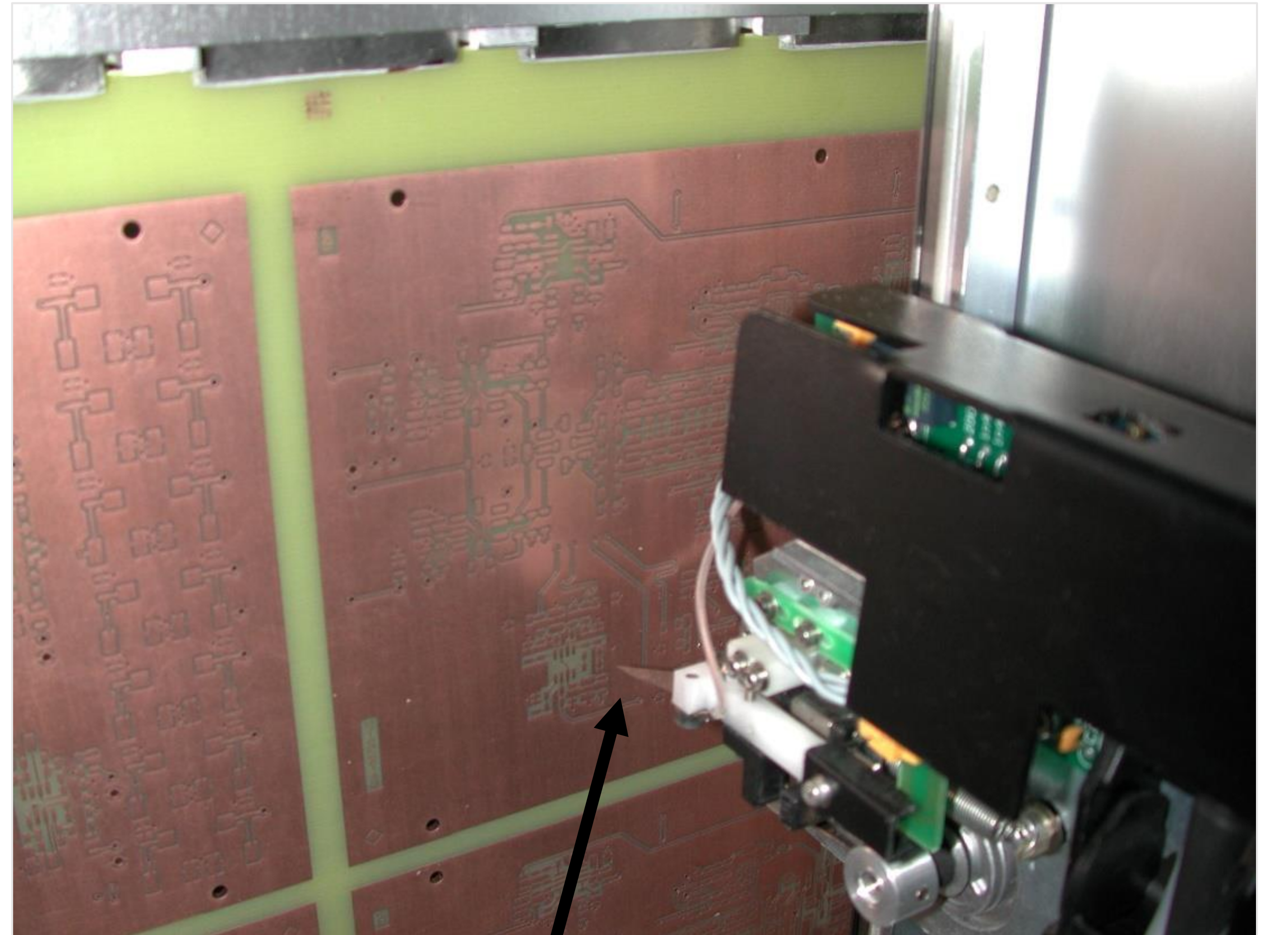
Short circuit



Open
Bonding pad



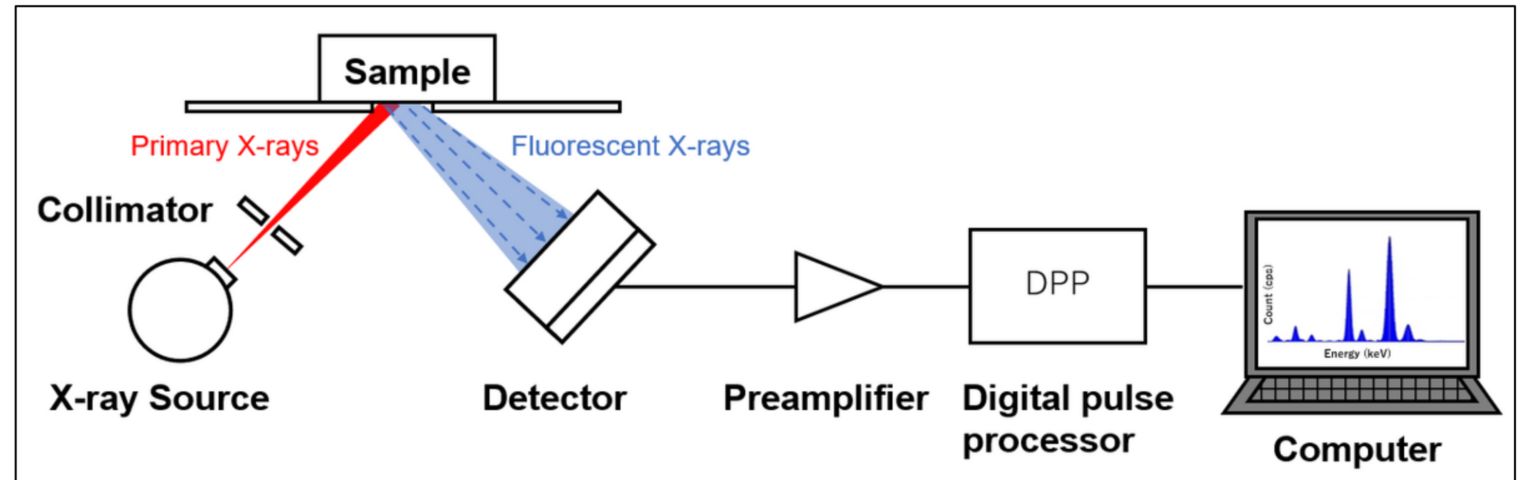
Electrical test



Control netlist integrity
Including PTH connections
Conductive / dielectric mode
Capacitive mode

Flying probe

XRF , X Ray Fluorescence



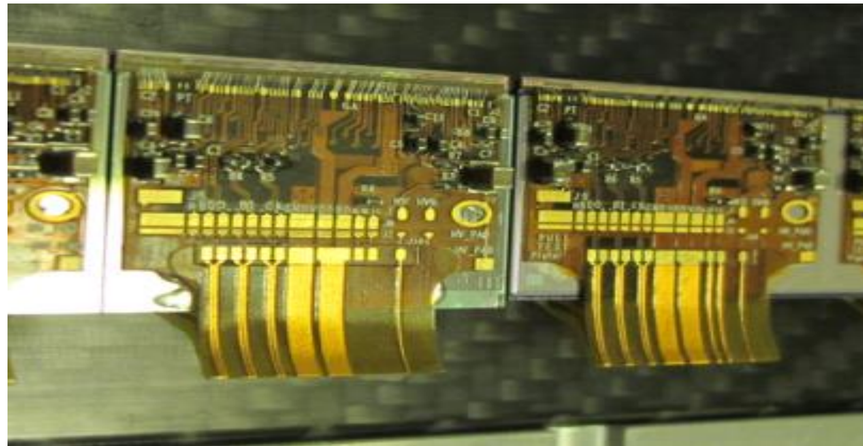
Can measure different metals nature and thicknesses
Used for ENIG and ENEPIG control

