

Ion feedback suppression using inclined MCP holes in a “Single-MCP+Micromegas+Pads” Detector*

J.Va’vra, SLAC, Stanford, CA 94305, USA**

T. Sumiyoshi, Tokyo Metropolitan University, Tokyo, Japan***

Abstract—We show that the ion backflow to photocathode can be completely suppressed if one uses inclined MCP holes in a presence of magnetic field. The inclined hole angles are chosen to be aligned with the Lorentz electron angle allowing the electron transmission and amplification, while positive ions, traveling along a different angle, are caught on the MCP hole walls. The detector under investigation is a new gaseous detector structure based on a tandem of two parts, the first one is a single MCP (Microchannel) plate, and the second one is a Micromegas with pad readout. The paper compares relative merits of gaseous and vacuum-based MCP detectors. We are aiming to develop a gaseous detector with the Bialkali photocathode.

I. INTRODUCTION

This presentation represents a continuation of the R&D effort to develop a permanently sealed gaseous photo-detector with the Bialkali photocathode. The amplification in this detector is provided by a combination of the MCP plate and a single Micromegas with pad readout, where the MCP holes were perpendicular to the faceplate [1]. In such geometry the ion feedback to the photocathode is significant, especially of MCP gain is high, and this would certainly limit the detector successful operation through a development of secondary cathode effects.

The reason for choosing the MCP rather than the GEM structure is twofold: (a) it is of much higher purity and therefore poisoning of the Bialkali photocathode is less likely, and the aging effects less severe if they exist, and (b) it allows the angled holes and therefore it allows tricks described in this paper.

Generally, it is desirable to limit the ion backflow into the drift region to (a) avoid the spatial distortions in high rate applications, and (b) to limit the secondary electron emissions at the cathode. The second point is important if there is a weak point on the cathode, which has a tendency to emit electrons, because arrival of ions makes the emission worse. An example of a weak cathode spot could be the Malter effect or a field emission on a sharp point. For example, in TPC geometries, the ion backflow reduction is achieved using the electrostatics methods, such as multiple GEMs or a field ratio around the

mesh in the Micromegas. However, in case of TPC, if the cathode emits electrons, the ions arrive to the same cathode spot as the electron source on the cathode. On the other hand, in the classical tracking drift chambers, there is no method available to limit ion backflow to the cathode wires. Again, one does not want to send the ions back to the same field wire spots, as this may form the positive feedback. Instead, one prefers to send the ions along a different path than the field emitted electrons. This can be achieved easily in geometries where E and B are perpendicular to each other, which is the case in most tracking drift chambers, such as BaBar or CDF. One can hardly envisage any existing high rate drift chamber operating successfully over a long period of time without such protection of the ExB effect.

This paper shows for the first time, to our knowledge, that it is possible to either eliminate the ion feedback entirely, or, reduce it to a very small level by aligning the MCP holes with the electron Lorentz angle. The ions follow a different path and are caught on the MCP holes. In a geometry, where one can arrange the MCP electric field to have a large angle with the magnetic field, one can indeed achieve this, and this paper provides a proof. For example, such geometry could be easily achieved in the Focusing DIRC by suitably rotating the focal plane.

One should note that the trapped ions on the MCP walls could also generate the secondary effects. If this happens, there would not be much advantage from the proposed geometry. However, we assume that it is less likely compared to the photocathode surface covered by a very sensitive material. Furthermore, the diffusion of electron cloud during the MCP amplification is large, and therefore any build up of ions on the MCP walls, which could trigger the Malter effect type of electron emission, will have a better chance to neutralize with electrons. Further tests will have to decide.

A 90%Ar+10%CH₄ gas (P-10) was chosen to minimize the photoelectron back-scattering effects. When considering the detector materials, it is important to choose the highest possible purity to minimize the aging effects [2]. Furthermore, the P-10 gas and materials used for Micromegas mesh and MCP glass were used successfully by Hamamatsu in combination with the Bialkali photocathode.

Presently, the strongest photon detector candidate for the development of the Focusing DIRC is a vacuum-based Multi-MCP-PMTs, for example, one made by Burle Co.¹ Therefore we will provide a discussion of pros and cons of the vacuum-

* Manuscript received on November 1, 2004.

