Thick GEM: a fast growing MPGD technology

Fulvio Tessarotto (INFN - Trieste)
THGEMs

Gaseous detectors and MPGDs

GEMs

THGEMs

THGEM characterization

Different materials, architectures and applications

THGEM-based Photon Detectors

Large cryogenic application projects

First step toward large area coverage: COMPASS RICH-1 hybrid PDs
Glorious tradition: 100 years of gaseous detector developments

1908: FIRST WIRE COUNTER
USED BY RUTHERFORD IN THE STUDY OF NATURAL RADIOACTIVITY


Nobel Prize in Chemistry in 1908

1928: GEIGER COUNTER
SINGLE ELECTRON SENSITIVITY

H. Geiger and W. Müller, Phys. Zeits. 29 (1928) 839

1911: CLOUD CHAMBER

COINCIDENCE METHOD

Charles T.R. Wilson
Nobel Prize in 1927

Hans Geiger

Ernst Rutherford

Walther Bothe
Nobel Prize in 1954

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From Spark Chambers to MWPCs

SPARK CHAMBER

1952: BUBBLE CHAMBER

Donald A. Glaser
Nobel Prize in 1992

1968: MULTIWIRE PROPORTIONAL CHAMBER

George Charpak
Nobel Prize in 1992

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To Micro Pattern Gas Chambers
MPGDs exist thanks to a few genial inventors
Great progress due to engineering for the use in experiments

Recently, a fundamental boost thanks to RD51:

“RD51, aims at facilitating the development of advanced gas-avalanche detector technologies and associated electronic-readout systems, for applications in basic and applied research.”

RD51 serves as an access point to MPGD “know-how” for the world-wide community

Unique in providing:
• Space and resources for non – project related R&D
• tools for the world-wide MPGD community AND BEYOND

~ 80 Institutes from 4 continents: Europe, Nord and South America, Asia, Africa
~ 450 physicists
RD51 Working groups

Technological Aspects and Development of New Detector Structures

Common Characterization and Physics Issues

Academia-Industry Matching Events, Training, Education

Common Facilities: Test Beam and Laboratory

Production, quality control, industrialization

MPGD Related Electronics

Simulations and Software Tools

GARFIELD & Co.
Many different MPGDs have been developed.

MICRO-GAP CHAMBER

Drift plane

Metal 1 (cathode)

Metal 2 (anode)

Polyimide

3 mm

200 μm

Substrate

MICRO-GROOVE CHAMBER

Contours of V

Drift plane 30 cm

Cathode - 300 V

Anode - 30 V

Equipotential and drift lines (with zero diffusion)

cathode

anode

MICRO-WIRE CHAMBER

1. Metal

Metalization

Kapton

2. Kapton

Kapton spacer

Anode

MICRO-PIN ARRAY

MICRO-PIXEL CHAMBER

Drift plane

Cathode

Anode

400 μm

50 μm

100 μm

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MICRO MEsh GAseous Structure (MICROMEGAS)
Thin gap Parallel Plate Chamber: micromesh stretched over readout electrode.


GAS ELECTRON MULTIPLIER (GEM)
Thin, metal-coated polymer foil with high density of holes, each hole acting as a proportional counter.


HIGHER LUMINOSITIES, HIGHER PRECISION EXPERIMENTS

1. MPGDs allow for
   • High rates (granularity & occupancy, signal formation time)
   • Fine space resolution
2. Technological maturity and accurate engineering FUNDAMENTAL for successful MPGDs
GEMs

CMS UPGRADE: 1000 m² of GEM foils

ALICE UPGRADE: 130 m² of GEM foils
other projects with GEMs

- **GEM ILC TPC**, T. Matsuda
- **CMD3 @ BES**
- **JLab Hall A**
  - GEM 40 x 50 cm²
  - Resolution vs Total - 1T
- **STAR - Forward GEM Tracker**
- **ILC TPC**
- **CBM: GEMs for tracking**
- **H calorimetry (GEM)**
  - (ATLAS, ILC)
- **CBM: GEMs for tracking**
- **GEM ILC HCAL**, A. White

Preliminary
THGEM

GAS ELECTRON MULTIPLIER FORMED BY A RIGID DIELECTRIC FOIL BETWEEN ELECTRODES, PROVIDED WITH A PATTERN OF HOLES.

In a proper gas and with electric bias it can provide large electron multiplication

Material:  
- FR4, permaglass, …  
- PTFE, PET, ARLON, …  
- glass, PEG3 (etchable glass), …  
- ceramic

Holes:  
- mechanical drilling  
  (1 € per 1000 holes)  
- water jet  
- laser  
- chemical etching  
- preformed (capillary plates)
Classical THGEMs

Standard PCB foil:
- robust
- mechanically self supporting
- large size
- industrially produced

Comparing to GEMs:
**Geometrical dimensions** $X \sim 10$
- But $e^-$ motion/multiplic. properties do not!
- Larger holes:
  - dipole fields and external fields are strongly coupled
  - $e^-$ dispersion plays a minor role