Production examples

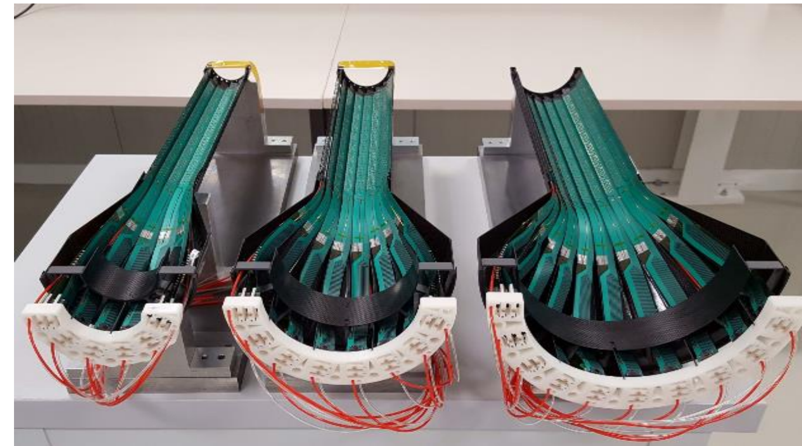
Inner Trackers → Low Mass Aluminium circuits

ALICE inner tracker BUS (5 Aluminum layers)

