**DMM**: A high-gain and low ion-backflow Double Micro-Mesh gaseous structure

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Outline

- Motivation
- Design and Fabrication
- Performance Characterization
- Optimization for further IBF suppression
- Summary
Motivation: GPD

- Gaseous Photon Detectors (GPD) with MPGD
  - large area, high spatial and timing resolution, resistant to magnetic field, IBF suppression, low cost ...

- Challenges
  - High gain: to be sensitive to single photons
  - Very low IBF
    - UV light: CsI, \(~mC/cm^2\)
    - Visible light: Bi-alkali, \(\sim \mu C/cm^2\)!

![PIC-SEC diagram](image1)

![Gas-PMT diagram](image2)

THGEM-like+MM, IBF\(~1\%
Mesh+Mesh, IBF\(~0.06\%, G\sim 10^4\)

Bi-alkali

F. Tokanai et al., NIM A 766 (2014) 176–179
Motivation: TPC

- Application of TPC in high-rate environments: ALICE upgrade, ILD, CEPC …
  - Very low IBF is the key: to minimize drift field distortion caused by ion space charge
  - Continuous readout to keep up with high event rate

**ALICE**

Quadruple GEM, IBF < 1%

**CEPC**

GEM+MM, Gain×IBF<~5
IBF <~ 0.1% required

MPGD is the only solution so far. Need to develop MPGD with very low IBF
DMM Design

• **DMM**: Double Micro-Mesh gaseous structure
  - Hole-type → mesh-type: to strongly reduce IBF
  - Double mesh: cascading avalanche for high gain

Stacked two meshes
  - Gap between the stacked meshes: **200-300um**, serving as pre-amplification (PA)
  - Gap between the bottom mesh and anode: **50-100um** as secondary amplification (SA)
  - Allows to achieve very high gain, and yet significantly reduce ion back-flow.
DMM Fabrication

• DMM is fabricated with the thermal bonding technique that has been developed at USTC.

Micromegas fabrication process with thermal bonding technique

Mesh stretching ~20N/cm
Setting spacers

Thermal bonding
Finished view
Cutting the meshes

A 2.5cm×2.5cm DMM prototype

See the talk by Zhiyong Zhang for details
Performance Characterization

- DMM with Ar (93%) + CO$_2$ (7%)
  - Electron transparency
  - Energy resolution and gas gain
  - Ion back-flow ratio
- DMM with Ne (80%) + CF$_4$ (10%) + C$_2$H$_6$ (10%)
  - Single photon electron response

Mesh specs
500 LPI, 27um thick, 40% opening rate
Electron Transparency

- Transparencies for electrons passing through PA and SA meshes are extracted by measuring PA, SA and total (PA and SA combined, DMM) gas gains
  - Combined gain = PA gain × SA trans × SA gain

\[ E_{PA}/E_{\text{drift}} \] is set to 200 to maximize transparency most of the time.

\[ \text{SA trans} \sim 15\% \quad @ \quad E_{SA}/E_{PA} \sim 1 \]
Gas Gain and Energy Resolution with $^{55}$Fe

Gain: PA, SA and combined

A typical $^{55}$Fe energy spectrum

- Combined gain can reach up to $7 \times 10^4$ for 5.9 keV X-rays.
- Combined resolution remains almost constant and is close to PA-alone resolution, suggesting a close-to-full collection of primary electrons for the high-voltage configurations of interest.
**Ion Back-Flow (IBF) Measurement**

\[
\text{IBF ratio} = \frac{I_{\text{Drift}} - I_{\text{Primary}}}{I_{\text{Anode}}}
\]

$I_{\text{Drift}}, I_{\text{Primary}}$(no avalanche)

Drift cathode (0V)

Pre-mesh (+HV)

Sec-mesh (+HV)

Anode (+HV)

$I_{\text{Anode}}$

Drift cathode (-HV)

Pre-mesh (-HV)

Sec-mesh (-HV)

Anode (0V)

Keithley (6482) Picoammeter with \(~10\text{-fA resolution in a range of } \pm 20 \text{ nA}\)
Validation of IBF Measurement

\[
\frac{Q_{\text{full-energy peak}}}{Q_{\text{Primary}}} = \frac{I_{\text{Anode}}}{I_{\text{Primary}}}
\]

- Gain measured with X-ray energy spectrum \( \left( \frac{Q_{\text{full-energy peak}}}{Q_{\text{Primary}}} \right) \) consistent with \( \frac{I_{\text{Anode}}}{I_{\text{Primary}}} \)
- \( I_{\text{Anode}} \) stays proportional to X-ray intensity in a rather wide range, suggesting no gas gain saturation in the IBF measurement.

- IBF ratios measured with 55Fe and X-ray tube are consistent

no gas gain saturation
• A high E-field ratio of SA/PA is desirable for IBF reduction, and an IBF ratio lower than 0.05% at a PA voltage lower than 550 V.
Ion Space-Charge Effect

- Our IBF measurements are reliable in terms of ion space-charge effect (impact is negligible).
Single Photon-Electron Response

Avalanche charge distribution for single photon-electrons

Gas gain can reach up to $3 \times 10^6$ for single electrons
Optimization for Extremely Low IBF

Two meshes are perfectly aligned

It’s impractical to make any precise alignment of the two meshes. So setting the two meshes with a crossing angle is a practical way to ensure their mis-alignment.

Two meshes are maximally mis-aligned
More for IBF Optimization

- Examined impact of mesh LPI and PA gap.

- 500 vs. 640 LPI (same opening rate)
- PA gap: 160 vs. 240 μm
Optimization Outcome

To push IBF down to an extremely low level:

✓ low PA electric field
✓ large PA gap
✓ high mesh density
✓ crossing mesh setting

A IBF ratio down to <0.03% can be achieved
Long-Term Stability

DMM: 240µm- 45° - LPI640
~24 hours of X-ray irradiation,
Gain ~ 5000

PA 650V

PA 550V

Spark probability < 10^{-9}

Reference for comparison
Summary and Outlook

- Developed a double-mesh structure of DMM featuring high gain and low IBF
- Demonstrated the performance of DMM with small-size prototypes:
  - Gain: $7 \times 10^4$ for 5.9 keV X-rays and $3 \times 10^6$ for single electrons.
  - IBF ratio: down to $\sim 0.03\%$
- Potential applications
  - Gaseous photon detectors
  - High-rate TPC readout
  - ...
- Going triple: promising to get another order of magnitude reduction of IBF!
Back-up
Sec-amplification (SA)

Full energy peak due to the lateral angle photoelectrons and Auger electrons

The transparency should be similar to PA’s, since their have the same mesh type.

Gain VS avalanche voltages

up to $2 \times 10^4$