High-Performance Plasma Panel Based Micropattern Detector

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The PPS, conceived as a high-performance, low-cost, particle detector, based on plasma-TV display panel technology.

Each pixel operates like an independent micro-Geiger counter, activated by direct ionization in the gas, or indirect ionization via a conversion layer.

Both “open-cell” and “closed-cell” PPS devices based on direct ionization are the primary focus of our research efforts.
PPS Detector Goals

• Scalable, low mass, long life, inexpensive
  – cm to meter size, with ultrathin glass & foil substrate capability

• Hermetically sealed & rad-hard material structure
  – no gas flow system & robust construction

• Performance
  – Pixel efficiency: ≈ 100%
  – Time resolution: ≈ 1 ns
  – Granularity: 200 µm
  – Spatial resolution: < 100 µm
  – Response range: ≈ 1 Hz/cm² to at least 10⁶ Hz/cm²
  – Gas pressure operational range: ≈ 760 to < 100 Torr

• Primary Applications – Particle Tracking & Active Pixel Beam Monitors*
  – Research: Nuclear physics / high energy physics
  – Medical: Particle CT imaging (NIH) / particle beam therapy (NCI)
  – Neutron Detection: Neutron scattering (DOE-BES) / DHS-DNDO

*ANL-ATLAS “Priority-I Ranking”, 2 days of testing planned for late-2015
Sources Used for Testing

Cosmic-Ray Muons ($\approx$ 4 GeV at sea-level)

Muon Beam: 180 GeV range (at H8-CERN for high energy physics)

Beta Particles (max. energy): $^{137}$Cs (1.2 MeV), $^{90}$Sr (2.3 MeV), $^{106}$Ru (3.5 MeV)

Proton Beam: 226 MeV (proton beam cancer therapy & proton-CT)

Neutrons: Thermal neutrons (neutron scattering & homeland security)

Gamma-Rays: $^{60}$Co (1.2 MeV), $^{137}$Cs (662 keV)

UV-Photons: “Black UV-lamp” with emission at 366 nm
“Open-Cell” Commercial Plasma Panel

- Columnar Discharge (CD) – Pixels at intersections of orthogonal electrode array
  - Electrode sizes and pitch vary between different panels

![Diagram of the plasma panel structure](image)

- SnO₂ or Ni .3 – 1.27 mm cathodes
- Dielectric
- Ni anode 0.8 – 1.27 mm
- Glass
- Discharge gap: 220 – 450 µm
PPS with CD-Electrode Structure

“Open-Cell” Structure

(≈ 20-25% active cell/pixel fill-factor)
Source Moved in 0.1 mm Increments

(1 mm pitch panel)
Collimated $\beta$-Source Position Scan ($^{106}$Ru)

Scan was in 100 $\mu$m steps

Linear Fit

slope = 0.999 ± 0.003

*Electrode Pitch 1.0 mm

Position resolution ~ 0.7 mm
Collimated $\beta$-Source Measurement ($^{106}$Ru)

Electrode Pitch = 1.0 mm
Spatial Resolution < 1 mm

FWHM = 3.05 $\pm$ 0.12 mm

Geant4 simulation
FWHM=2.6 mm
Stability – Response to Cosmic Muons

The graph shows the stability of the response to cosmic muons over a run time of 2.5 days. The x-axis represents the run time in hours, ranging from 0 to 55, and the y-axis represents the entries per hour, ranging from 0 to 100. The data points are indicated by red markers with error bars, indicating variability within the measurements.
“First” PPS Neutron Detection Results

• $^3\text{He}$ gas mixture at 730 Torr with 0.3 mm gas gap

• Geant4 simulation (GE) of the neutron capture rate based on source activity: $0.70 \pm 0.14$ Hz

• PPS measured rate at GE: $0.67 \pm 0.02$ Hz

$\approx 100\%$ of captured neutrons were detected*

*cannot do gamma discrimination, but can be almost gamma "blind"
### Beam Energy Loss in **UltraThin** Glass vs. Ti-foil

**(Application: Active Pixel Beam Monitors)**

Energy Loss is **25 μm thick glass** cover PPS for selected Ion Beams
(gas is 0.50mm of Ar at 200 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>0.13 (4,700)</td>
</tr>
<tr>
<td>3.0 (Sn-124)</td>
<td>372</td>
<td>348</td>
<td>0.57 (21,000)</td>
</tr>
<tr>
<td><strong>3.0 (U-238)</strong></td>
<td><strong>714</strong></td>
<td><strong>570</strong></td>
<td>1.52 (58,000)</td>
</tr>
</tbody>
</table>