Double-sided flex for ILC Vertex sensor

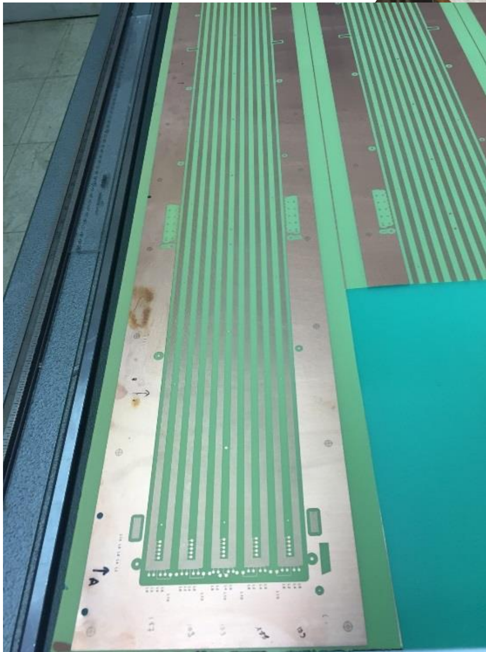


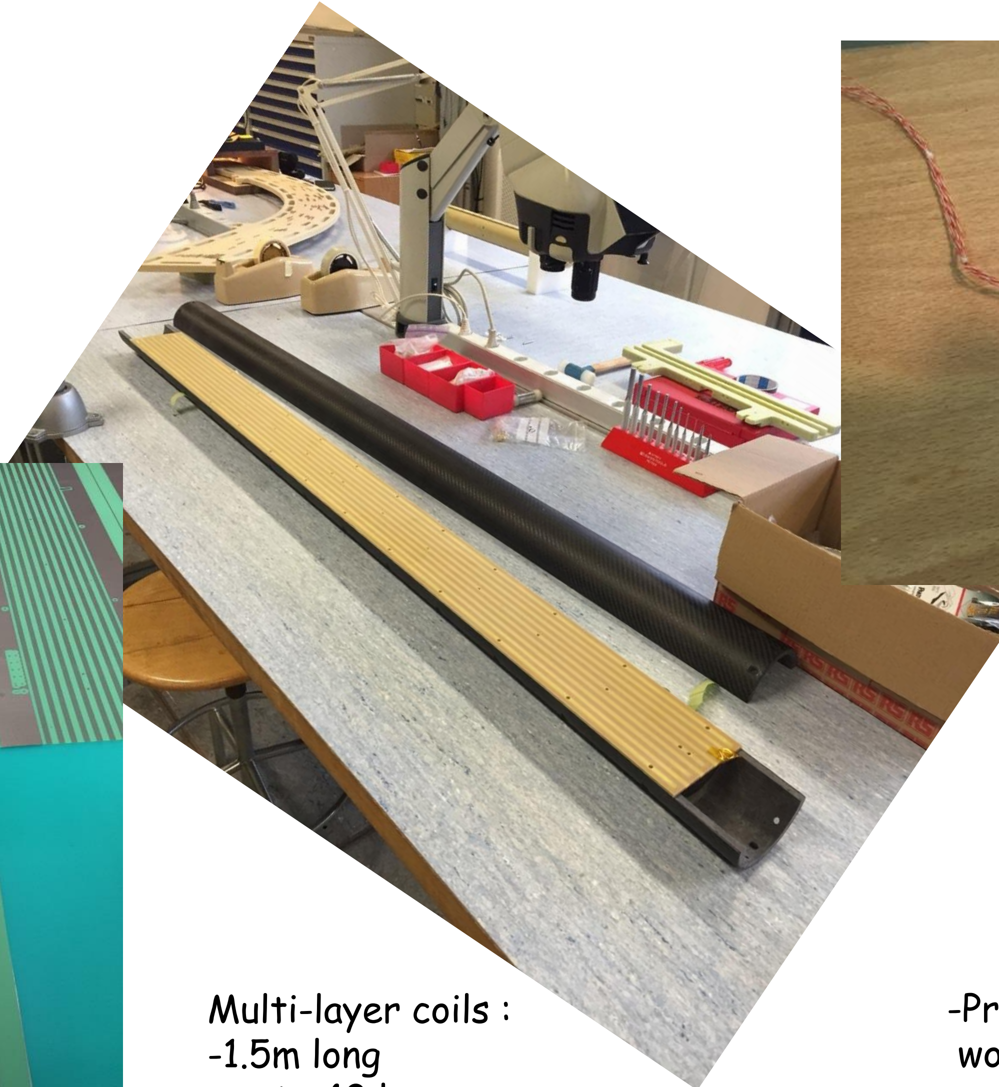
ATLAS IBL Low Mass 8 layers

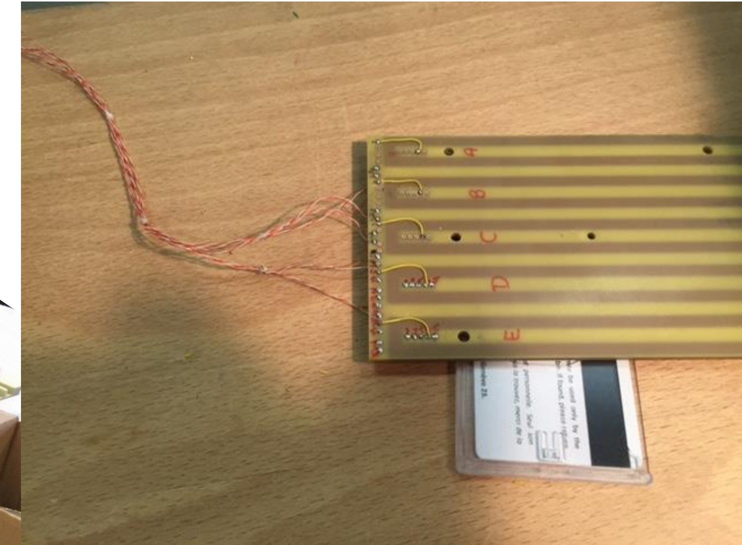


ALICE inner tracker

Magnets calibration → ultra precise field sensors



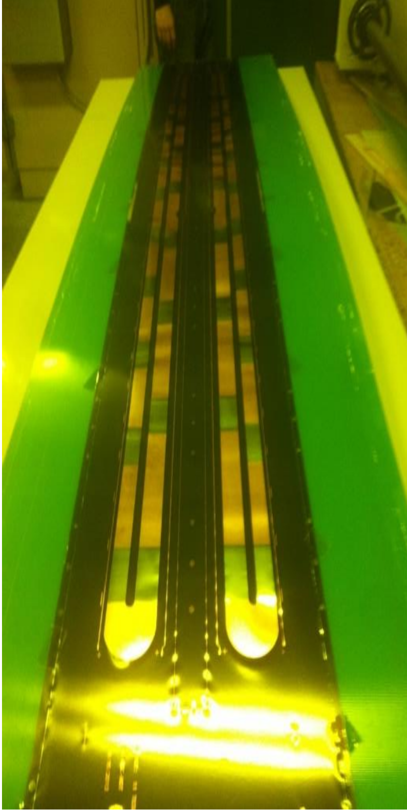




Multi-layer coils :
-1.5m long
-up to 40 layers
-30um maximum registration error
-Line and space down to 50um/50um

-Printed Coils are 10 time more accurate than wounded structures

LHC machine protection



Stainless steel or SS/Cu mix Quench Heaters
Long flexes up to 15m x 0.6m

Others:
- Heating foils
- High power resistors
- Optical targets compatible with UHV
- etc..

