Micro pattern gas detector production

Rui de Oliveira on behalf of CERN GDD and CERN DEM groups

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History of MPGD in our Workshop

GEM
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- Examples
- Process situation for large size GEMs
  - LDI, glass mask, electrochemical, chemical
- Present limitations for large size at CERN
- Quality control
- Future

Micromegas
- Principle of operation
- Production description and limitations
  - Initial Micromegas, doted mesh and bulk
- Examples
- Present limitations at CERN
- Quality control
- Future

THGem (LEM)
- Production processes: rim, rimless, small rim,
- Resistive thick GEM processes
- Examples

Read-out board

Summary
History of Gas Detectors in CERN PCB Workshop

‘96: GEM 50 x 50mm with a gain of 10.
‘97: GEM 100 x 100mm with gain of 10000.
‘98: GEM 400 x 400mm; 1D and 2D readouts; micro-groove and micro-well detectors; first THGEM
‘00: 3D GEM readout; 1D readout for Micro-megas in COMPASS.
‘01: Pixel GEM readout; doted Micromegas mesh; 2D Micromegas readout.
‘03: Pixel Micromegas readout.
‘04: bulk Micromegas detector, MSHP structures
‘06: Half cylindrical GEM detector (NA49).
‘08: First full cylindrical GEM detector (Kloe), GEM 700mm x 450mm, Bulk 1.5m x 500mm, curved Bulk, RETGEM, Resistive spreading read out boards, resistive protections
GEM Principle

Difference of potentials of ~ 500V is applied to each GEM foil. Primary electrons released by radiation, drift towards holes where high electric field triggers electron multiplication process.
Electrons created in the multiplication (avalanche) process in GEM holes are collected on segmented readout electrode. Signal induced on the readout segments allows precise reconstruction of the time and position of the passage of original radiation (charged particles, X-rays).

Signals induced on the readout electrode by the electrons created in the avalanche process

Map of the reconstructed positions of the passage point of charged particles measured at very high intensity beam at CERN in COMPASS experiment.
GEM foils are produced at CERN using proprietary process.

- 50 μm Kapton
- 5 μm Cu both sides
- Photoresist coating, masking and exposure to UV light
- Metal chemical etching
- Kapton chemical etching
- Second masking
- Metal etching and cleaning
GEM manufacturing

- Polyimide Etching in a Static Bath with Temperature Control
- Biconical Hole Shape Control

- Defect
- Good (80% opening)
- Perfect (Co2 laser Eximer laser)
STD GEM Examples

25-200 µm holes, 50-300 µm pitch

Wide range of shapes and sizes
1500+2000 foils manufactured at CERN
1 cm² to 1000 cm²
GEM Detector

Gas Electron Multiplier Detector consists of drift electrode, 3 GEM foils and readout electrode.

Semi-cylindrical GEM detector

GEM foils before being mounted into detector
Frames and support

- Mechanical rigidity after foil stretching and gluing!
- Spacers
- Gas flow channels; gas connectors
- Glue flow preventing grooves
# Choice of materials

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Only certified materials:
- outgassing and ageing test!
- radiation hardness
- electrical properties

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Large size GEM
Large size: Bi-conical LDI

- Same process as standard GEMs
- Laser direct imaging of the resist
- Max size 800mm x 500mm
- Rapid 1GEM/ min (exposure)
- High pattern accuracy
- No masks needed

But…
- Bad Top to bottom alignment (>30um)

70 um holes 140um pitch
Large size with glass mask

- Same process as standard GEMs
- Large Glass masks instead of polyester films
- No thermal or hygrometry problems (0.1% with film)
- Perfect alignment top to bottom on 1m x 500mm
- High tooling price: up to 60 000 $ for 1mx 0.5m GEM

but...
UV exposure

Base material + resist

Glass Mask

Glass Mask

Up to 100 um bowing over 1 meter
Not compatible with pattern accuracies of 2 um

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TS-DEM
Electrochemical conical single mask

Raw material

Top patterning

Polyimide etching

Electrochemical etch
Acidic cupric sulfate bath

Top Electrode

Non connected
Non etched

Cu++

Electrodes

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TS-DMM
Perfect pattern
Low sparking voltage
Due to metal spikes around the edges

