A high-gain, low ion-backflow double micro-mesh gaseous structure

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Abstract

Micro-pattern gaseous detectors with high gain and very low ion-backflow (IBF) provide cost-effective solutions to large-area and position-sensitive photon detection and readouts of high-rate time projection chambers. We have developed and optimized a double micro-mesh gaseous structure (DMM) with two avalanche stages, which has a low IBF ratio and high gain. An IBF ratio as low as 0.025% was obtained and a gain of up to 3 × 106 was reached for single electrons with the DMM. We have further developed a triple micro-mesh gaseous structure (TMM) to fully explore the potential of the multi-mesh approach to suppressing IBF. An ultra-low IBF of ~0.003% was achieved with the TMM, which is the lowest IBF value ever obtained in gaseous detectors.

1. Introduction

Gaseous detectors with high gain and very low ion-backflow (IBF) have a broad range of applications, such as gaseous photo detectors (GPD) and readout of time projection chambers (TPC) for high rate experiments [1–3]. The most common examples of GPDs are photon detectors for ring-imaging Cherenkov counters (RICH) [4–5] and gas photomultiplier tubes (gas-PMTs) [6–8]. The effect of ion-backflow may cause aging of the photocathodes of GPDs. The quantum efficiency of a GPD will degrade when its photocathode is bombarded by ions [9-10], which are produced during the gas multiplication process. For TPCs, the back flowing ions will cause distortion of the electric field in the drift volume, thus degrading the performance of TPCs. Some detector structures, based on micro-pattern gaseous detectors (MPGD), have been studied [11] to suppress the IBF ratio, such as the multiple gas electron multiplier structures (multi-GEMs) [12], hybrid structure [13], cascaded GEM to micro-mesh gaseous structure (Micromegas) [14], and micro-hole and strip plates (MHSP) [8,15].

We have proposed a double micro-mesh gaseous structure (DMM) [16–18] with two avalanche stages to achieve high gain with low IBF. Fig. 1 shows the schematic design of the DMM, which has two layers of mesh to provide cascading avalanche amplification. It has a 3 mm gas gap for particle primary ionization and electron drift, followed by a ~0.2 mm pre-amplification (PA) gas gap and a ~0.1 mm secondary amplification (SA) gap. The double avalanche gaps ensure a high gain for a single electron and, with proper configuration of the electric field, a very low IBF ratio.

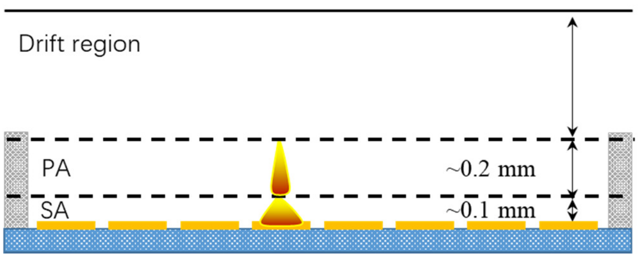

Fig. 1 Schematic design of the DMM.

2. R&D status

We developed multiple DMM prototypes using a thermal bonding method [19], and studied their performance with X-ray and UV lights. The high-gain ($>10^6$) and low IBF (~0.05%) features of the DMM have been validated [16]. We then optimized the DMM structure to further suppress its IBF by changing the size of gas gaps, the density of the wire mesh, and more significantly, by aligning the two mesh layers with a crossing angle. A series of DMM prototypes with differing crossing angles, PA gaps, and mesh types were fabricated and tested with X-rays (5.9 keV from ^{55}Fe source and 8.0 keV from an X-ray gun) [17,18]. The results from the tests indicate that a low PA voltage, large PA gap, high mesh density, and crossed mesh setting can improve on IBF suppression at the same total gain. A IBF ratio as low as 0.025% was obtained with one of the prototypes, which was made of 650 LPI mesh and had a PA gap of 240 μm and a cross angle of 45°. The methods for measuring the gas gain and the IBF ratio were validated. The ion space charge effect was studied and verified to be negligible in the IBF measurement. The operation of the DMM was also found to be very stable with a sparking probability lower than 10^{-9}, in a period 20 h. These features of the DMM present its strong potential for applications to Gas-PMTs, RICH photon detection, and high-rate TPC.

To fully explore the potential of the mesh structure for IBF suppression, a triple micro-mesh gaseous structure (TMM) was developed and studied. An extremely low IBF of ~0.005% was achieved while a high gain was maintained. This is one order of magnitude lower than that of the DMM and represents the lowest IBF value ever obtained with a gaseous detector.