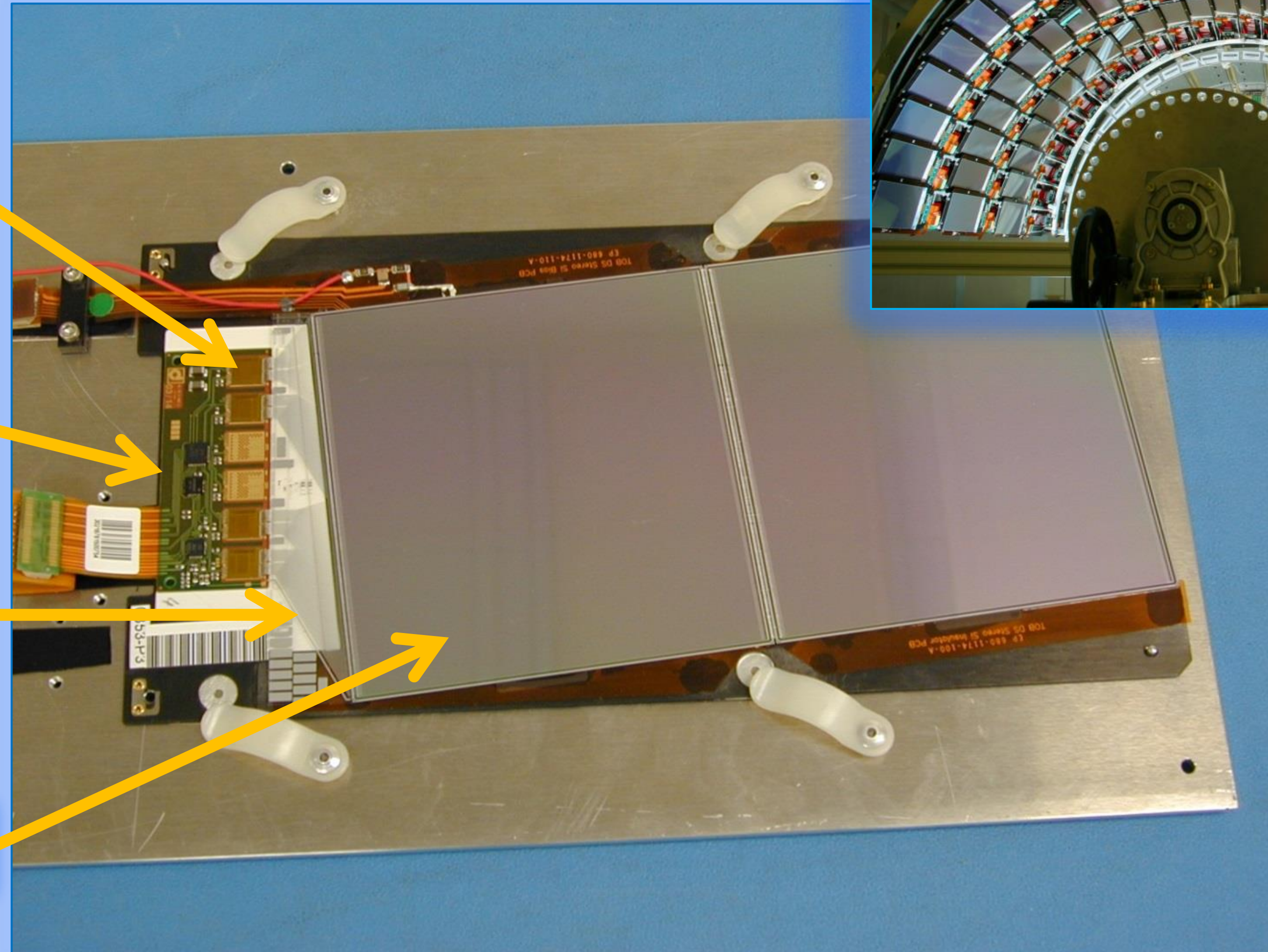
HDI CMS strip detectors

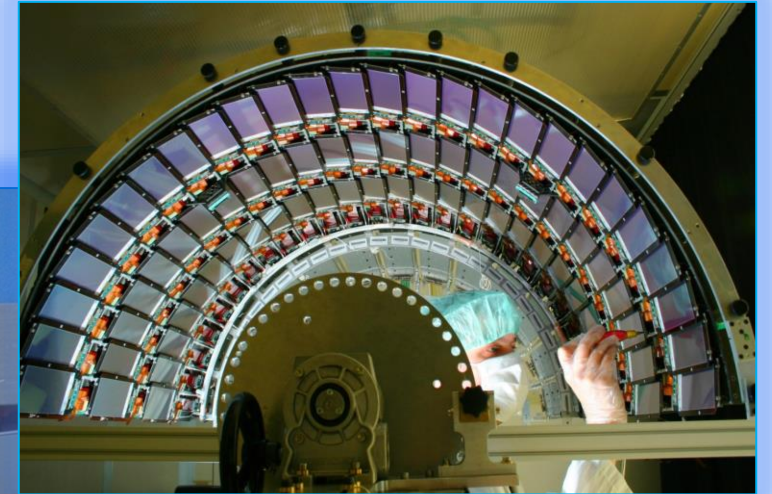
Front end Asics

Rigid flex

Glass pitch adaptor

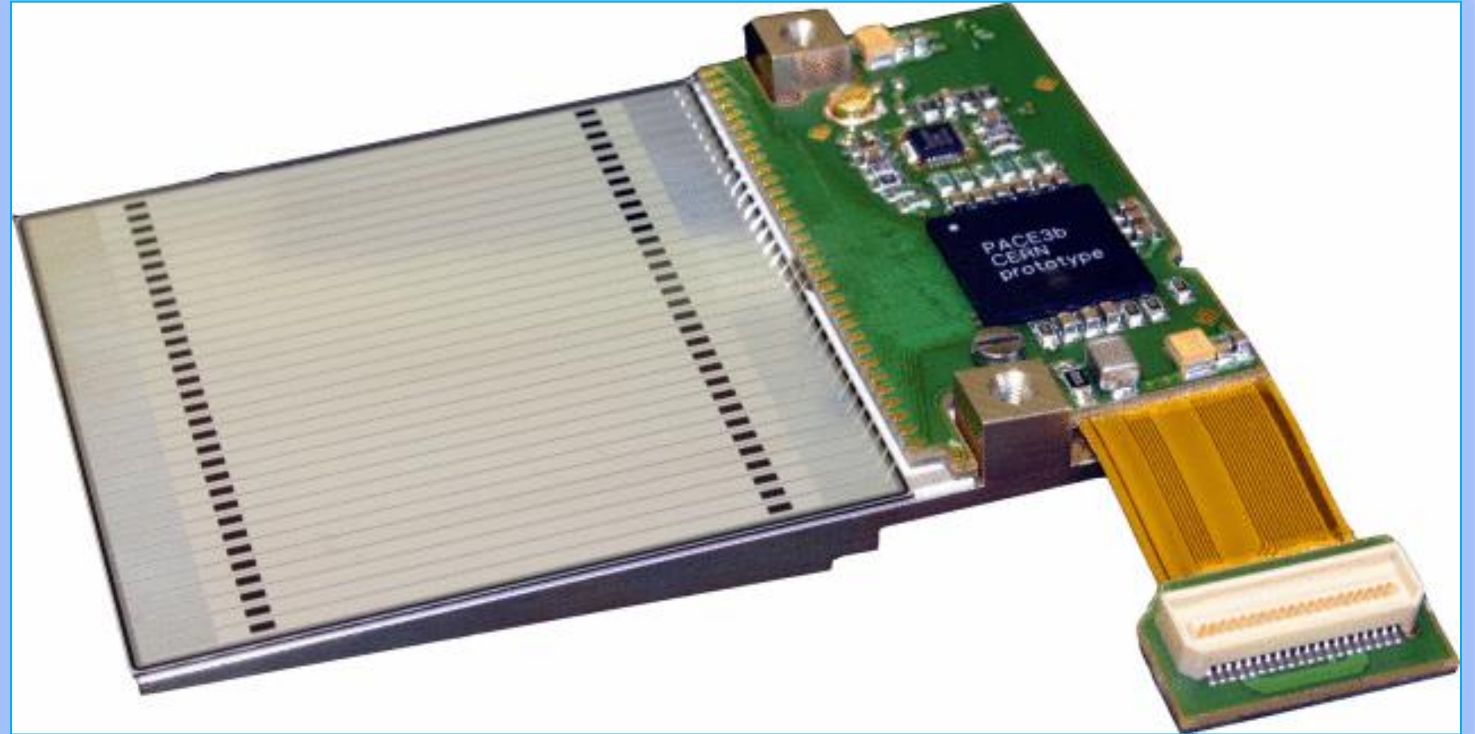
Silicon strip detector



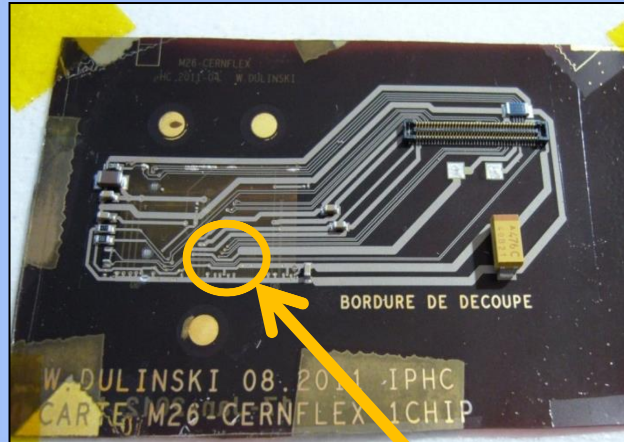


Size in the range of 10cm x 20cm

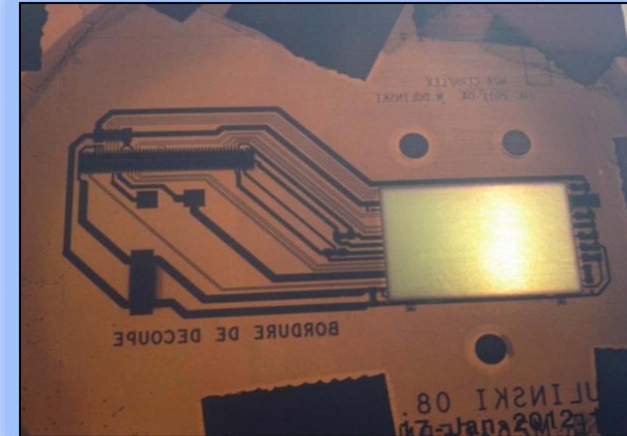
PCB for CMS Pre-shower



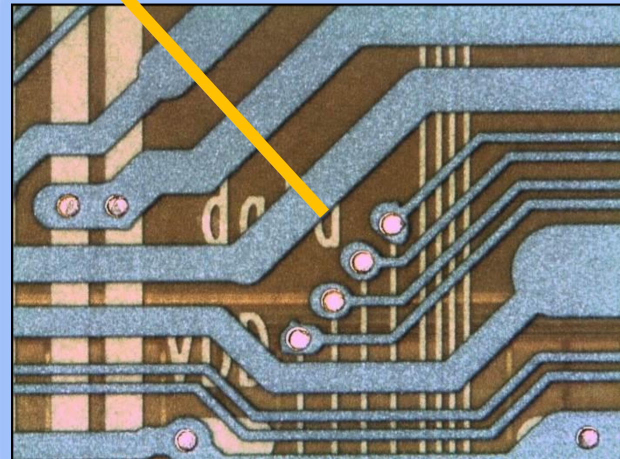
Full Aluminium flex with embedded silicon detector (R&D)