** Work supported by the Department of Energy, contract DEAC03-76SF00515

*** This work was supported in part by a Grand-in-Aid for Scientific Research from JSPS under Grant No. 14340083 and the Japan/U.S. cooperation program in the field of high energy physics.

¹ Burle Technologies Inc., <http://www.burle.com>

based and gaseous-based photon detectors utilizing Bi-alkali photocathode, as it looks to us at present.

II. CALCULATION OF THE LORENTZ ANGLE

Fig. 1 shows the principle of the proposed detector. Typically, the operating parameter space of this type of detector would be [1]: $E_{MCP-entrance} \sim 350V/cm$, $E_{MCP-exit} \sim 1.25kV/cm$, E_{MCP} up to $10kV/cm$, and $E_{Micromegas}$ up to $50kV/cm$, corresponding to an average gain of a $2-3 \times 10^5$.

For the presented idea to work, it is crucial to assume that the electric field in the MCP with the inclined holes is perpendicular to the faceplates², i.e., not aligned with the MCP hole direction. The next step is to calculate the Lorentz angle. To do this calculation, we used a computer program Magboltz, version 7.1 [3]. Fig. 2 shows the Lorentz angle calculation for a case of electric field perpendicular to the magnetic field. The Lorentz angle is $\sim 6.5^\circ$ at $E_{MCP} \sim 10kV/cm$. Assuming the MCP thickness of $1mm$ and the MCP hole diameter of $25\mu m$, one can achieve a complete opacity for the ions with such an angle. Fig. 3 shows a similar calculation as a function of the Ar/CH₄ gas mix ratio at $E_{MCP} = 9kV/cm$. One can see that the Lorentz angle is not very sensitive to the exact mix ratio.

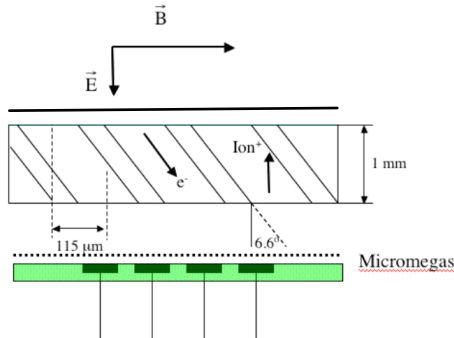


Fig. 1. Principle of a detector “single MCP+Micromegas+pads” with the inclined MCP holes for a geometry where E and B are perpendicular to each other. The MCP holes are chosen to be the same as the electron Lorentz angle. The backflow ions, following a different angle, are trapped by hole walls.

The calculation also indicates relatively large electron diffusion within the MCP holes: $\sigma_{long}(along_E) \sim 106\mu m^2/ns$ and $\sigma_{transv.}(along_B) \sim 245\mu m^2/ns$ in $90\%Ar+10\%CH_4$ for $E_{MCP} = 9kV/cm$ and $B = 15kG$, with corresponding calculated average drift velocity is $v_{along_E} \sim 36.75\mu m/ns$ and $v_{along_B} \sim 4.21\mu m/ns$. This means that some electrons will be lost on the walls or more likely participate in the electron-ion recombination along the MCP walls.

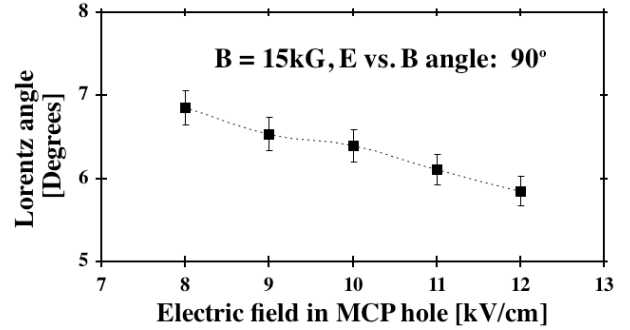


Fig. 2. Calculation of the Lorentz angle as a function of electric field gradient in $90\%Ar+10\%CH_4$ gas. The electric and magnetic field are perpendicular to each other and magnetic field is $B = 15 kG$.