Energy Loss is **7.6 μm thick Ti-foil** cover PPS for selected Ion Beams
(gas is 0.50mm of Ar at 200 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>0.19 (7,300)</td>
</tr>
<tr>
<td>1.0 (Sn-124)</td>
<td>124</td>
<td>111</td>
<td>0.47 (17,000)</td>
</tr>
<tr>
<td><strong>1.0 (U-238)</strong></td>
<td><strong>238</strong></td>
<td><strong>199</strong></td>
<td>0.99 (37,000)</td>
</tr>
<tr>
<td>3.0 (Ni-64)</td>
<td>192</td>
<td>81.5</td>
<td>0.62 (23,000)</td>
</tr>
<tr>
<td>3.0 (Sn-124)</td>
<td>372</td>
<td>160</td>
<td>1.18 (45,000)</td>
</tr>
<tr>
<td><strong>3.0 (U-238)</strong></td>
<td><strong>714</strong></td>
<td><strong>298</strong></td>
<td>2.14 (80,000)</td>
</tr>
</tbody>
</table>
Top Row: Photos of **0.026, 0.20 & 0.30 mm** thick glass. Electrode pitch is **2.54 mm**.

Electrode width 1.02 mm in active area, and 0.31 mm at bottom. Note 26 μm glass is 1/4 the thickness of single sheet of copy paper.

Bottom Right: High resolution electrodes on 26 μm thick glass. Electrode pitch in active area (center) is **0.35 mm**, electrode width is 0.15 mm. The narrow electrode width & spacing on the slightly bowed glass created the Lissajou type interference pattern, which is an optical artifact of image magnification and viewing angle. The actual electrode pattern is very uniform.
UltraThin PPS-2 (“open” panel)

(≈ 60-99% active cell/pixel fill-factor)
“Closed - Cell” Microcavity Concept

Closed gas cell individually quenched by an external resistor

Electrostatic simulations in COMSOL

Electric field a few MV/m → gas breakdown
"Closed-Cell" Microcavity Concept

Perspective view of a pixel array with gas channels. Metallized cathode cavities on bottom plate with vias to HV bus. Anodes on top plate.
First Microcavity-PPS Panel
The Prototype – Back Plate (63 pixels)

Bottom Side – quench resistor for each pixel.

Top Cavity Side with metal vias and gas channel.

Metallized cavities 1 x 1 x 2 mm
Collimated $\beta$-Source Test Setup

- RO lines
- HV lines
- Collimated Source
- Gas line

Microcavity Detector
Typical Microcavity-PPS Signal Pulse

Similar in shape to “open-cell” PPS, but smaller amplitude (capacitance), less jitter, and higher rate capability.

- $|A|=2.2\,\text{V}$
- FWHM=2.5 ns
- Rise Time 2.3 ns

$(HV=1150\,\text{V})$
Pixel Response vs. HV

Collimated source over a single pixel

Region of constant rate

Source (\(^{106}\text{Ru}\))

No Source

High S/N - Negligible Background Rate (orders-of-magnitude lower than signal rate)
Hit rates for “collimated” source over a single pixel on RO line 6, for a nine (9) channel, 23 pixel array.

Collateral hits are minimal:
Due to collimation/positioning uncertainty of source and substrate scattering.

*Not* due to crosstalk
Collimated source "centered" over each of 52 pixels at 1100V
Long Term Stability (9 days)

1st test with same panel but different gas mixture (2.7 days)

Uncollimated source 15 cm above panel (HV = 1000V)

Many days of stable response, RMS variation ≈ 3%
Pixel Efficiency ($\beta$-source)

Pixel 1: eff = 0.95 ± 0.02
Pixel 2: eff = 1.01 ± 0.01
Systematic error ~ 10%
Single Pixel Rate vs. Time

Uncollimated source on pixel

Rate (Hz)

Time (sec)

1290V
1250V
1200V
1150V
1100V
1050V
1000V
950V
Pixel Time Resolution - Jitter

Pulse arrival time w.r.t. scintillator trigger

\[ \sigma_{\text{detector}} \approx 2.4 \text{ ns} \]

after subtracting trigger jitter

\[ \sigma = 2.83 \pm 0.05 \text{ ns} \]
Summary

• PPS devices have demonstrated high gain, fast timing, and high position resolution for a variety of particle sources including: betas, protons, muons and neutrons. Three (3) different ultrathin PPS device structures are under development – two (2) based on glass substrates and one (1) based on foil cover plates.

• The microcavity-PPS prototype shows very promising results in terms of pixel-to-pixel uniformity, time-stability of signal shape and rates, pixel response isolation, time resolutions of a few nanoseconds, excellent S/N, and efficiencies above 95% over a 100 volt range for beta-particles sources.

• Based on our successful Phase-II program, Integrated Sensors is moving forward with interested parties on ultrathin-PPS particle detectors primarily for medical and scientific applications.