Top

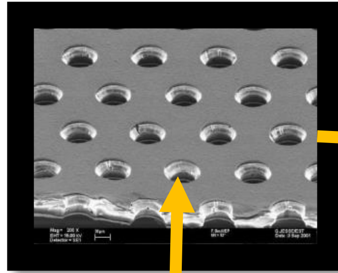


bottom

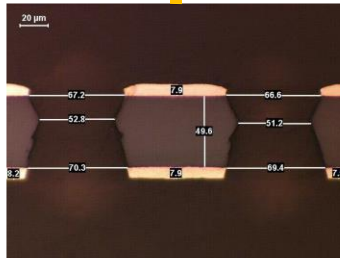


Thinned chip 50um
100um thick end device
Full aluminium
No bonding

CMS GEM Single Mask

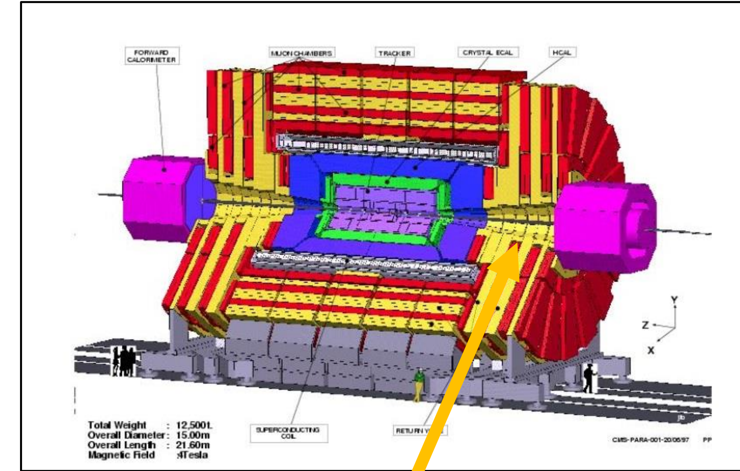


Microscopic view

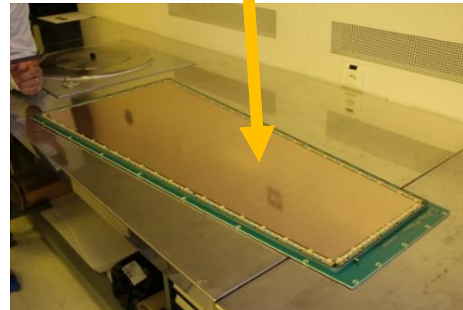


Cross section

Single mask GEM



CMS experiment



Triple GEM stack

GE1/1 Muon detector

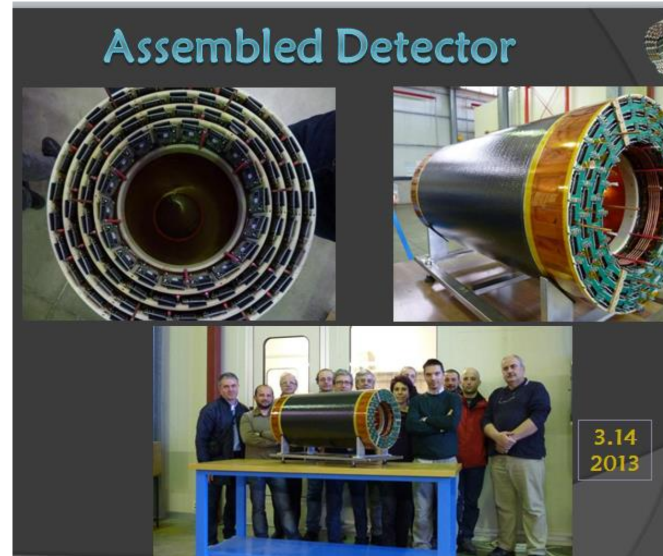
CMS nose

GE1/1 → 400 GEM (1.3m x 0.5m) made at CERN
GE2/1→ 1000 GEM (1.3m x 0.5m) CERN/Korea

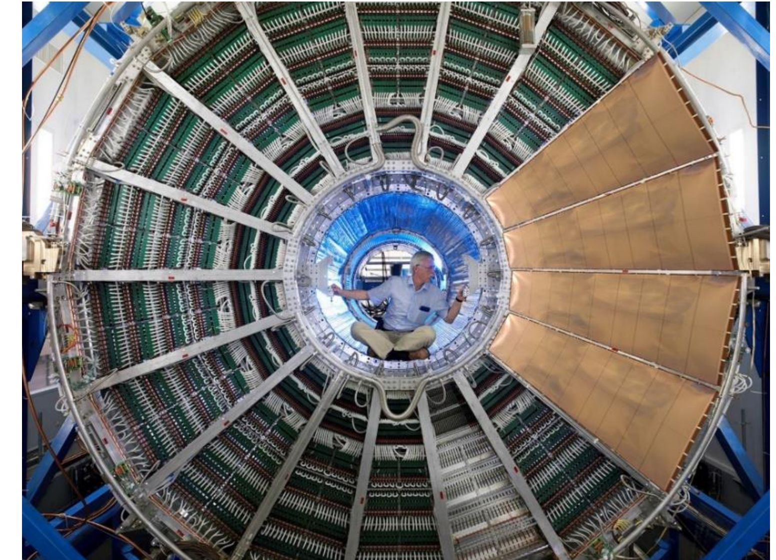
GEM producers' capabilities:
-CERN MPT : 500m2/year
-Mecaro Korea : 250m2/year

Other detectors with GEM single mask technique

CMS ME0 → 1000 GEMs



KLOE – Cylindrical Detector



ALICE TPC → 700 GEM

And many more

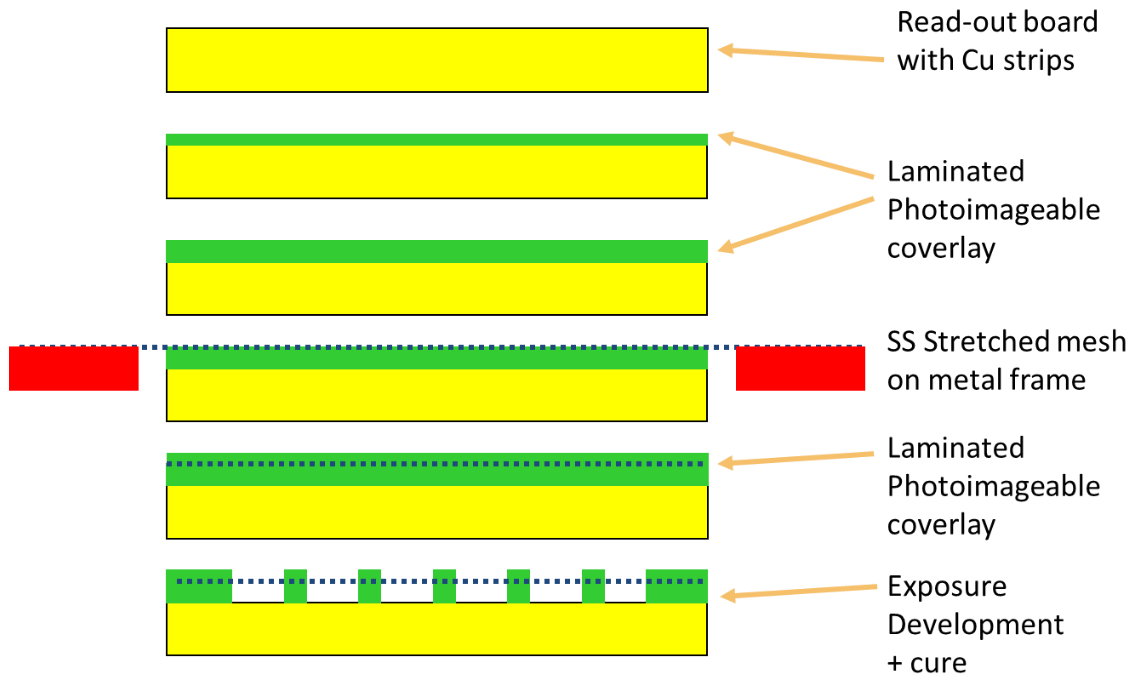
-BM@N in Dubna (1.6m x 0.5m)
-SBS tracker Jefferson lab
-CBM at Fair
-BESIII China

