Gain of a gas photomultiplier with CsI photocathode

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Abstract. A Gas PMT with the CsI photocathode was fabricated as a phototube of a glass vessel identical to a conventional vacuum PMT. A GEM and a Micromegas were installed in the phototube of the Gas PMT. The Gas PMT was operated with two different gas mixtures, Ar (90%) + CH₄ (10%) and Ne (90%) + CF₄ (10%), at the gas pressure of 1 atm. The gain of 10⁶ was obtained for both the gas mixtures. It was found that the gain of the Gas PMT can be described using the Townsend ionization coefficient for the Micromegas. The imaging capability of the Ne gas mixture was checked by an optical imaging capillary (CP) gas detector, using X-ray beams. The image of an X-ray resolution chart indicates that the imaging resolution is determined by the diameter of the capillary, here 100 µm. The Ne gas mixture appropriate to the Gas PMT is well suited for a fine imaging detector.

1. Introduction

The advantages of hole-type micro-pattern gaseous detectors (MPGD) [1, 2] are that electron gas multiplications are confined in each fine hole and that the hole allows taking out directly the electrons and the scintillation lights. Since the charge and/or the light signals can be used for the position determination, the hole-type detectors are able to provide a true two-dimensional (2D) imaging detector with a remarkable position resolution less than 20 µm, combining them to positional signal read-out devices such as anode pixels [3] and CCD cameras [4,5].

An application of the hole-type gaseous detector is to use it for the electron multiplication of the gaseous photomultiplier tube (Gas PMT) [6-9]. Although the gas gain of conventional gas proportional counters is approximately 10⁴ at most, the gain of 10⁶ can be realized fabricating multi-stage hole-type gaseous detectors as in a vacuum photomultiplier tube (PMT).

PMTs are most reliable photon detector. However, there are limits for the fabrication of a large area PMT going beyond 20 inches in diameter and for the operation in pressurized environments because of the structure of evacuated tube. Moreover, the position resolutions of PMTs would be restricted to 1 mm even the multi-anode PMT. The Gas PMT could go over these limits and it has an advantage for the operation in magnetic fields, although the quantum efficiency of the Gas PMT is inferior to that of the PMT [6, 10, 11].

Because the photocathode is sensitive to the air, gases, and the materials inside the PMT, it is necessary in the development of the Gas PMT to investigate the effects due to the filled gas and the...
different materials replaced from a vacuum PMT. Our final goal is to fabricate the Gas PMT with a bi-alkali photocathode. First of all, we constructed a Gas PMT with a CsI photocathode, because it is less sensitive to the gas and materials in the tube than the bi-alkali. The phototube is made from a glass vessel. The electrodes and insulators are the same as the vacuum type PMT. Note that it is important to test the operation of the Gas PMT with the same configuration to the conventional vacuum PMT considering the replacement to the Gas PMT.

Secondly, it is important to check the imaging capability for the gas mixture filled in the Gas PMT tube, because the basic characteristics are useful to fabricate an imaging Gas PMT composed by the Gas PMT and fine position sensitive detectors.

2. Gas Photomultiplier Tube
We have investigated the gain of a Gas PMT with two stages of the electron multipliers which consists of a hole-type MPGD and a parallel plate type MPGD [12]. The hole-type MPGD plays roles of pre-amplification by multiplying the electrons before the second stage. It is important to fabricate the Gas PMT as simple as possible when we consider the reliability of the operation and the manufacturing process.

2.1. Gas PMT with CsI photocathode
Figure 1 a) is a photograph of the Gas PMT with CsI photocathode which is semitransparent. As the hole-type MPGD we used a gas electron multiplier (GEM) [2] made by SciEnergy Co. in order to check whether or not the material of GEM affects the operation of the Gas PMT, even if the photocathode with CsI is rather insensitive for impurities in the phototube. The Gas PMT includes a GEM and a Micromegas [12] and they are enclosed in the 50 mm diameter glass tube. The GEM with 70 μm diameter holes plays a role of the pre-amplification of electrons and the micromesh detector is a kind of parallel plate gas proportional counter with the cathode plane of micromesh has square holes of 43 μm x 43 μm with a spacing of 78 μm. The gap between the micromesh cathode and the anode plane is 300 μm.