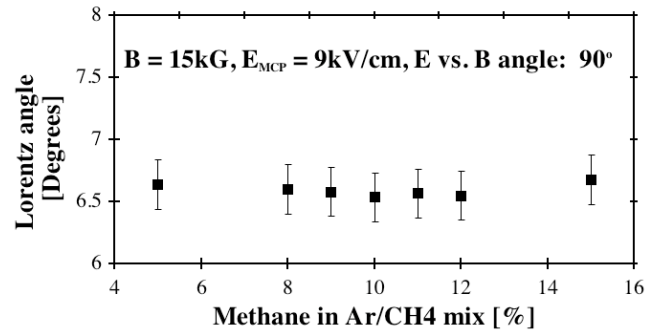


Fig. 3. Calculation of the Lorentz angle as a function of Ar/CH₄ gas mix ratio. The electric and magnetic field are perpendicular to each other, magnetic field is $B = 15 kG$ and electric field gradient $E_{MCP} = 9 kV/cm$.

III. EXPERIMENTAL SETUP AND MEASUREMENTS

Ref. 1 showed already that the ion backflow in a MCP with the perpendicular holes could be substantial. In this paper we have repeated the measurement with higher accuracy. Fig. 4 shows the experimental setup. These measurements were with the magnetic field off. The photocurrent was generated with the Mercury UV lamp and a dense s.s. mesh defining the cathode in this detector.

Fig. 5 shows that the ion feedback is close to $\sim 10\%$, when varying the gain with the MCP voltage. Fig. 6 indicates a rate close to $\sim 3\%$, when varying the gain with the Micromegas voltage. Both numbers are significant for any practical application.

² This assumption was confirmed by Hamamatsu and Burle.

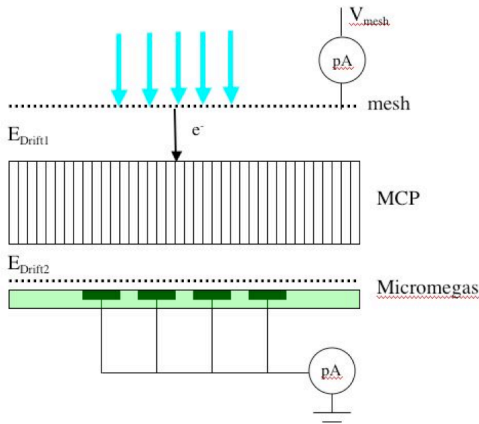


Fig. 4. Experimental setup with a “single MCP+Micromegas+pads” detector to measure the ion backflow to cathode. The MCP has perpendicular holes (angle 0°) and $B = 0$ kG.

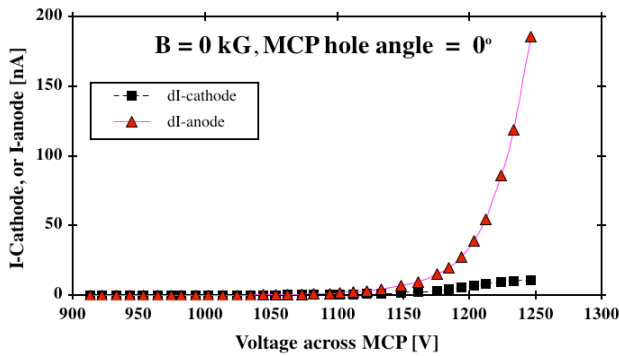


Fig. 5. The ion backflow rate as a function of the MCP voltage in the experimental setup of Fig. 4 (MCP hole angle 0° and $B = 0$ kG). The cathode current is about 10% of the anode current at $V_{MCP} = 1200$ V ($E_{MCP} = 12$ kV/cm) and in 90% Ar+10%CH₄ gas.