-SOLID
-BONUS 12
-P-RAD
-S-Phenix TPC

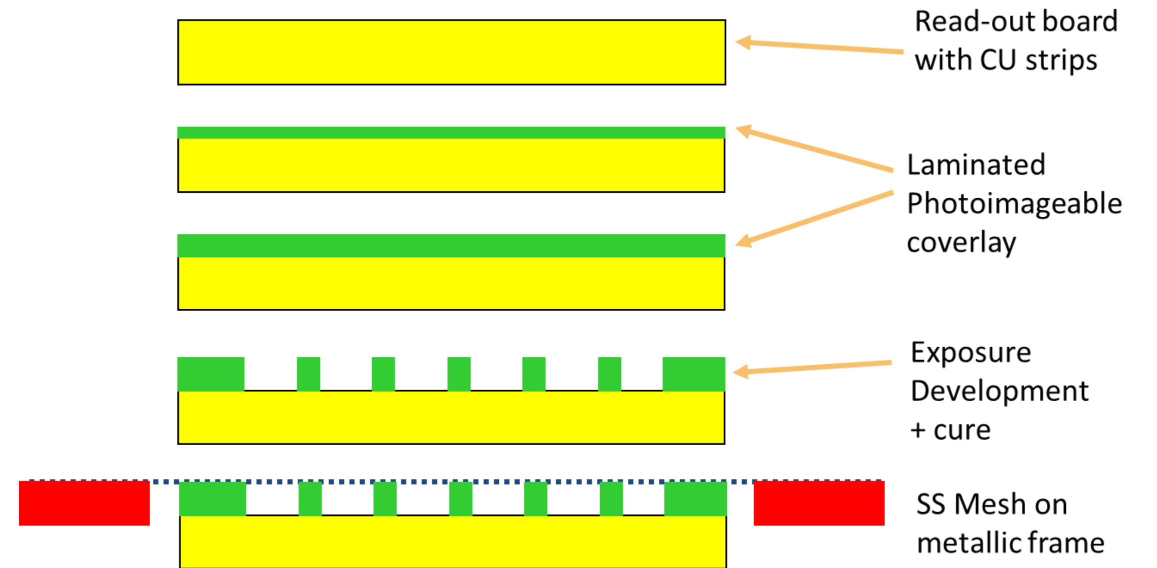
-COMPASS upgrade
-GEM for nuclear physics TPCs
-ESS for neutron detectors
-and lot of small GEMs for academic purpose

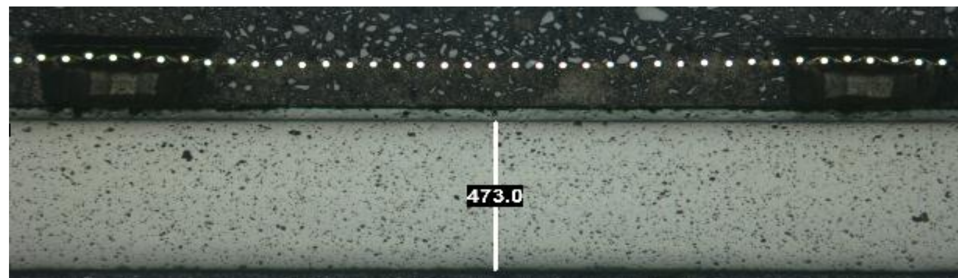
BULK and Floating mesh Micromegas detectors