3. Plans and goals

We will conduct more simulation and experimental studies to fully understand the underlying physics of the multiple mesh gaseous structure and identify all important factors on the gain, IBF suppression and energy resolution of the structure, so as to provide solid guidance in optimization of the detector concept. The IBF is not the only parameter that decides the choice of the detector. Trade-offs between IBF and other performance parameters may be required for some specific applications. We will specifically aim for applications of DMM to a high-rate TPC at CEPC running at Z pole and TMM to Gas-PMTs for visible light. We will also further develop the thermal bonding method and relevant techniques for manufacturing the multi-mesh detectors in large size for example 500mm×500mm.

References

[1] D.S. Bhattacharya, P. Bhattacharya, P.K. Rout, et al., Experimental and numerical simulation of a TPC like set up for the measurement of ion backflow, Nuclear Instruments and Methods in Physics Research Section A, 861 (2017) 64–70.

[2] M. Ball, K. Eckstein, T. Gunji, Ion backflow studies for the ALICE TPC upgrade with GEMs, Journal of Instrumentation, 9 (2014) C04025.

[3] F. Sauli, L. Ropelewski, P. Everaerts, Ion feedback suppression in time projection chambers, Nuclear Instruments and Methods in Physics Research Section A, 560 (2006) 269–277.

[4] M. Alexeev, R. Birsa, F. Bradamante et al., THGEM-based photon detectors for the upgrade of COMPASS RICH-1, Nuclear Instruments and Methods in Physics

Research Section A, 732 (2013) 264–268.

[5] M. Alexeev, R. Birsa, F. Bradamante et al., The quest for a third generation of gaseous photon detectors for Cherenkov imaging counters, Nuclear Instruments and Methods in Physics Research Section A, 610 (2009) 174–177.

[6] K. Matsumoto, T. Sumiyoshi, F. Tokanai et al. Ion-feedback suppression for gaseous photomultipliers with micro pattern gas detectors, Physics Procedia, 37 (2012) 499–505.

[7] F. Tokanai, T. Moriya, M. Takeyama et al., Newly developed gaseous photomultiplier, Nuclear Instruments and Methods in Physics Research Section A, 766 (2014) 176–179.

[8] A.V. Lyashenko, A. Breskin, R. Chechik et al., Development of high-gain gaseous photomultipliers for the visible spectral range, Journal of Instrumentation, 4 (2009) P07005.

[9] J. Va'vra, A. Breskin, A. Buzulutskov et al., Study of CsI photocathodes: volume resistivity and ageing, Nuclear Instruments and Methods in Physics Research Section A, 387 (1997) 154-162.

[10] T. Moriya, F. Tokanai, K. Okazaki et al., A concise quantum efficiency measurement system for gaseous photomultipliers, Nuclear Instruments and Methods in Physics Research Section A, 732 (2013) 269-272.

[11] S. Dalla Torre, Status and perspectives of gaseous photon detectors, Nuclear Instruments and Methods in Physics Research Section A, 639 (2011) 111–116.

[12] A. Bondar, A. Buzulutskov, L. Shekhtman et al., Study of ion feedback in multi-GEM structures, Nuclear Instruments and Methods in Physics Research Section A, 496 (2003) 325–332.

[13] Y.L. Zhang, H.R. Qi, B.T. Hu et al., A hybrid structure gaseous detector for ion backflow suppression, Chinese Physics C, 41 (2017) 056003.

[14] Y. Giomataris, Ph. Rebourgeard, J.P. Robert et al. MICROMEGAS: a high-granularity position-sensitive gaseous detector for high particle-flux environments, Nuclear Instruments and Methods in Physics Research Section A, 376(1996) 29-35.

[15] A. Lyashenko, A. Breskin, R. Chechik et al., Efficient ion blocking in gaseous detectors and its application to gas-avalanche photomultipliers sensitive in the visible-light range. Nuclear Instruments and Methods in Physics Research Section A, 598 (2009) 116–120.

[16] Z. Zhang, B. Qi, C. Liu et al., A high-gain, low ion-backflow double micro-mesh gaseous structure for single electron detection, Nuclear Instruments and Methods in Physics Research Section A, 889 (2018) 78–82.

[17] Z. Zhang, B. Qi, M. Shao et al., Study on the double micro-mesh gaseous structure

(DMM) as a photon detector, Nuclear Instruments and Methods in Physics Research Section A, 952 (2020) 161978.

[18] BinbinQi el al., Optimization of the double micro-mesh gaseous structure (DMM) for low ion-backflow applications， Nuclear Inst. and Methods in Physics Research A, 976 (2020) 164282.

[19] J. Feng, Z. Zhang et al., Thermal bonding method for fabricating Micromegas detector and its applications, arXiv:1910.03170, 2019, available at https://arxiv.xilesou.top/abs/1910.03170.