Development of gaseous PMT with micropattern gas detector

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   - Quantum efficiency
   - Production of photocathode
   - Gain
   - A novel CP gas detector for the gaseous PMT
   - Photon and Ion feedback

3. Summary and future plans
## Advantages of Gaseous PMT

<table>
<thead>
<tr>
<th></th>
<th>Q.E.</th>
<th>Δt</th>
<th>Δp</th>
<th>B</th>
<th>area</th>
<th>Cost/ch</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMT</td>
<td>○</td>
<td>○</td>
<td>△</td>
<td>△</td>
<td>△</td>
<td>△</td>
</tr>
<tr>
<td>Gaseous PMT</td>
<td>△</td>
<td>△</td>
<td>○</td>
<td>○</td>
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Very useful for high energy experiments such as a **RICH** and clinical applications using a combination of **PET** and **MRI**.

(c) Kamioka Observatory, ICRR (Institute for Cosmic Ray Research), The University of Tokyo
Photons are converted to PEs.

PEs undergo electron multiplication.

Multiplied charge is recorded.

In VUV range, a gaseous PMT consists of a CsI photocathode coupled to a MWPC that has been successfully and widely utilized as a RICH counter.

The open geometry of the MWPC limits the sensitivity and lifetime of the CsI photocathode due to both photon and ion feedback.
These feedback cause faster degradation of the bialkali photocathode than that of the CsI photocathode, because the work function of bialkali photocathode is lower than that of CsI.

Open geometry

The maximum achievable gain are limited to \(~100\) for gaseous PMT with bialkali photocathodes due to these feedback.
Recent development of gaseous PMT

To satisfy demand for higher sensitivity (gain > $10^5$) and long-term visible photon detector, several recent developments have been achieved using MPGDs.


- NDIP 2002, D. Mörmann et al.
- NDIP 2005, A. Breskin
Development of gaseous PMT using MPGD (CP, GEM, and Micromegas)

To evaluate the MPGD in a gaseous PMT sensitive to visible light.

We investigated the characteristics of sealed gaseous PMTs with a bialkali photocathode combined with MPGDs.

- production of the photocathode
- quantum efficiency (QE)
- gain
- photon and ion feedback
Quantum efficiency in gas mixtures

Double Micromegas detector in a gaseous PMT

The glass vessel, electrode and insulator are the same as those used in the vacuum-type PMT.

The tube was filled with

\[
\text{Ar (90\%)+CH}_4(10\%) \quad \text{Ne(90\%)+CF}_4(10\%)
\]

The QE and gains were determined by measuring electric current from the photocathode and anode with a current meter.
Quantum efficiency in gas mixtures

The maximum QEs are 14% and 12% for the neon and argon gas mixtures at wavelengths of 350 and 420 nm, respectively.

The QE for the neon gas mixture is similar to that for the argon gas mixture.

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Quantum efficiency in gas mixtures

There was no deterioration of the QE over one and half years (581d).

There is no degradation of the bialkali photocathode in a gas environment.

QE in vacuum ~20%

QE in the gas ~12%

It recovered its original value when the gas was evacuated again.

Check QE every 2~3 months

There was no deterioration of the QE over one and half years (581d).
Gain of the gaseous PMT with D-Micromegas

A gain of over $10^5$ is necessary for practical operation.

Unexpected signals at a gain above 2000.

This secondly effect was also observed with argon gas mixture.

A gain of over $10^5$ is necessary for practical operation.

We concluded the double Micromegas is not appropriate to a single-photon detector.

We started to develop a gaseous PMT using a hole-type MPGD.
Material inside the gaseous PMT

Bialkali PC is chemically unstable, the material must satisfy the high level of cleanliness required for the PC production.

What kind of material is suitable?

Lead glass for CP  →  Kapton for GEM

We fabricated gaseous PMTs with a bialkali photocathode.