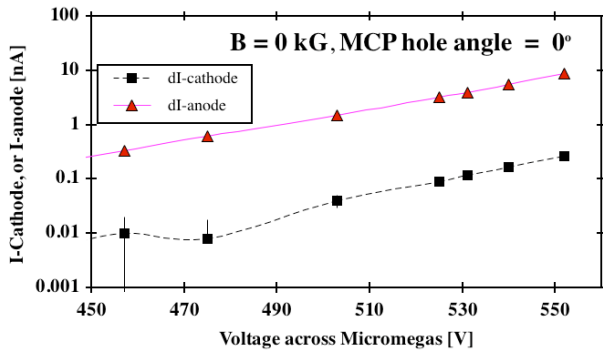


Fig. 6. The ion backflow rate as a function of the Micromegas voltage in the experimental setup of Fig. 4 (MCP hole angle 0° , $B = 0$ kG, and 90% Ar+10%CH₄ gas). The cathode current is about 3% of the anode current for this particular choice of parameters.

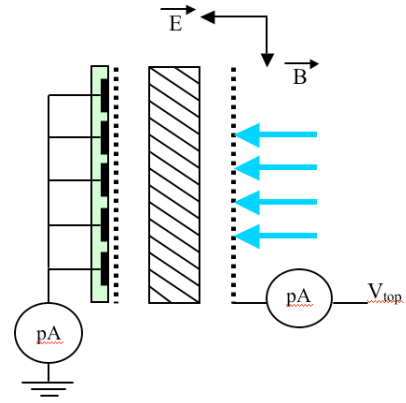


Fig. 7. Experimental setup a “single MCP+Micromegas with pads” detector to measure the ion backflow to cathode. The MCP has inclined holes (angle 6.5°) and $B = 15$ kG.

Fig. 7 shows the experimental setup to measure the ion backflow in the magnetic field. The magnetic field is chosen to be perpendicular to electric field. Fig. 8 shows a cut through our MCP indicating the inclined hole angle if 6.5° .

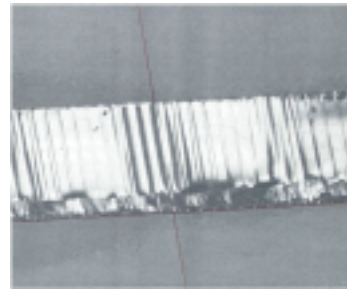


Fig. 8. Cut through the Hamamatsu MCP with the inclined holes, used in our tests. The MCP hole angle is 6.5° .

Fig. 9a shows the actual experimental vessel placed in the dipole, which was capable of delivering up to 15kG (Fig. 9b). To achieve a full electron transmission, it is necessary to rotate the MCP around its axis. The detector vessel could rotate to align the MCP hole with the electron Lorentz angle.

Fig. 10 shows the result of the experimental tuning of the MCP azimuth angle to achieve the best electron transmission and therefore the optimum alignment between the MCP hole and the electron Lorentz angle. At this angle, the ion backflow current is very small, and consistent with the pico-ammeter noise of ~ 5 pA. The noise was somewhat larger than a usual ~ 1 pA level because the Keithley pico-ammeters were affected by the magnetic field and it was necessary to place them far from the magnet, and therefore far from the chamber.

Once the optimum azimuth was chosen, we proceeded with the measurement of the ion backflow. Fig. 11 shows the ion backflow measurement as a function of Micromegas voltage for several choices of MCP electric gradient. In each case, the ion backflow current is negligible relative to anode current, and consistent with the pico-ammeter noise of ~ 5 pA.

Fig. 12 shows the relative gain as a function of the voltage across Micromegas for several choices of electric gradient

across MCP. One can see a usual exponential behavior. If one does the same gain curve as a function of MCP voltage, it is convoluted with the electron acceptance in the holes due to changing Lorentz angle as a function of E_{MCP} . Resulting gain curve is still exponential, but less steep, and probably less meaningful.

It is clear that the detector with the inclined MCP holes has no gain (the anode current is zero) for $B = 0$ kG. This means that it cannot be tested easily in a lab without the magnet. That represents, perhaps, a certain operational difficulty in early R&D stages. However, during a real experiment, typical conditions are with the magnetic field on.

