Development of the micro pixel chamber based on MEMS technology

Taito Takemura (Kyoto Univ.)

Outline

- Introduction
  - Micro pixel chamber (μ-PIC) and its application
  - Requirements for μ-PIC

- μ-PIC based on MEMS Technology

- Gain Simulation of MEMS μ-PIC with Garfield++

- Measured spectrum and gain of MEMS μ-PIC

- Summary
Micro pixel chamber ($\mu$-PIC)

- A gaseous 2D imaging detector with strip read out
- Manufactured with PCB (Printed Circuit Board) technology
- Cu electrodes and polyimide substrate
- Each pixel is placed with a pitch of 400 $\mu$m
- Gas gain: Max ~ 15,000, stable operation ~ 6,000
- Fine position resolution (RMS ~ 120 $\mu$m)
- Large detection area: 10 x 10 cm$^2$, 30 x 30 cm$^2$
- Time of operation: > 2 years (30 x 30 cm$^2$)

T. Nagayoshi+ (NIMA, 2003)
Application for neutron imaging

Application for MeV Gamma-Ray astronomy
ETCC (Electron-Tracking Compton Camera)

T. Tanimori+
(Astrophysical Journal 2015)

Application for Dark Matter Search
talk id[108] Thursday 15 10:25~ Mr. IKEDA (Kobe Univ.)

K. Nakamura+
(PTEP 2015)

Application for MeV Gamma-Ray astronomy
ETCC (Electron-Tracking Compton Camera)

T. Tanimori+
(Astrophysical Journal 2015)

Using \(\mu\)-PIC as TPC

J.D. Parker+ (NIMA 2013)
Requirements of $\mu$-PIC for TPC

1. Higher gas gain
2. Suppression of discharge
3. Precise 3D tracking

A gap of anode cap makes discharge easily

For Gamma-ray imaging

The precision 3-D tracking is essential to determine the Point Spread Function for gamma ray

$S : N = 10^3 : 10^6$ (simulation)

Present imaging

15 degree diameter

4.71σ

Imaging with precise 3D tracking

Cumulative ratio in PSF (Point Spread Function)

### PCB Technology & MEMS Technology

#### µ-PIC based on PCB technology

- Substrate (dielectric constant): Polyimide (Pl: 3.2)
- Aspect ratio of anode (height/diameter): ~ 2 (100 μm/60 μm)
- Processing accuracy: ~ 10 μm
- Pitch length: > 400 μm
- Cost: ~ PCB (if 10 x 10 cm²)

#### µ-PIC based on MEMS (Micro-Electro-Mechanical Systems) technology

- Substrate (dielectric constant): Silicon (+ thin SiO₂) (Si: 11, SiO₂: 4.5)
- Aspect ratio of anode (height/diameter): ~ 8 (400 μm/50 μm)
- Processing accuracy: ~ several μm
- Pitch length: > 200 μm
- Cost: ~ PCB (if 10 x 10 cm²)

<table>
<thead>
<tr>
<th></th>
<th>PCB µ-PIC</th>
<th>MEMS µ-PIC</th>
</tr>
</thead>
<tbody>
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</tr>
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<td></td>
</tr>
</tbody>
</table>

- Higher gas gain
- Suppression of discharge & Uniformity
- Precise 3D tracking

We studied MEMS -PIC with ever the same pitch to focus on only the difference between PCB and MEMS.
Electric Field

PCB

Anode

Cathode

100μm

Cu

Polyimide

MEMS

Anode

Cathode

400μm

Simulation (Elmer)

Simulation (Elmer)
Simulation
MEMS $\mu$-PIC structures and types

The structure is manufactured by basic MEMS technology (through-hole technology).

The Structure is similar to that of present $\mu$-PIC.
Gas Gain of MEMS $\mu$-PIC in Simulation

Simulation suggests:

1. The gain of MEMS $\mu$-PIC is 2 times higher than that of PCB $\mu$-PIC.
2. The gains of two types MEMS $\mu$-PIC are same.

PCB $\mu$-PIC simulation: A. Takada+ (JINST 2013)
Dependence on polyimide layer of gain (MEMS μ-PIC type A)

Material around anode disturb electric field
Hole diameter of polyimide should be large
Measurement
Setup of Experiment MEMS μ-PIC

- **Drift Voltage** 250[V/cm]
- **Drift Space** ~3mm
- **ΔGEM** 300V (Gain ~ 20)
- **Induction field** 1[kV/cm] ~3mm
- **Ar:** 90%, C₂H₆: 10%, 1atm

**MEMS μ-PIC**
- **Cathode strip** × 12
  - 5 mm
  - 10 mm
- **Anode strip** × 20
  - 10 cm
  - 10 cm

**DAQ MEMS μ-PIC**
- **Anode20 strip**
- **Cathode 12 strip**
- **Preamplifier & Discriminator**
- **FPGA**
  - 25MHz
- **FADC**
  - 25MHz

**System Diagram**
- **Memory Board**
- **PC**

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_Mizumoto+ (NIMA, 2015)_
MEMS μ-PIC structure and types