Poor pattern
Chemical conical single large mask

- Raw material
- Single side copper patterning
- Chemical Polyimide etching
- Chemical Copper reduction
Present situation: hole diameter are really close
The quality at the micron level is still better with STD GEM
We are working to improve this parameter
Copper rim
-Top side : 3 to 5um
-Bottom side : 2 to 3um
Biggest GEM produced at CERN
2 GEMs glued together
700 mm x 800mm possible active area

650mm
Present limitation at CERN
Resist lamination

UV exposure

GEM production

Resist development

Drying

Micro-etch

Polyimide etch

Copper etch
Quality control

- **Microscope optical measurement**
  - on several points on the GEM
  - Copper hole : $70 \pm 2 \mu m$
  - Polyimide hole : $55 \pm 5 \mu m$

- **High voltage test**
  - $< 10nA @ 600V$ for $100mm \times 100mm$
  - @ 35%HR max
Light transmission measurement

Good quality
GEM A: 70 \( \mu \text{m} \) copper hole, 47 \( \mu \text{m} \) polyimide hole
Transmission = 9.5\% \( \pm \) 0.5\% max over all surface

Bad quality
GEM B: 83 \( \mu \text{m} \) copper hole, 55 \( \mu \text{m} \) polyimide hole
Transmission = 13.5\% \( \pm \) 4\% max over the all surface

DigiDens T6R, ColorPartner GmbH
QC: GEM foils

Optical inspection: hole diameter and defects
Future possibilities with investment

- Size: 47cm x 100m active area
- Roll to roll 100% automatic process compatible
- Low price for large volume production
- Up to 40 square meter / day
Micromegas: How does it work?

Y. Giomataris, Ph. Rebourgeard, JP Robert and G. Charpak,
NIM A 376 (1996) 29

Micromesh Gaseous Chamber: a micromesh supported by 50-100 μm insulating pillars, and held at \( V_{\text{anode}} = 400 \text{ V} \)

Multiplication (up to \( 10^5 \) or more) takes place between the anode and the mesh and the charge is collected on the anode (one stage)

Funnel field lines: electron transparency very close to 1 for thin meshes

Small gap: fast collection of ions

\[
\frac{S2}{S1} = \frac{E_{\text{drift}}}{E_{\text{amplif}}} \sim \frac{200}{60000} = \frac{1}{300}
\]

Practical operation of Micromegas
Practical operation of Micromegas
Micromegas first productions

- Drift electrode
- Frame
- Readout board
- Spacer
- Fishing wires or photoimageable solder mask
- Mesh
- Electroformed NI (5um)
evolution 1: doted mesh

Polyimide + 5um copper

Image Transfer + Copper Etching
30um holes / 60um pitch

Frame Gluing

Polyimide Etching + Cleaning

- better Energy resolution
- remove some delicate steps in the production
- limited to 40cm x 40cm
- Mechanically fragile but mesh on frame by process
Examples

CAST Experiment (special Plexiglas frame)

Zoom on polyimide dots on the mesh

KABES Experiment

Maximum size 40cm x 40cm
Dot thickness 12.5um to 50um
Bulk evolution 2

- Easy manufacturing
- Large size compatible
- Low cost
- Robust and electrically testable at the production level
Mesh stretching

Mesh stretching control: from 10Ncm to 15Ncm

Over mesh cutting

Glue deposit
Detail on the sector partitioning

0.8mm 0.6mm 0.8mm

Coverlay

Mesh
Read-out board
Spacer pillar

2.4mm
T2K Micromegas Bulk detector

- A 30 μm thick 400 Lpi woven micromesh is embedded between 2 layers of pyralux
- 4 layers PCB with internal shielding layer & 6,875x9,675 mm pads / 7x9,8 mm pitch
- 128 μm amp. gap / 12 x φ0,3 mm pillars per pad / « stretched » mesh procedure
- 93% of PCB surface is active area / less than 2 faulty pads per module
Inner structure of T2K read-out PCB

- Pad for signal collection
- Connector pad
- PCB 2.2mm thick
- Hermetic by design and process
- Halogen free, 4 metals layers with *blind* holes
MM1-001 results: Gain corrected

\[ G_{\text{corr}} = \frac{G_i}{G_{\text{fec}}(x)} \times G_{\text{moy}}(14) \]

Very high precision when corrected for capacitance

Gain variation: 2.2%

Gain: ~1550
Present limitations

1500 x 500
1m²/day

Future limitations

2000 x 1000
10m²/day

Stretched mesh 1500 x 500
Laminator 600 x 1500
Exposure 2000 x 600
Development 600 x 1500
Milling 1500 x 600
Oven 1500 x 500
Problem when mesh is not under tension

Waves in the mesh up to 30 µm for a gap of 128 µm
QUALITY CONTROL
Bed of nails

Test: current < 20 nA @ 800V @ 35% HR max
No standard tool for test!