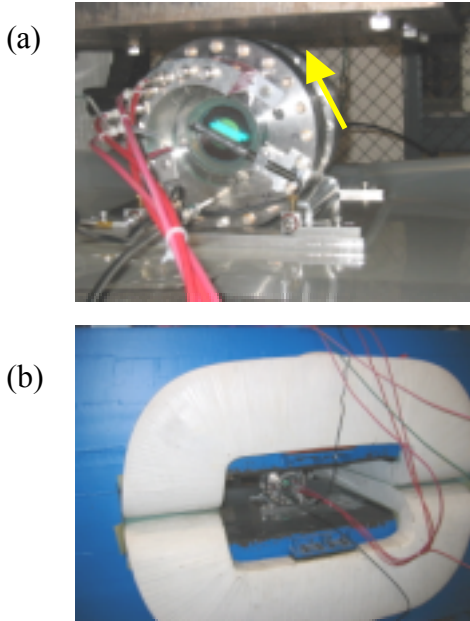


Fig. 9. Experimental setup in a 15 kG dipole magnet. It uses a Mercury UV lamp. The detector vessel can rotate to find an optimum angle at which the electron transmission is at maximum. The arrow indicates the direction of rotation.

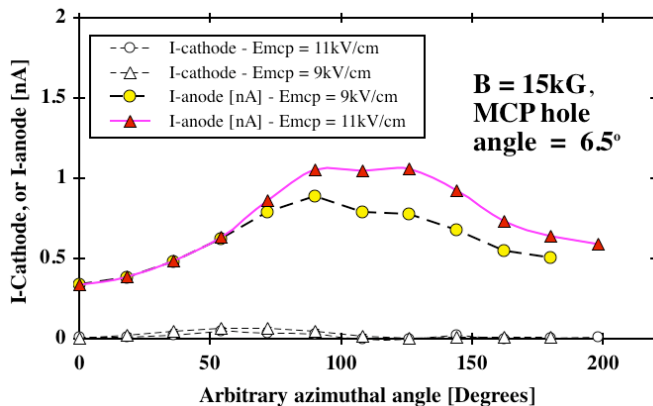


Fig. 10. Experimental tuning of the MCP azimuth angle to achieve the best electron transmission and the optimum alignment. At this angle, the ion backflow current is very small and consistent with the pico-ammeter noise of ~ 5 pA. The gas is 90% Ar+10%CH₄.

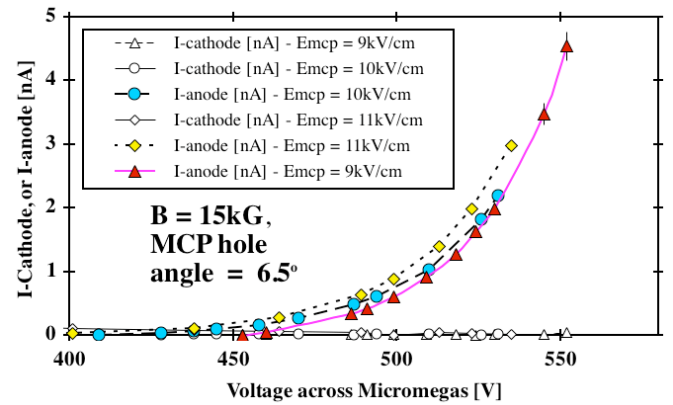


Fig. 11. The ion backflow measurement as a function of Micromegas voltage for several choices of MCP electric gradient. In each case, the ion backflow current is negligible, i.e., consistent with the pico-ammeter noise. The gas is 90% Ar+10%CH₄.

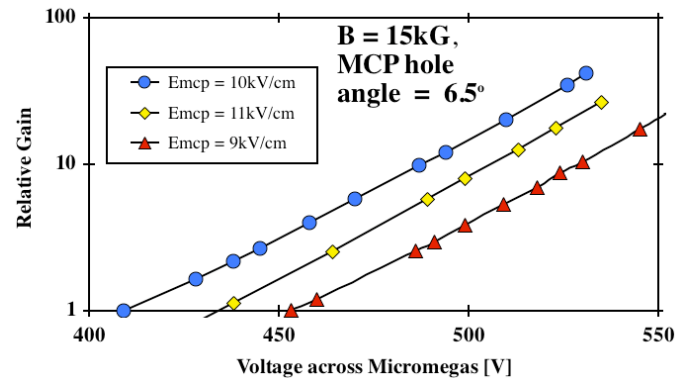


Fig. 12. Relative gain as a function of voltage across the Micromegas for several choices of electric gradient across the MCP in 90%Ar+10%CH₄ gas.