Type A

Anode

Cathode

Type B

Anode

Cathode

<table>
<thead>
<tr>
<th>Material</th>
<th>Thickness</th>
</tr>
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<tbody>
<tr>
<td>Cu</td>
<td>400 μm</td>
</tr>
<tr>
<td>Si</td>
<td>400 μm</td>
</tr>
<tr>
<td>SiO2</td>
<td>15 μm</td>
</tr>
<tr>
<td>Pl</td>
<td>10 μm</td>
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</tbody>
</table>
## Discharging Voltage

<table>
<thead>
<tr>
<th>Type</th>
<th>Discharging Voltage [V]</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCB</td>
<td>~550</td>
<td>~10,000</td>
</tr>
<tr>
<td>Type A (Anode Hole; Pl 157.5 µm)</td>
<td>570</td>
<td>~8,000</td>
</tr>
<tr>
<td>Type A (Anode Hole; Pl 80 µm)</td>
<td>590</td>
<td>~10,000</td>
</tr>
<tr>
<td>Type B (like PCB; SiO₂ 10 µm)</td>
<td>570</td>
<td>~10,000</td>
</tr>
<tr>
<td>Type B (like PCB; SiO₂ 1 µm)</td>
<td>530</td>
<td>~1,700</td>
</tr>
</tbody>
</table>

It took a long time that current of SiO₂ 1 µm MEMS u-PIC settle down

(SiO₂ 1 µm: >20 nA ~4h)

(Other u-PICs: >20 nA ~1 min)
PCB and MEMS μ-PIC spectra

For the first time, we succeed in test operation of MEMS μ-PIC

GAS Ar90% C₂H₆10%, 1 atm
X-ray source Fe-55

Bad Energy resolution
probably due to much small detection area (10 mm x 5mm)
A lot of electrons escape from detection area
The gain of MEMS $\mu$-PIC is smaller than PCB $\mu$-PIC. This result is inconsistent with Garfield++ simulation.
Issue with Si?

By the experiment,
MEMS $\mu$-PIC with $\text{SiO}_2$ 1 $\mu$m has a much lower gain than MEMS $\mu$-PIC with $\text{SiO}_2$ 10 $\mu$m

Assumption
Deterioration of gain against simulation is caused by Si near anode working as semiconductor
MEMS µ-PIC

In order to study the effect of Si near anode

- Various thickness of SiO2 layer ($\geq 15 \, \mu m$) we’ll experiment with MEMS µ-PIC with SiO$_2$ 15 $\mu m$ soon
- GALASS substrate

Both MEMS µ-PIC can be manufactured
Summary

- We expect MEMS technology improves gas gain, suppression of discharge and precise tracking capability of μ-PIC
- Garfield++ simulation suggests that the gain of MEMS μ-PIC is twice higher than that of PCB μ-PIC
- For the first time, we succeed in test operation of MEMS μ-PIC
- Measured gain of MEMS μ-PIC is 16% - 40% of simulation value (@ Anode 500 V, GAS: Ar 90% + C_{2}H_{6} 10%, 1 atm)
- We assume the deterioration is caused by Si working as semiconductor (We hope Garfield++ include semiconductor working)

Future

- We’ll investigate relation SiO_{2} thickness and gas gain, and we’ll experiment with MEMS μ-PIC with SiO_{2} 15 μm soon
- We have started study of MEMS μ-PIC with short pitch in simulation
Supplemental Slides
Problem of Si?

By the experiment, MEMS μ-PIC with SiO₂ 1 μm has a much lower gain than MEMS μ-PIC with SiO₂ 10 μm, though gain of MEMS μ-PIC in simulation has no relation between gain and SiO₂ thickness.

**Supposition**

Deterioration of gain against simulation is caused by Si near anode working as semiconductor.
Si working as semiconductor
MEMS spectrum

MEMS Type A (Pl 80 μm)

41.19% (FWHM)
@Anode 540 V
Gain 2279

MEMS Type B (SiO₂ 10 μm)

53.1% (FWHM)
@Anode 520 V
Gain 2904

MEMS Type A (Pl 157.5 μm)

29.7% (FWHM)
@Anode 520 V
Gain 2836

MEMS Type B (SiO₂ 1 μm)

56.7% (FWHM)
@Anode 520 V
Gain 1208

GAS Ar90%.C₂H₆10%, 1 atm
X-ray source Fe-55
Polyimide Edge
Type B u-PIC
Manufacturing process of MEMS μ-PIC [1]

[1] Manufacturing alignment

[2] DRIE (Deep Reactive Ion Etching) Bosch process

[3] Manufacturing insulating layer (SiN/SiO₂)

This process enables to make high aspect ratio
Manufacturing process MEMS μ-PIC [2]

Type A
[1] manufacturing surface insulating layer (Polyimide)
[2] manufacturing seed layer
[3] photolithography, metal plating, seed etching

Type B
[1] manufacturing seed layer
[3] CMP (Chemical Mechanical Polishing)
[4] manufacturing surface insulating layer (Polyimide)
[5] photolithography, metal plating, seed etching
[6] seed etching
Anodeの山形の崩れと
ポリイミド層形成的制御が失敗によりゲインが出なかった
放電が1度起こると、とまらなくなった（SiO2の放電による傷が原因か？）

次タイプのMEMSはSiO₂膜を厚く
PCB and MEMS $\mu$-PIC spectrum

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