Micro-pattern detectors based on plasma display panels: Past, present, and future developments

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The Collaboration

- University of Michigan, Department of Physics
  - J. W. Chapman, Claudio Ferretti, Dan Levin, Curtis Weaverdyck, Robert Ball, Bing Zhou, Michael Ausilio

- Tel Aviv University, School of Physics & Astronomy
  - Meny Ben Moshe, Yan Benhammou, Rivka Ben Simon, Merlin Davies, Erez Etzion

- Oak Ridge National Laboratory, Physics Division
  - Robert Varner

- Integrated Sensors, LLC (Toledo, OH)
  - Peter Friedman
Motivation: Plasma Panel Sensor (PPS)

Plasma Display Panel (PDP)
Pixel Array

- Easily scalable
- Long life
- Use each pixel as independent Geiger-Mueller Counters
- Potentially high
  - Spatial and time resolution
  - Detection Efficiency
The Basics

- Apply a **High E-field** on a Penning gas mixture
- **Incident ionizing particles** produce streamers in a cell leading to gas breakdown

Voltage drops on $R_q$
- Measure signal pulse on $R_t$
- Cell recharges in time: $R_q C$
  - $R_q$ is large enough to **quench** a continuous gas breakdown
PPS Design: First Prototype

- Open cell prototype
- Modified commercial PDP

Typical Gas Mixture: 90% Ar + 10% CF₄

To be optimized

Hermetic seal

Pixel

Anode

Cathode

~30 cm
PPS : Typical Pulse

- Excellent Signal/Noise ratio
- Uniform shape throughout the panel
- Panel sealed 7 years prior

- Rise time ~ 1-2 ns
- FWHM ~ 3 ns
- Operating Voltage: O(1) kV
- Large pulse: No amplification needed
PPS : Spatial Resolution

• **Source**: \(^{106}\)Ru \(\beta\) (3.54 MeV end-point)
• Electrode Pitch = 1.0 mm
PPS: Spatial Resolution

Hit Variance

Geant4 Simulation

X-coords of Hits
Lorenztian
Gaussian

FWHM = 2.6 mm

+ Hits

FWHM 2.6 mm

FWTM 6.5 mm

Counts

X-position (mm)
PPS : Spatial Resolution

- **Source**: $^{106}$Ru $\beta$ (3.54 MeV end-point)
- **Electrode Pitch** = 1.0 mm

**Data**

Resolution : $< 1$ mm
Able to reconstruct the position of the source in steps 10 times smaller than the electrode pitch.
The Micro-Cavity (MiC) : Conceptual Design

Anodes

Individual gas cells

Cathodes

1 mm
MiC : Cell Geometry

- Has **1x1x2 mm closed** gas cells
- Individually quenched by an external 1 GΩ resistor
- Electric field of a few MV/m

Field Lines Topography: COMSOL
The Micro-Cavity (MiC)

Front

Back
MiC : Pulse Characteristics

- Clean pulse: no amplification needed

HV = 1150 V
Neon based mixture
Amplitude = 2.2 V
FWHM = 2.5 ns
Rise time = 1-2 ns
Experimental Setup
MiC : General Performance

- Using a **collimated** $^{106}$Ru **source** placed directly above the micro-cavity
- All cells show very **limited noise** ($10^2$ better than the open cell prototype)
- The measured **rates** of each individual cell are **similar**

![Graphs showing single pixel rate and average pixel rates with High S/N and Negligible Background](image)

- Efficiency constant over a wide range of voltages
- Keep in mind: imprecision in the position/collimation of the source
Collateral hits are minimal:
Due to collimation/positioning of the source
Not due to cross-talk

\( ^{106} \text{Ru Collimated source on channel 6} \)
Simulation is used to estimate source rate within the cells’ geometrical acceptance —> 10% syst. uncertainty

Efficiency: Near 100%

Remains high in the plateau region > 100 V range

Fit \( \frac{\varepsilon}{1+\exp\left[-(x-V_0)/\lambda\right]} \)

Pixel A
- \(\chi^2 / \text{ndf} = 4.783 / 7\)
- \(\varepsilon = 0.95 \pm 0.02\)
- \(V_0 = 1003 \pm 4\)
- \(\lambda = 25 \pm 3\)

Pixel B
- \(\chi^2 / \text{ndf} = 7.533 / 7\)
- \(\varepsilon = 1.012 \pm 0.004\)
- \(V_0 = 1008 \pm 2\)
- \(\lambda = 16 \pm 2\)
MiC : Time Resolution