A thin layer of Sb is deposited on Koval glass, and is activated by bialkali (K-Cs) metals.
Material inside the gaseous PMT

Piece of Kapton in glass ampoule

The ampoule was filled with K or K-Cs vapor.

Gradually changed to grey as K evaporated, and then to dark brown as soon as the Cs started to evaporate.

These changes are due to absorption reaction between Kapton and bialkali photocathode.

Photocathode sensitivity

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<tr>
<th></th>
<th>glass CP</th>
<th>Kapton-GEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC Sensitivity</td>
<td>56.3</td>
<td>1.5</td>
</tr>
<tr>
<td>(μA / lm)</td>
<td></td>
<td></td>
</tr>
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</table>

The PC sensitivity of Kapton-GEM is less than 3% of that of the glass CP.

The material of GEM chemically reacts with the bialkali metals and affect the production of the bialkali PC on the substrate of the Koval glass.
Problem for glass capillary plate

For the lead glass CP, the production of the bialkali photocathode seems to be problem-free.

The **conductivity** on the lead glass CP **changed**.

A chemical reaction between the lead glass and the bialkali metal occurs on the surface of the wall.

The penetration of the bialkali metal causes the deterioration of the electric field in the drift region.

We started to develop a **hole-type MPGD with other glasses** that allow the problem-free production of bialkali photocathodes.
A Pyrex CP gas detector for the gaseous PMT

By employing a novel technique, we successfully produced a new CP using Pyrex glass.

Each hole has a double-conical shape.

<table>
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<tr>
<th>Dimension</th>
<th>Value</th>
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<tbody>
<tr>
<td>Thickness</td>
<td>300 μm</td>
</tr>
<tr>
<td>Diameter at entrance</td>
<td>160 μm</td>
</tr>
<tr>
<td>Diameter at center</td>
<td>124 μm</td>
</tr>
<tr>
<td>Pitch</td>
<td>300 μm</td>
</tr>
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Pyrex glass CP: Performance test using X-rays

Basic performance tests were carried out by irradiating 5.9 keV X-rays.

- Gains of up to $10^4$ are safely achieved using a CP.
- Energy resolution is 23%, which agrees with the result obtained by the lead glass CP.
- Pyrex glass CP can act as a hole-type MPGD.
The electrical resistivity didn’t change before and after the production of the bialkali photocathode.

The QE shows **good agreement** with that obtained using the PMT with a **double Micromegas detector**.
Gain property of the gaseous PMT with the Pyrex CP

Divergence from the exponential curve starts at a gain of \(\sim 10\).

This behavior was reported by Mörmann et al (2003) and results from the effect of ion feedback.
Gain property of the gaseous PMT with the Pyrex CP

Demonstration of the ion feedback using the simulation codes of Maxwell and Garfield.

The ion feedback is calculated to be 0.3 for this configuration.
Future plan

To reduce the ion feedback, we are currently developing the gaseous PMT with **cascaded Pyrex glass CPs** according to Breskin et al. (2002) and Peskov et al (2002).

A higher gain of up to $10^5$ can be attained without the occurrence of ion feedback.
Summary

✓ We have started to develop the gaseous PMTs with a bialkali photocathode combined with the MPGDs.

✓ Quantum efficiencies of up to 12% were obtained for the gaseous PMT.

✓ We found that Pyrex glass is a more suitable material as a visible sensitive gaseous PMT with a hole-type MPGD.

✓ For the Pyrex CP gas detector, we successfully obtained a gain of up to $1.5 \times 10^4$ for 5.9 keV X-rays.

✓ Divergent behavior due to ion feedback is observed for the gaseous PMT combined with the bialkali photocathode and the Pyrex glass CP gas detector.

✓ The development of a gaseous PMT with cascaded MPGD is under way.
The sensitivity was decreased by 80% in 100 hours operation. The accumulated charges on PC was $\sim0.2 \, \mu$C/mm$^2$. 