Development of a Novel Position-Sensitive Microchannel Plate Detector

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- Good spatial information is essential for quality imaging.
  - Good time information is also essential in certain applications (e.g. positron emission tomography).

- Whether detecting photons, ions, or neutrons inevitably one is concerned with the detection of electrons.

- We aim to develop a detector with:
  1. single-electron sensitivity
  2. sub-millimeter spatial resolution
  3. sub-nanosecond time resolution
  4. the capability of resolving two spatially separated, simultaneous electrons


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Concept of the Induced Signal Approach

- Using a microchannel plate (MCP), an electron is amplified to a cloud of $10^7$–$10^8$ electrons before being sensed by two wire planes oriented in orthogonal directions.

- Each sense wire plane consists of 50 wires with a pitch of 1 mm, where each wire is connected to a tap in a delay line.

- Position is determined by measurement of the time difference between the two signals arriving at the two ends of the delay line.


http://faculty.chem.queensu.ca/people/faculty/stolow/Research/Facilities.html
Spatial Resolution of the Induced Signal Approach

- Digitized signals with a 2 GS/s waveform digitizer (CAEN V1729A).
- The induced signals have the expected bipolar shape, where the zero-crossing point corresponds to the passage of the charge cloud past the sense wire plane.
- Each induced signal is amplified by a low-noise amplifier with a gain of 30.

Resolution = 466 μm FWHM

This resolution relies on only the zero-crossing point; but, the entire signal contains useful information.

An Approach to Characterize the Induced Signals

- Using a resistive anode, which independently measures position, different electron cloud positions can be measured.
- Selecting different positions on the RA will allow us to explore how the induced signals depend on position.

- How does the induced signal depend on the trajectory of the electron cloud between wires?

\[
Y = \frac{Q_0 + Q_1}{Q_0 + Q_1 + Q_2 + Q_3}
\]
\[
X = \frac{Q_0 + Q_3}{Q_0 + Q_1 + Q_2 + Q_3}
\]
Raw Position Spectrum for the Resistive Anode (RA)

- Total charge of the electron cloud is measured for the MCP using a QDC (CAEN V862).
- By measuring the charge at the four corners of the RA, using charge sensitive amplifiers, shaping amplifiers, and a peak sensing ADC (CAEN V785), the position was determined.

\[
Y = \frac{Q_0 + Q_1}{Q_0 + Q_1 + Q_2 + Q_3}
\]

\[
X = \frac{Q_0 + Q_3}{Q_0 + Q_1 + Q_2 + Q_3}
\]

- The active area of the MCP is evident.
- All slits in the mask are visible (100 μm wide with a 4.2mm pitch).
- There is a non-linear distortion at the edges of the RA.
Incomplete charge collection is associated with particles detected at the edge of the RA that have risetimes longer than the integration time.

Selection of complete charge collection and selection of a relatively big charge on the MCP drastically improved the resolution from 500 μm to 157 μm FWHM.


Pulse Shape Analysis for the Resistive Anode (RA)

- Using only charge division $\rightarrow$ 157 $\mu$m FWHM

Can the joint use of the charge division and pulse shape information improve the spatial resolution?

- A clear correlation is evident between the summed risetime and $Y$ position.
- Pileup is also evident.
- Use of the signal risetime in addition to the charge division method results in a significantly improved resolution.

Resolution = 64 $\mu$m FWHM

Conclusions and Outlook

Conclusions:

<table>
<thead>
<tr>
<th>Position-Sensitive MCP Detector</th>
<th>Incident Particle</th>
<th>Spatial Resolution FWHM (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induced Signal</td>
<td>Single Electron</td>
<td>466</td>
</tr>
<tr>
<td>Resistive Anode– Best Charge Division (CD) Previously Reported†</td>
<td>UV Photons (high flux)</td>
<td>134</td>
</tr>
<tr>
<td>Resistive Anode– CD</td>
<td>Single Electron</td>
<td>157</td>
</tr>
<tr>
<td>Resistive Anode– CD + Risetime Analysis</td>
<td>Single Electron</td>
<td>64</td>
</tr>
</tbody>
</table>


Outlook:

- Use a RA to characterize the position dependence of the induced signals.
- Implement use of a second generation detector with a differential readout (for improved spatial resolution).
- Use the position-sensitive MCP detector for neutron radiography measurements.
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Concept of the Induced Signal Approach

The incident electron is amplified by a Z-stack of three microchannel plates resulting in an average gain of $\sim 1 \times 10^8$. The voltage drop across the Z-stack is approximately 2950 V.

The microchannel plates were standard commercial devices with 10 $\mu$m diameter channels with a 12 $\mu$m center-to-center spacing with a length to diameter ratio of 60 to 1. Following the microchannel plate stack, designated “sense wire planes” in Fig. 3, is a PCB with 25 $\mu$m diameter Au-W wires stretched across a 50 mm $\times$ 50 mm opening. Located behind the PCB is a metal anode where the electrons are collected. The field in the region between the MCP and wire plane is 70 V/cm while in the region between wire plane and the anode it is 90 V/cm.

As the electron cloud passes the wire, a signal is induced on the wire. The induced signal is amplified by a standard low noise RF amplifier (LNA-530, RFbay Inc.) and subsequently digitized. This amplifier provides a gain of 30 dB. The amplified signals are digitized by a fast sampling VME ADC (2 Gs/s, 12-bit, 300 MHz bandwidth; Caen V1729A (Ref. 9)).

Signals in both the X and Y directions exhibited the same characteristics. Due to a limited number of digitizer channels both dimensions could not be examined simultaneously. Independently, both dimensions manifested the same position resolution. For brevity we subsequently discuss the characteristics and analysis of the signals in the Y dimension. Both the anode signal and the amplified, induced signal triggered by the coincident alpha particle are displayed in Fig. 4.

The digitized signals in the VME ADC are read out and recorded using a PC-based data acquisition system. For each experimental condition tested a total of 30,000 coincidence triggers are recorded in order to determine the position resolution of the detector. Use of the coincidence of the MCP with the mask and wire plane setup allows for very precise control over the position of the electron cloud on the wire plane.

 offsets used in displaying each trace are indicated in parentheses.
Spatial Resolution of the Resistive Anode (RA)

\( \Delta V_{Z, \text{stack}} = +3512 \text{V} \)
\( \Delta V_{\text{MCP-RA}} = +164 \text{V} \)