**About PCB geometrical dimensions:**
- Hole diameter: 0.2 – 1 mm
- Pitch: 0.4 – 4 mm
- Thickness: 0.2 – 2 mm

Introduced in // by different groups:

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THGEM characterization

More than 50 different THGEM types have been characterized by us using X-ray:
- optimized drift field (specific for each type)
- large rim \(\rightarrow\) large gain but good gain stability guaranteed for small rim or no rim
- production procedure details are very important
- good rate capability

Using UV light source prototypes of small THGEM-based PD's have been built and tested:
- photoelectron extraction and collection efficiency,
- timing properties of the signal (using 600 ps long light pulses)
- photoelectron detection efficiency with digital r/o

Many prototypes of small THGEM-based detectors have been built and tested
Effective gain = $0.91 \times 10^6$

PARAMETERS:
- Diam. = 0.4 mm
- Pitch = 0.8 mm
- Thckn. = 0.4 mm
- Rim = 10 μm

Ar/CH₄: 50/50

Gain ~ 1 M, time resolution ~ 8 ns

Small size PD's (active area = 30x30 mm²):
- typical max. stable gain: with UV light in lab: 1 M (during test beam: 0.2 M)
- efficient detection of single photons
- signal formation time ≈ 100 ns, time resolution ≈ 8 ns
THGEM R&D for RICHes

ALICE VHMPID
THGEM & HYBRID

COMPASS, RICH-1 upgrade by Triple THGEM detectors

V. Peskov et al., NIMA 695 (2012) 154
THGEM resistive WELL

- Drift electrode
- MIP
- ~5 mm
- SRWELL
- "Blind" Cu strip
- THGEM
- MIP
- 2.5-4 mm
- SRWELL
- 1.5 mm

10^9 Ω cm resistive plate → discharge free operations. 99% eff. up to ~ 10^5 Hz/cm²

proposed for digital hadron calorimetry

S. Bressler et al. JINST July 2013 arXiv:1305.4657
L. Moleri et al., NIMA 845 (2017) 262
HYBRID THGEM + THCOBRA

2 THGEMs
a THCOBRA with 2 d R-O structure

- Gas Photomultiplier (GPM) : 2D-THCOBRA
  - Good Performance
  - Gain of $10^6$
  - IBF values of about: 20%
  - 2D-THCOBRA adequate to obtain image
  - Position Resolution: FWHM = 300 $\mu$m, $\sigma$ = 128$\mu$m
  - Count rate of 100kHz

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Structure</th>
<th>Hole Diameter ($\mu$m)</th>
<th>Pitch ($\mu$m)</th>
<th>RIM ($\mu$m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>THGEM 1</td>
<td></td>
<td>400</td>
<td>800</td>
<td>5</td>
</tr>
<tr>
<td>THGEM 2</td>
<td></td>
<td>700</td>
<td>1300</td>
<td>100</td>
</tr>
<tr>
<td>2D-THCOBRA</td>
<td></td>
<td>400</td>
<td>1000</td>
<td>80</td>
</tr>
</tbody>
</table>

T. Lopes 2013 JINST 8 P09002
Gaseous Compton camera for medical imaging

Electroluminescence light is detected by THCOBRA with 2D R-O
Drift time provides the third coordinate
The advantage of the gaseous PMT:
- It can achieve a very large effective area with moderate position and timing resolutions.
- It can be easily operated under a very high magnetic field.

**Gaseous PMT**

<table>
<thead>
<tr>
<th>Sensor type</th>
<th>Sensitivity</th>
<th>Position Resolution</th>
<th>Timing Resolution</th>
<th>Uniformity</th>
<th>Price</th>
<th>Magnetic Field</th>
<th>Effective Area</th>
</tr>
</thead>
</table>
Scintillating Glass-GEM imager

1. Glass Substrate (PEG3)
2. UV exposure (1st exp)
3. Crystal formation (heat treatment)
4. Via etching (hydrogen fluoride wet etching)
5. Cr sputter & Cu plating

PHOTO ETCHABLE GLASS 3 : PEG3
- Promising technique for precise patterning
- Able to create high aspect ratio
- 500μm deep hole (ex. CERN GEM: 500μm)

Max: 500,000 photons @5.9keV

T. Fujiwara, et al., JINST 8 C12020, 2013

Imaging setup

Sample
Cathode
Glass GEM
ITO Glass Window
Scintillation light
Mirror

D = 290 mm
E1 = 10 mm
E2 = 2 mm
Cooled CCD Camera

Obtained image of leaves (2 sec integration time)

Excellent spatial resolution ≈500μm
Quick imaging of low Z material with low energy X-rays (≈7 keV)

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CRYOGENIC MPGD-PDs

Read-out elements of cryogenic noble liquid detectors

Rear event detectors (ν, DM)
Detecting the scintillation light produced in the noble liquids
Options of scintillator light and ionization charge detection by a same detector!

with WINDOW

WINDOWLESS
(2-PHASES)