The gain of Gas PMT was investigated using the electric currents as shown in Figure 1 b). The photocathode of CsI was illuminated by UV light from a mercury lamp. The current $I_{pc}$ of photoelectrons leaving the photocathode was monitored with a picoammeter. The gas gain at GEM was obtained by measuring the ratio of electric current $I_B$ of the lower GEM electrode to $I_{pc}$ as a

Figure 1. Left) Photograph of a sealed gaseous PMT with a CsI photocathode.  
Right) Schematic view of the sealed gaseous PMT with a CsI photocathode.
function of the applied voltage between the GEM electrodes ($\Delta V_{GEM}$). Finally, the gain of the Gas PMT was evaluated from the relationship between the electric current $I_a$ of the anode of the Micromegas as a function of the applied gap voltage, for a fixed $\Delta V_{GEM}$.

The Gas PMT was operated with two different gas mixtures at a gas pressure of 1 atm. One is a conventional mixture of Ar (90%) + CH$_4$ (10%) for gas proportional counters and the other is a gas mixture of Ne (90%) + CF$_4$ (10%) having an advantage in the Townsend ionization coefficient compared with the Ar gas mixture. The Gas PMT tube was filled by the gas mixture after evacuation and the tube was sealed by melting the inlet glass tube. The gain $M$ was calculated using $I_a / I_{pc}$. When the gas gain is $G_g$ at the GEM stage, the transfer rate of the electrons from the GEM to the micromesh is $\eta$, and the gas gain is $G_m$ at the micromesh detector, $I_a$ is described as $I_{pc} G_g \eta G_m$ and hence $M = G_g \eta G_m$.

2.2. Gain of Gas PMT

Figure 3 shows the gain curves of the Gas PMT as a function of the applied voltage for Micromegas, where the $\Delta V_{GEM}$ are 390 V and 280 V for the Ar and Ne gas mixtures, respectively. For the Ne gas mixture, a gain of $10^5$ was obtained with an applied voltage of 600 volts and for the Ar gas mixture the applied voltage was 900 volts.

If the first Townsend coefficient is given by the Rose and Korff formula: $\alpha = \exp(-Bp/dV)d$, the gas gain of $G_\alpha$ is roughly represented by $G_\alpha = \exp(Ap \exp(-Bp/dV)d)$, where $p$, $d$, $V$ are respectively the gas pressure, the gap space and the applied voltage for the Micromegas. The constants $A$ and $B$ depend on the gas mixture. Hence $M$ is represented as $M = c \exp(Ap \exp(-Bp/dV)d)$, where $c$ is a constant value. From the fit of the gain curve to this equation by a least-squares method, we can obtain the constants $A$ and $B$ as the best-fit parameters. In the figure the solid curve lines show the gain curves obtained using the constants $A$ and $B$. They indicate that the gain of the Gas PMT is well described using the Townsend ionization coefficient.

Figure 4 shows the first Townsend coefficients for both gas mixtures, calculated by the Magbolz program [13]. A two parameter exponential fit according to the Rose and Korff formula is performed and the constants $A$ and $B$ are derived. In the figure the solid lines show the best-fit curves for both the gas mixtures, respectively. In the range of the applied voltages to the Micromegas the Ne gas mixture had higher coefficients compared with that for the Ar gas mixture. The result is that for the Ne gas mixture the Gas PMT is operating at lower applied voltage than for the Ar gas mixture.
3. Optical X-ray Images
A promising kind of gas PMT is a tube with imaging capability (very small pixels). We have checked that capability for the Ne gas mixture used in the Gas PMT tube by constructing an optical imaging capillary (CP) gas detector, using a microfocus X-ray source.

3.1. Optical imaging CP gas detector
Figure 4 shows the optical imaging CP gas detector set-up which uses a cooled CCD camera via an optical lens. In the test of the imaging capability, X-rays which passed through a sample and the window mesh in the CP detector irradiated each capillary of the CP. In each capillary gas multiplications occurred and the scintillation light was simultaneously emitted. Using this scintillation light, the images of X-rays were obtained by the CCD camera.

3.2. X-ray Image
In order to investigate the performance of a hole-type micro-pattern detector for the Ne gas mixture, the electrons produced by the X-rays in the drift range are suppressed to enter in the CP applying a reverse voltage for the drift region. Hence, the position resolution for the imaging is determined by the size of hole-diameter, because the seed of the emitted light is confined in each capillary.