BULK Micromegas



Floating mesh Micromegas

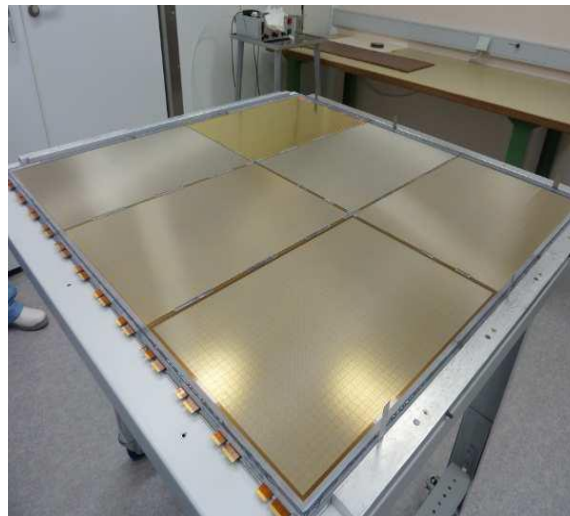




7

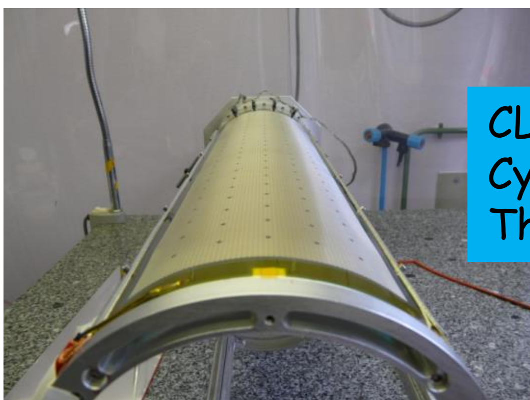
BULK Micromegas detectors

T2K TPC ,J.Beucher
1.8m x 0.8m plane
With 12 detectors

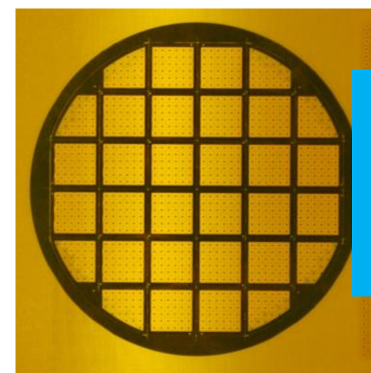


ILC DHCAL , M.Chefdeville
1m x 1m plane
With 6 detectors

Early ATLAS NSW R&D
Joerg Wotschack
1.5m x 0.5m plane
Single panel

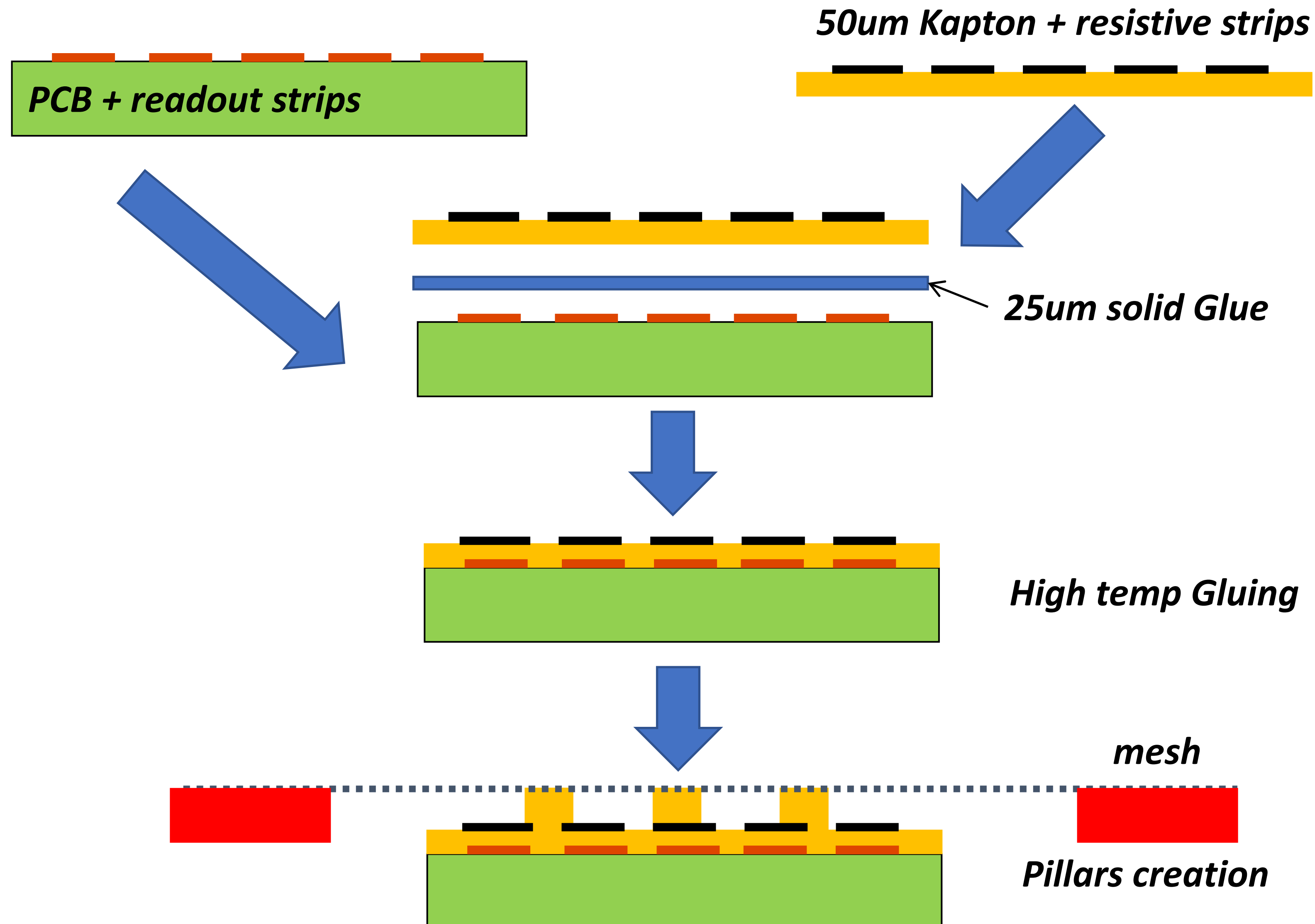


CLAS 12
Cylindrical Micromegas bulk
Thin substrate



33 sectors , 12cm diameter detector
2.5mm dead space for sectorizing
1mm hole for HV connection

Introduction of resistive layers in floating MM



Atlas NSW

Close to 2000 Micromegas detectors produced with modules sizes up to 2m x 0.5m

PCBs with pillars built at ELTOS (IT) and ELVIA (FR)
Panels construction and detector Assy :

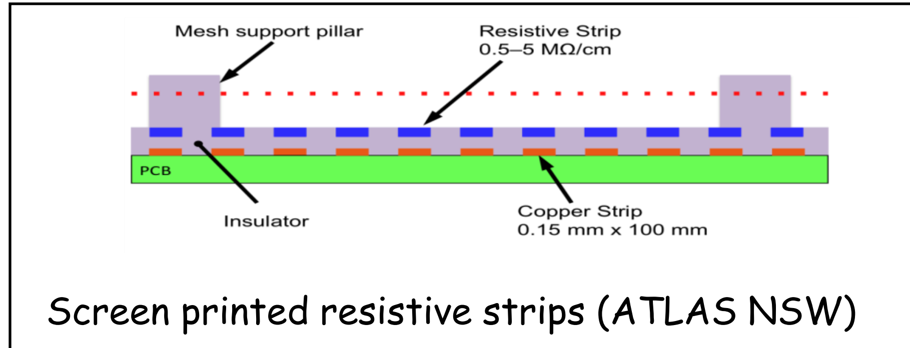
- -Dubna
- -INFN Frascati
- -CEA Saclay
- -LMU Munich

MPT participated to the R&D and was also involved in the mass production with industry

- -Specification
- -Companies selection
- -Technology transfer

Resistive MM structures

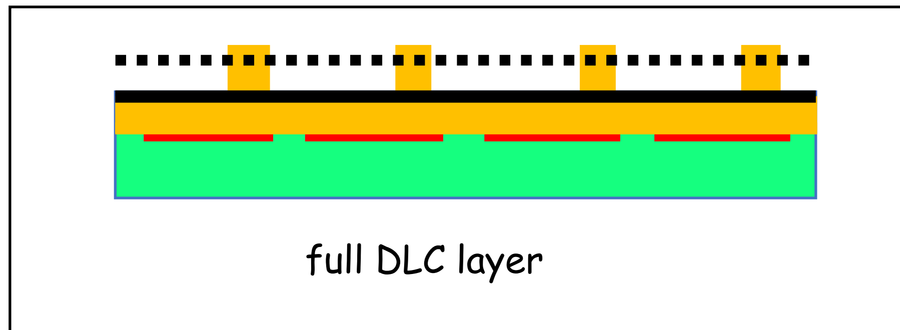
<u>Medium-rate detectors 100kHz/cm2</u>
Side evacuation of the charges



Screen printed resistive strips (ATLAS NSW)

2013

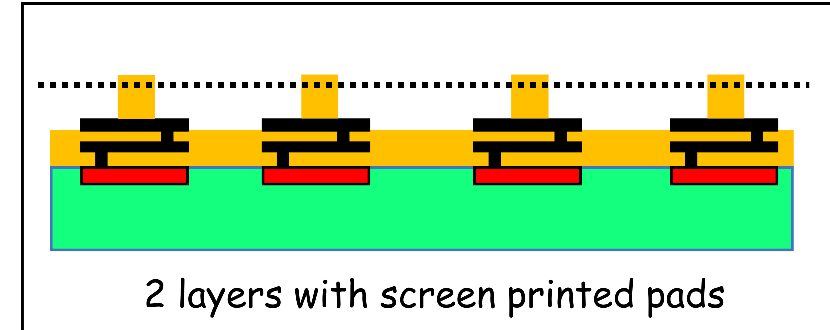
or



full DLC layer

2015

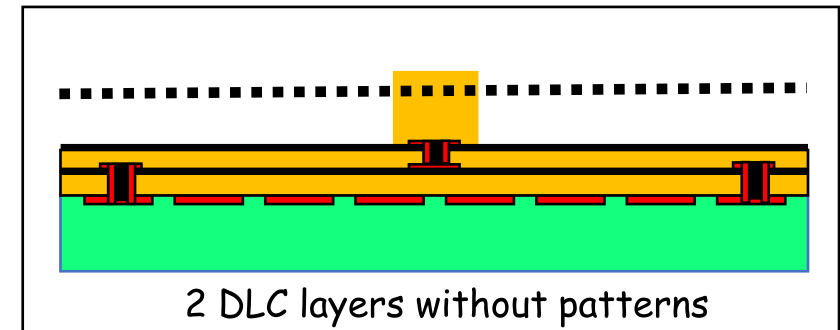
<u>High-rate detectors 10Mhz/cm2</u>
Charge evacuation inside active area



2 layers with screen printed pads

2015

or

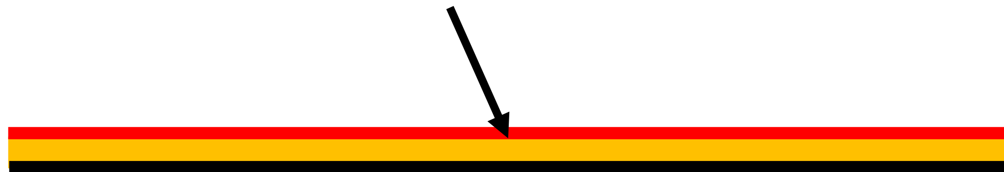


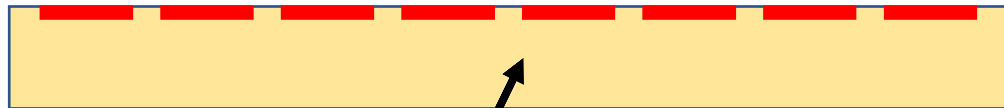
2 DLC layers without patterns

2020

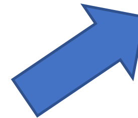
Micro Resistive well detectors

Polyimide coated foil: copper top , DLC bottom

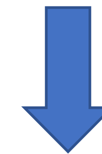




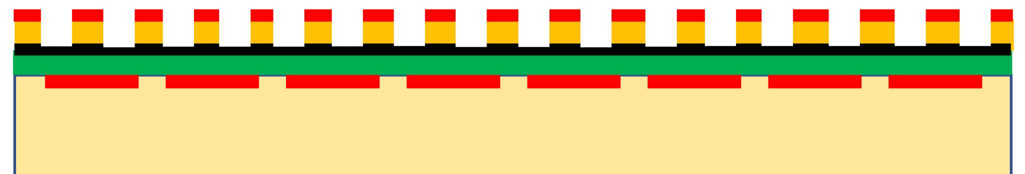
Any PCB or flex with any kind of R/O structure
X/Y , UVW , Pads, Capacitive sharing etc..