OPERATED IN THE
CRYOGENIC LIQUID

S.Duval et al., JINST 6 (2011) P04007
A. Bondar et al., NIMA 556 (2006) 273
L.Arazi et al., JINST 8 (2013) C12004
Triple THGEM Gaseous Photo-Multiplier for DM

- WIS R&D on **GPMs** for future multi-ton LXe TPCs for dark matter searches (within DARWIN)
- Aim for **4π coverage** – not practical with PMTs (cost, bulkiness) or SiPMs (dark count rate)
- Successful demonstration of 4” cryogenic **triple-THGEM GPM** with reflective CsI coupled to dual phase LXe TPC: ([arXiv:1509.02354](http://arxiv.org/abs/1509.02354))
  - Stable gain $\sim 10^5$
  - Large dynamic range: $1 - O(10^3)$ photoelectrons
  - 1 ns timing (~ 200 PEs)
  - Expected PDE ~15% after optimization
- Also: on-going R&D on **n/γ imaging** with pixilated readout ([arXiv:1501.00150](http://arxiv.org/abs/1501.00150))
Bubble-assisted electroluminescence in LXe

A “local dual-phase” noble-liquid detector

TOWARDS LARGE-SCALE NOBLE-LIQUID DETECTORS

Energy resolution 5MeV alphas: $\sigma/E = 7.5\%$
Time resolution: $\sigma = 10$ ns
Bubble (under THGEM, GEM) stable for days
CsI on THGEM: high pe extraction
PTFE THGEMs for CDEX

Low level radioactivity THGEMs

PMT disadvantages:
- high cost, limited area,
- unmatched spectral response, radioactivity

→ PTFE THGEMs
Almost no radioactivity, demonstrated to operate nicely at 117 K

Table:
- t = 0.38 mm,
- d = 0.3 mm,
- p = 0.7 mm,
- r = 30 μm

Fig. 1. Scheme design of the cryostat in CDEX.

Fig. 2. A photograph of the PTFE-THGEM; the enlarged part (right) shows the holes and the rims surrounding them.

Fig. 3. Schematic diagram of the experimental setup. On the left is the test of the PTFE-THGEM at cryogenic temperature; and on the right is the internal structure of the PTFE-THGEM used.

Dual-phase LAr LEM TPC

Goal: Neutrino oscillation experiments: WA105 (on ground) and future (underground) DUNE.

“demonstrators”

DC: 5nA/LEM(50x50)
Stable gain \(\sim20\) (fine)

C. Cantini et al., JINST 10 P03017 (2015)

\(~3500\text{V};\) spark on edges
(use COMPASS RICH solution?)
Charging up of rims: gain stabilizes. OK

DUNE: \(\sim3000\) LEMs (50x50)

Ongoing R&D on RESISTIVE WELL concepts
LARGE SIZE PROJECTS

- **LBNO – GLACIER (THGEM)**
- **DARWIN**
- **Panda-X, THGEM + MM (dark matter)**
- **DUNE (40-kt LAr)**
- **NEXT-100 (neutrino-less double beta decay)**

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FIRST STEP TO LARGE SIZE

COMPASS RICH UPGRADE

poster by Chandradoy Chattarjee

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Replaced by Hybrid THGEM + Micromegas PDs

PCB material selection: 50 THGEMs 300 mm x 600 mm sent for production to ELTOS SpA
A post production specific surface treating and cleaning procedure developed in Trieste is applied:
- Surface Polishing.
- High pressure water cleaning.
- Ultrasonic Bath with Sonica PCB solution (PH11), distilled water rinsing and oven @ 160 ºC
Assembling, CsI coating and mounting the detectors on COMPASS RICH-1
Commissioning and 2016 COMPASS run

- 1.4 m² of hybrid PDs operated
- Stable data taking conditions
- Effective suppression of signals from charged particles
- Ion Back-Flow < 3%
- More Cherenkov photons seen with respect to MWPCs + CsI

HV monitor and control system

~ 20 discharges/day during running

1% p,T variation → ~ 40 % gain variation without HV compensation, → 10% stability with HV compensation

APV25 samples the signal waveform

Cherenkov signals are clearly seen
CONCLUSIONS

THE DEVELOPMENT OF MPGDS IS SUCCESSFUL AND EXPANDING

Consolidated technologies are spreading over small and large projects
Advanced R&D is making continuous progress on new solutions

THGEMS ARE PROPOSED FOR VERY LARGE AREA DETECTORS OF $\gamma$, $X$, $n$

After long R&D phase it is now an almost consolidated technology
1.4 m$^2$ of detectors of single UV photons in operation at COMPASS RICH-1

BRIGHT FUTURE FOR:

Inventions: new ideas, new techniques
Technology consolidation, new applications
Large scale projects
COMPASS MWPC's with CsI
neutron detectors

NMX Spectrometer @ ESS

LOKI-SANS Instrument @ ESS

BANDGEM Modules
As rear detector panels

entrance wind

Triple GEM + 3D borated cathode
Thermal neutrons

B(Gd)-GEM & uTPC concept

B(Vd) modules

As rear detector panels

Using low θ values (few degs) the path of the neutron inside the B,C is increased → Higher efficiency when detector is inclined