Figure 5 shows the image of a resolution chart due to X-ray beams from a microfocus X-ray tube with an operated at 50 kV. In this figure, the lines below the numerical character 3.7 are due to the chart of 3.7 line pairs per mm and hence the width of the line image is expected to 135 µm. In fact, since the lines are composed by one or two bright spots, it indicates that the imaging resolution is determined by the diameter of the capillary 100 µm. Moreover, in the figure the image of the honeycomb mesh installed in the CP can be seen. As the thickness of the stainless mesh is 80 µm and the pitch is 1 mm, the imaging resolution is consistent to that of the X-ray resolution chart.

The position resolution is in good agreement with the result obtained in the same setup with the Ar + CF4 gas mixtures [14]. These imaging resolutions indicate that the Ne gas mixture appropriate to the Gas PMT is good also for the fine imaging detector.

4. Conclusions
The advantages of gaseous PMT are mainly the capability of a large area and a fine position resolution compared with vacuum PMTs. We have investigated the gain of a Gas PMT with two stages of the electron multipliers which consists of a hole-type MPGD and a parallel plate type MPGD. The Gas
PMT with the CsI photocathode is made from a phototube of a glass vessel as well as a conventional vacuum PMT. A GEM and a Micromegas are installed in the phototube of the Gas PMT.

The Gas PMT was operated with two different gas mixtures at a pressure of 1 atm. One is a conventional gas mixture of Ar (90%) + CH\(_4\) (10%) for gas proportional counters and the other is a gas mixture of Ne (90%) + CF\(_4\) (10%). The gain of 10\(^5\) was obtained for both the gas mixtures.

It was shown that the gain of the Gas PMT is well described using the Townsend ionization coefficients due to the applied voltage for the Micromegas. From the analysis of the Townsend coefficients for both the gas mixture, it was figured out that for the Ne gas mixture the Gas PMT is operating at a lower applied voltage than for the Ar gas mixture.

The imaging capability of the Ne gas mixture was checked by an optical imaging capillary (CP) gas detector, using X-ray beams. The image of X-ray resolution chart indicates that the imaging resolution is determined by the diameter of the capillary 100 µm. Hence the Ne gas mixture appropriate to the Gas PMT is good also for the fine imaging detector.

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References

[1] Sakurai H, Tamura T, Gunji S, and Noma M 1996 Nucl. Instr. and Meth. A 374 341
[2] Sauli F 1997 Nucl. Instr. and Meth. A 386 531
[3] Costa E, Soffitta P, Bellazzini R, Brez A, Lumb N and Spandre G 2001 Nature 411 662
[4] Tsukahara M, Sakurai H, Saito S, Noma M, Gunji S and Tamura T 1997 IEEE Trans. Nucl. Sci. 44 676
[5] Tokanai F, Atsumi T, Endo T, Fujita Y, Ohishi Y, Okada T, Sakurai H, Gunji S, Kishimoto S 2006 Nucl. Instr. and Meth. A 567 376
[6] Peskov V, Silin E, Sokolova T and Radionov I 1999 Nucl. Instr. and Meth. A 433 492
[7] Breskin A, Balcerzyk M, Chechik R, Guedes G. P., Maia J and Mörmann D 2003 Nucl. Instr. and Meth. A 513 250
[8] Va’vra Jand Sumiyoshi T 2004 Nucl. Instr. and Meth. A 535 334
[9] Tokanai F, Atsumi T, Gunji S, Okada T, and Sakurai H 2005 IEEE Trans. Nucl. Sci. 52 1698
[10] Chechik R. Balcerzyk M, Breskin A, Buzulutskov A, Guedes G P, Mörmann D and Singh B K 2003 Nucl. Instr. and Meth. A 502 195
[11] Sakurai H, Tokanai F, Gunji S, Kaneko M, Sumiyoshi T, Endo T, Fujita Y, Ohishi Y, Okada T, Sugiymama H, Atsumi T Proc. of Imaging 2006 Sweaden, submitted to Nucl. Instr. and Meth. A.
[12] Giomataris Y, RebourgeardPh, Robert J P and Charpak G 1996 Nucl. Instr. and Meth. A 433 29
[13] Biagi S MAGBOLTZ Program to compute gas transport parameters, CERN
[14] Tokanai F, Sakurai H, Gunji S, Kaneko M, Endo T, Fujita, Atsumi T, Okada T 2007 Nucl. Instr. and Meth. A 571 289