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PCB 0.2 to 3mm
Resist covering
CNC drilling
Rim ?
Electrodes etching

Charging up effects not fully understood
Large effect of the rim on the gain and on the rate capacity
Resistive THGEM

- Reduce the dead time following a spark
- Reduce the energy during a spark
- Limits the possible maximum rate

Raw material
Electrodes etching
Paste screen printing or resistive polyimide
CNC drilling
CNC Direct drilling
Spikes

Electrochemical polishing
Reduce thickness
Remove sharp edges
(butanol, phosphoric acid)

Or chemical micro etch to produce a small rim.
Paste from 10 Ohm/square to 1 MOhm/square

Polyimide resistive sheets 200 Ohm/square or 1 MOhm/square
600 x 600 mm² THGEMs produced at ELTOS (Arezzo, Italy) for the Trieste INFN group
Readout Circuits

1 Direction

2 Directions

3 Directions

Pixel

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Cartesian read-out

**Compass**

**NA49-future**

**CAST**
TOTEM experiment
Max size for this technology: 600mm x 450mm
Mice Experiment, 350um cell
30cm active area
Pixel read out

512 electronic channels from a few mm² active area are individually read out by means of a multi-layer PCB fan out.

- X-ray polarimetry (220um pads)
- Compass: pixel (1mm pads) 30mm x 30mm active area
- T2K: pads 7mm x 10mm
Alice HMPID cell made of 2 PCBs
- Hermetic by design
- Special Ni/Au and polishing for CSI deposition
- Front end electronics in the back
- Max size: 600 x 500 per board
Readout Board
330x500 mm²

Base steel plate, t=2 mm

Example of sharing for larger read out board
Read-out optimisation

- Resistive protection
  - Reduce the energy of a spark
  - Avoid dead time during sparking
  - Avoid protection circuits
  - Reduces the maximum rate

- Resistive spreading + capacitive coupling
  - Reduce the pad or line count for the same spacial resolution
  - Reduce the number of electronic channels and the cost
  - But reduces the maximum rate

Embedded passive components in the read-out board
Spark or charges

- Printed polymer up to 50 Mohms/square
  - Kapton/carbon: $10^6$ or $10^{11}$ commercially available
  - Vacuum deposition: any value but difficult to process

- The signal is transmitted by the parasitic Capacitor of the resistive layer
- The resistive value should be high to minimise the resistive coupling from pad to pad ($10^9$ Ohms/square min)
Signal in

Read-out lines

Printed resistor
A few ohms to Several Mohms

Parasitic line capacitor
1Kohms/square resistor to define a cell

Signal 2

10Kohms/square resistor

Signal 1

Signal 3

Signal 4

1cm

Copper
Prepreg defining the capacitor dielectric
FR4
resistive layer for charge spreading

200mm x 150mm
Bulk micromegas with
Resistive spreading

resistive layer polarization
Pads for read out

For details contact Paul Colas
Signal in

Signal 1

Signal 2

Signal 1

Signal 2
Conclusions

**GEM:**
- 700 mm x 400 mm: OK
- 1 meter x 450mm (beginning 2009), 2 meters (end 2009)
- 0.5 to 1 m²/day
- Future: up to 40 m²/day possible

**Micromegas Bulk:**
- 1.5 meter x 0.5 meter: in a few weeks
- 1 square meter/day
- Future: up to 10 m²/day possible (2 meter x 1 meter)
Gem detector with XY readout

internal element mounted
RD51 detector assembly training session 16/20 February
Mr Bencivenni INFN training GEM
GEM stretching
Glue dispensing
Paul Colas training
Iron spectrum after assembly
CERN GEM training

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TS-DEM