After gluing

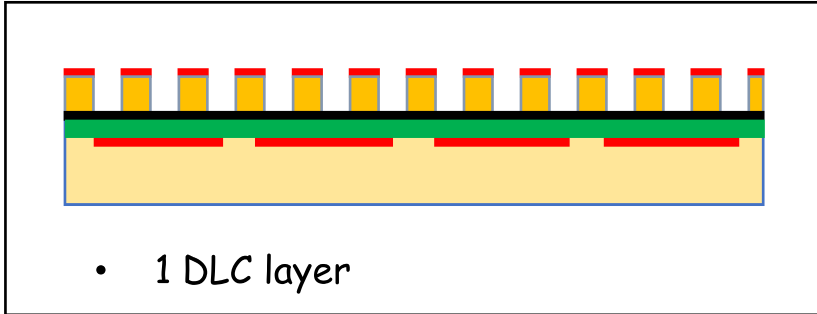


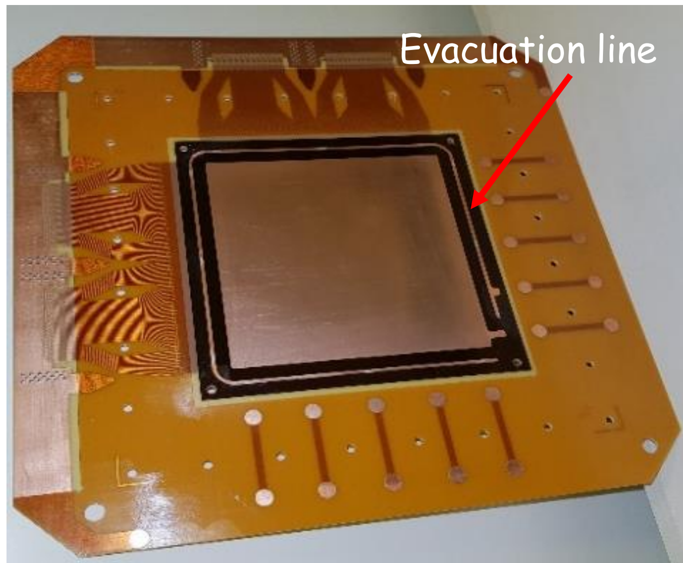
Chemical drilling (GEM process)



Medium rate μRwell

Lateral evacuation of charges



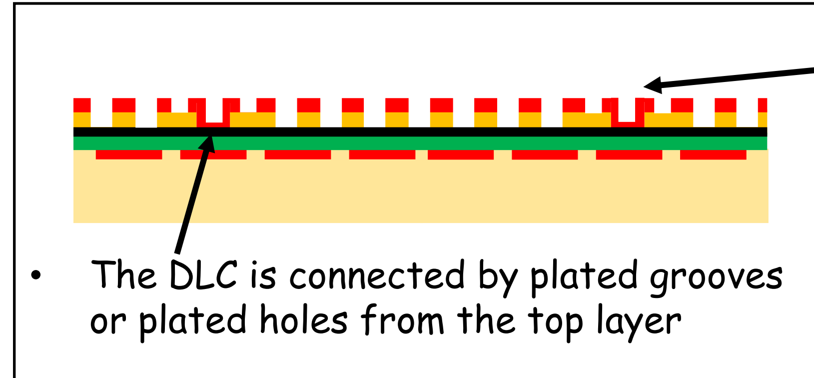


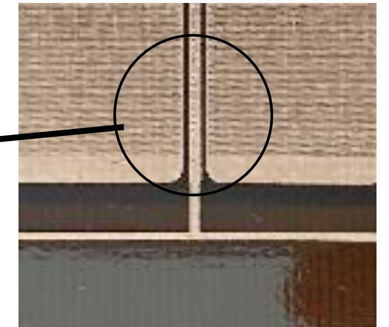
10cm x 10cm μRwell detector

High rate uRwell

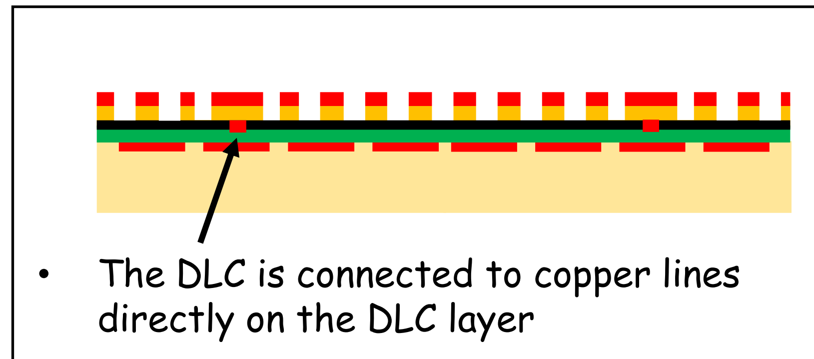
Charge evacuation in the active area

PEP→ Pattern Etch Plate



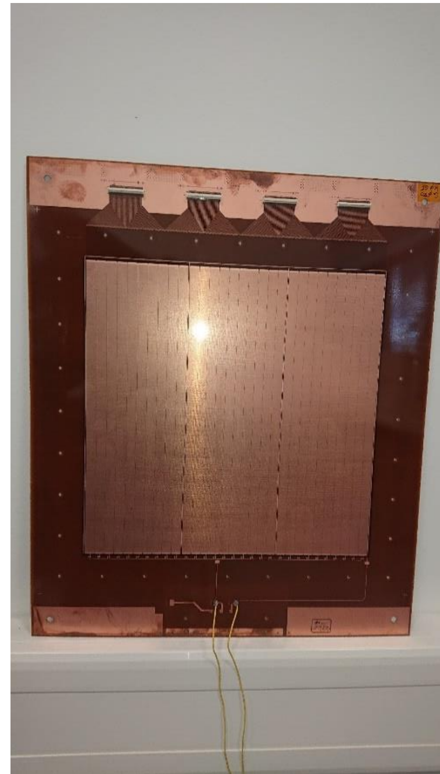


SG→ Silver Grid



uRwell examples

Frascati R&D
1D PEP uRwell
Active area:
40cm x 5cm



Frascati R&D
1D PEP uRwell
Active area:
30cm x 30cm

CLAS12 R&D
2D PEP uRwell
Active area:
150cm x 50cm

CLAS12 uRwell
rolled in an oven
for E-cleaning

Thank you for your attention