IV. DISCUSSION

Table 1 attempts to compare pros and cons of two approaches to MCP-based detectors. There are many clear advantages of the vacuum-based MCP detectors such as the Burle multi-anode MCP-PMT. They are well established, at least in the R&D efforts if not in a large experiment, and deliver a superior timing resolution approaching 50-70ps. However, there are still many questions left to answer. For example, the aging and reliability issues, the overall cost, or ability to retain a good timing resolution in a large system of ~ 25 k channels, which would be required for the good imaging system such as the Focusing DIRC, etc.

The gaseous detectors based on the MCP concept have many similar questions to answer, if not more. For example, a compability of the Bialkali photocathode with a gas, aging, timing resolution, etc.

At present, Hamamatsu is developing the permanently sealed gaseous detectors working with the Bialkali

photocathode. Fig. 13 shows the first attempts where the Micromegas part of the detector is installed next to the Bialkali photocathode and working with the P-10 gas. It is not yet operating in the single electron detection mode, but, it is the first step.

Table 1 – Comparison of vacuum and gaseous MCP-based detectors

Issue	Vacuum-based MCPs	Gaseous-based MCPs
Operation with Bialkali	Well established	Needs very clean gas
Main cause of aging	Ion bombardment of photocathode	Secondary processes during ion recombination
Timing resolution (1 μe^-)	$\sigma \sim 40\text{-}80\text{ps}$ reached	Still to be measured
Photoelectron Entrance collection efficiency	Less than 70% due to a typical geometry of holes	The collection efficiency should be $>98\%$
Magnetic field ($B = 15\text{kG}$)	Requires 6-10 μm holes	50 μm holes are OK
Timing tail origin	Recoiled photoelectrons	Focusing into the holes
Ion generating process	Residual gas bombardment	Avalanches in gas
Method to limit ion bombardment of the photocathode	Chevron arrangement of holes (6-12° inclination)	We propose: Angled holes in a direction of electron's Lorentz angle
Cost	Expensive if one chooses "non-standard" parameters	Standard hole sizes & angles



Fig. 13. The first attempt by Hamamatsu at permanently sealed gaseous detector with Bialkali photocathode and the Micromegas, filled with the P-10 gas.

The ideas presented in this paper could be used in some other areas of detector physics, including, for example, limitation of the ion feedback in TPC. One could achieve a similar ion blockage for 4-6 Tesla, if one rotates the MCP by 10° and increases thickness of the MCP.

V. CONCLUSION

This paper shows for the first time, to our knowledge, that it is possible to either eliminate the ion feedback entirely, or, reduce it to a very small level by aligning the MCP holes with the electron Lorentz angle. The ions follow a different path and are caught on the MCP holes. In a geometry, where one can arrange the MCP electric field to have an angle with the magnetic field, one can indeed achieve this, and this paper provides a proof. For example, such geometry could be easily achieved in the Focusing DIRC by suitably rotating the focal plane. Other applications are possible. To limit charging effect in some applications one may have to switch to lower resistance soda glass [4].

VI. ACKNOWLEDGMENT

We would like thank S. Biagi for useful comments how to run the Magboltz program, and M. McCulloch for help to construct the detector.

VII. REFERENCES

- [1] J. Va'vra and T. Sumiyoshi, "Single electron Amplification in a Single-MCP+Micromegas+Pads Detector," IEEE Trans. Nucl. Sci., vol. 51, No. 5, October 2004, and Nucl. Instrum. Methods, Vienna 2003, to be published.
- [2] K. Kurvinen, private communication, and IEEE Trans. Nucl. Sci., "Aging of Proportional Counters with Gas Mixtures Containing Impurities of Aromatic Hydrocarbons," N39-2, October 2004, Rome, Italy.
- [3] S. Biaggi, "Accurate Solution of the Boltzmann Transport Equation," Nucl. Instrum. Methods, vol. A273, pp. 533-535, 1988.
- [4] F. Tokanai et al., "Soda Glass Capillary Plate Gas Detector," IEEE Trans. Nucl. Sci., N25-8, October 2004, Rome, Italy.