$^{106}$Ru β collimated source

Pulse arrival time w.r.t. scintillator trigger

$\sigma = 2.83 \pm 0.05 \text{ ns}$

$\sigma_{\text{detector}} \simeq 2.4 \text{ ns}$

after subtracting trigger jitter
Next Generation

• Developing a **hexagonal design**
  • Higher spatial coverage
  • Higher spatial resolution

Performance Goals:
• Pixel efficiency: ≈ 100%
• Time resolution: ≤ 1 ns
• Granularity: same level
• Spatial resolution: < 1 mm
• Wide response range: ≈ 1 Hz/cm² to at least 10⁶ Hz/cm²

Commercial substrate
150 µm
Conclusion

- **Both prototypes** show good
  - Spatial/Time resolution
  - Low spontaneous background
  - High efficiency
  - Cell isolation
- **The Micro-Cavity greatly improves upon the PPS** on all of these points
- **Promising results** towards a **high performance particle detector** that is
  - Gas sealed
  - Easily scalable
  - Long life
Thank You!
Bonus Slides
Proof of concept

- Building an array of these panels for a tracker
- Optimizing gas composition to maximize efficiency
  - The nature of the quenching gas (\text{CF}_4, \text{CO}_2, \text{etc}...) and its proportion in the Penning mixture have a large impact on the performance of the panel
The commercial prototype

- β source sensitivity: $^{106}$Ru : 39.4 KeV (Q-value)
- Source placed directly over 4 adjacent cells.

No background contamination below ~885 V

99%Ar 1%CO$_2$ at 600Torr
Ultra Thin Glass Properties

**Beam Energy Loss in UltraThin Glass vs. Ti-foil**

Energy Loss in 25 μm thick glass cover PPS for selected Ion Beams
(gas is 1mm of Ar at 760 Torr; no nuclei get through the glass at 1MeV/A)

<table>
<thead>
<tr>
<th>Energy (MeV)/A</th>
<th>Ion Energy (MeV)</th>
<th>Energy loss in Glass (MeV)</th>
<th>Energy loss in Gas MeV (# ion pairs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0 (Ni-64)</td>
<td>192</td>
<td>190</td>
<td>0.95 (36,000)</td>
</tr>
<tr>
<td>3.0 (Sn-124)</td>
<td>372</td>
<td>348</td>
<td>4.34 (160,000)</td>
</tr>
<tr>
<td>3.0 (U-238)</td>
<td>714</td>
<td>570</td>
<td>11.60 (440,000)</td>
</tr>
</tbody>
</table>

Energy Loss in 7.6 μm thick Ti-foil cover PPS for selected Ion Beams
(gas is 0.25mm of Ar + 10% CO₂ at 600 Torr)

<table>
<thead>
<tr>
<th>Energy (MeV)/A</th>
<th>Ion Energy (MeV)</th>
<th>Energy loss in Ti-foil (MeV)</th>
<th>Energy loss in Gas MeV (# ion pairs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 (Ni-64)</td>
<td>64</td>
<td>60.5</td>
<td>0.29 (11,000)</td>
</tr>
<tr>
<td>1.0 (Sn-124)</td>
<td>124</td>
<td>111</td>
<td>0.70 (26,000)</td>
</tr>
<tr>
<td>1.0 (U-238)</td>
<td>238</td>
<td>199</td>
<td>1.48 (56,000)</td>
</tr>
<tr>
<td>3.0 (Ni-64)</td>
<td>192</td>
<td>81.5</td>
<td>0.93 (35,000)</td>
</tr>
<tr>
<td>3.0 (Sn-124)</td>
<td>372</td>
<td>160</td>
<td>1.77 (67,000)</td>
</tr>
<tr>
<td>3.0 (U-238)</td>
<td>714</td>
<td>298</td>
<td>3.21 (120,000)</td>
</tr>
</tbody>
</table>
PPS: Simulated Field Properties

- **E-field** produced at the anode/cathode intersection

- Simulated **capacitances**
  - Stray capacitances – coupling of all lines included

- Given the single volume gas geometry
  - The **capacitance** depends on the **number of lines**

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**COMSOL**

**SPICE**

\[
C_{\text{Fit}} = 0.21 \times (\text{Pixels})^{0.26}
\]
Origin of the first prototype: