Isolating the Effects of Microchannel Plate Parameters on the Ultimate Resolution in Time-Of-Flight Mass Spectrometers

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Overview:

Purpose:

To quantify the contribution of the microchannel plate (MCP) entrance geometry on the achievable mass resolution for a time-of-flight mass spectrometer.

Methods:

A series of TOF resolution measurements of calibrant samples were made using a single detector housing and four different MCP input geometries.

Results:

Smaller pores and higher bias angles improve resolution (Table 1):

Case	Pore (μm)	Bias Angle (deg.)	Global Flatness (μm)	Max Penetration Depth (μm)	$\Delta\tau_{max}$ 1500 Da (ps)	$\Delta\tau_{max}$ 3000 Da (ps)
A	5	12	8.4	23.5	814	1151
B	5	19	9.8	14.5	503	711
C	2	12	7.4	9.4	326	461
D	2	19	8.7	5.8	201	284

Table 1: Results of all four test scenarios.

Introduction:

- Any effect that increases the overall width of the peaks in a TOF mass spectrometer acts to degrade the mass resolution of the instrument (Equation 1).
- The ion detector contributes to the width of the peak measured in the TOF in two ways:
  - The width of the pulse produced by the detector
  - The uncertainty in the ion arrival time ("time jitter")
- The two components add in quadrature (Equation 2).
- The TOF instrument also contributes to the spread in the ion arrival time values for a given mass.

$$R = \frac{m}{\Delta m} = \frac{\tau}{2\,\Delta\tau}$$
$$m = mass$$
$$\tau = time\ of\ flight$$

Equation 1.

$$\Delta\tau_d{}^2 = \Delta\tau_{FWHM}{}^2 + \Delta\tau_{jitter}{}^2$$

Equation 2.

Microchannel Plates (MCPs):

- MCPs are arrays of parallel cylindrical electron multipliers with pore diameters on the order of micron and channel densities of 106-107 channels/cm^2.
- MCPs have very low transit-time spreads due to the small geometry of the pores. With proper detector design, MCPs with smaller pores produce faster pulses.
- The channels of the MCP are not normal to the surface, but are pitched at a slight angle called the bias angle.

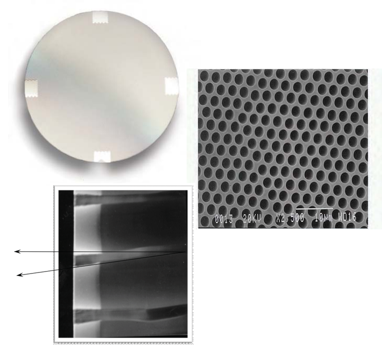

Figure 1: MCP Pores.

Introduction (continued):

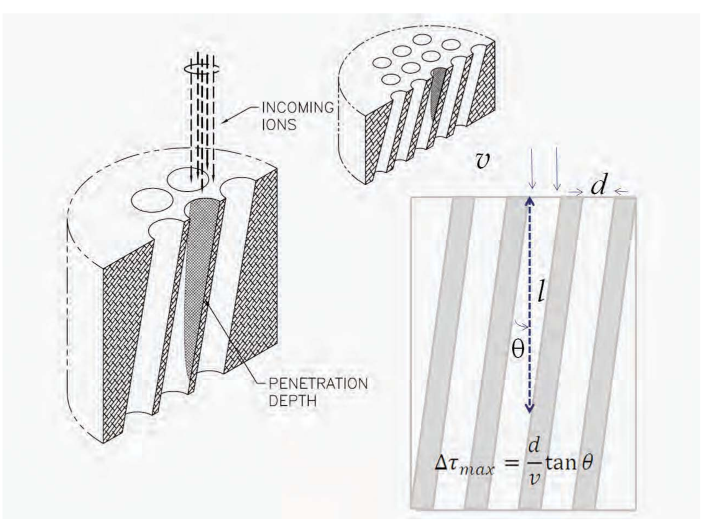

Figure 2: Ion Penetration Into MCP Pores: Cross-sectional views of MCP channels showing entrance geometry and the distribution of penetration depths for the incoming ion packet (shaded area) past the input surface of the MCP. Two configurations are shown to scale; 5 μm diameter pores with a 12° bias angle, and 2 μm diameter pores with a 19° bias angle. The variation of ion penetration values produces an uncertainty in the overall path length travelled by the ion, which limits mass resolution. By reducing the pore size of the MCP and increasing the bias angle, the maximum penetration depth can be reduced from 23.5 μm to 5.8 μm and the resolution can be improved by ~15% for masses of 1000-3000 Da.

Minimizing Detector Time Jitter:

- To minimize time jitter:
  - The electromagnetic environment in front of the detector should not perturb the arriving ions.
  - The spread in electron transit times for electrons due to the initial ion impact within the detector should be small.
  - The conversion surface of the detector (the place where the ion produces the first secondary electron) should be planar and parallel to the arriving ion packet.
- MCP-based detectors do not require grids and fields in front of the detector, and have very fast first strike transit times, but:
  - They may not have a flat surface that is planar with respect to the incoming ion packet.
  - They do not have a conversion surface that is parallel to the arriving packet.

Methods:

Detector:

- A Bipolar TOF detector was utilized for these measurements.
  - Uses a single MCP pressed to the mounting flange (No tolerance stack-up).
  - Surface global flatness <15 μm controlled by front flange (See Figure 4).
  - Sub-nanosecond peak widths (In this study 660 ps) that are essentially independent of MCP parameters.

Figure 3: BiPolar TOF Detector

Methods (continued):

Global Flatness:

- To measure the degree to which the input surface of the MCP is planar, we map the input surface with a machine-vision system similar to those used in the semiconductor industry.
- The system produces an overall measurement of the maximal focus plane deviation (a global flatness value) as well as a map of the MCP surface (an indication of MCP surface shape).
- Measurements can be made on bare MCPs and on MCPs mounted in the detector hardware.
- Examples of measurements are shown in Figure 4.
- Values are reported in the literature preceded with a "±" should be doubled for comparison with flatness measurements presented in this work.

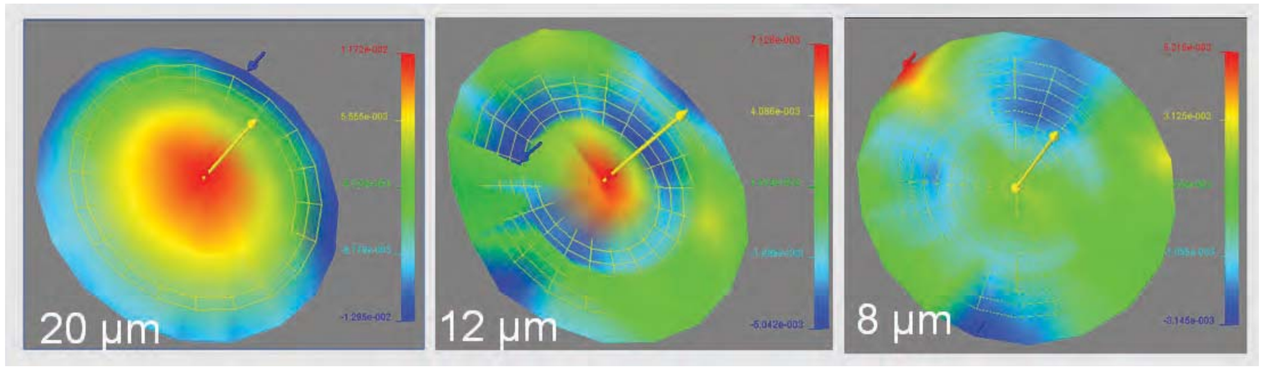

Figure 4: Flatness Maps of MCP Input Surfaces: A machine-vision system was used to measure the global flatness of all of the MCPs in this study both as bare MCPs and mounted in the detector hardware. This measurement system determines the overall focus plane deviation across the input surface of the MCP to an accuracy of 0.2 μm, and can be programmed to sample the surface in order to get a map of the overall shape of the input surface of the MCP. Here three sample MCP maps are shown, showing both different flatness values and different surface shapes. The shape of the MCP input surface is of particular importance if the incoming ion beam subtends only a fraction of the input area of the MCP.

Measurement of TOF Spectra:

- Positive ion TOF spectra measured on calibrant samples in a orthogonal TOF mass spectrometer.
- Resolution measurements were made on a 3 GHz analog bandwidth LeCroy 7300A oscilloscope operating at 20 Gs/second.
  - The scope was triggered off the pusher pulse.
  - Measured jitter of the pusher pulse trigger was <50 ps.
- Tests were performed in sequence using a single detector.
- The results for all four test cases were combined to determine the contribution of the instrument to the overall pulse widths.

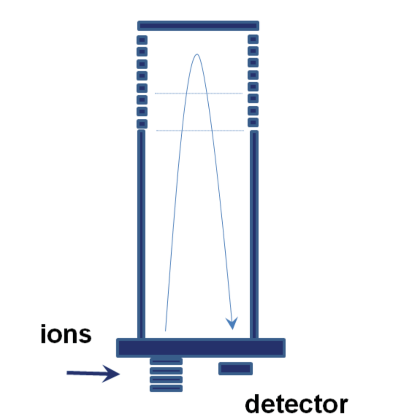

Figure 5: Orthoganol TOF System

Results:

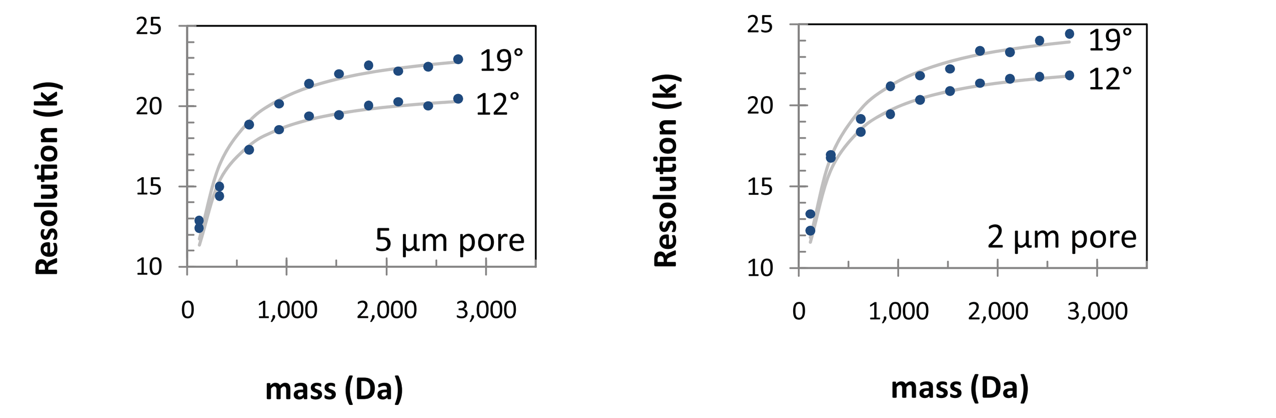

Figure 6: Resolution Improvement Based On MCP Input Surface Geometry: Measured (·) and predicted resolution measurements (lines) for four different MCP Configurations measured using calibrant samples in an orthogonal TOF instrument with a ~2 m flight length and 6.5 keV flight energy. The detector pulse width was 660 ps. Small changes in detector input geometry produce improvements in mass resolution. Note that, due to the nature of the bipolar TOF detector, the improvements in going from 5 μm to 2 μm are only based on penetration depth, not pulse width. For a detector based solely on MCPs, the switch to 2 μm MCPs would also produce a resolution improvement due to a faster pulse.

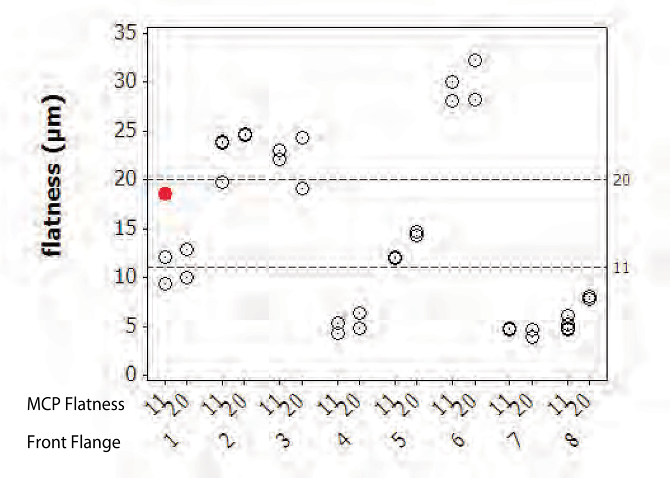

Figure 7: Detector Hardware Controls Flatness: Results from a flatness study where a single bipolar TOF detector was repeatedly assembled with two different MCPs and eight different input flanges. The flatness of the unmounted MCPs were measured as 11 μm and 21 μm (dashed lines) and the flatness values of the input flanges were measured prior to the test. Measured values reflect the properties of the front flange rather than the MCP, showing that good hardware can improve MCP flatness and bad hardware can degrade it. For one case (shown in red) improper assembly produced poor results even when the hardware and MCP are good.

Conclusions:

- TOF mass resolution can be improved with the use of MCPs that utilize smaller pore diameters and steeper bias angles with no measured loss in detection efficiency.
- Changing from a 5 μm diameter pore / 12° bias angle MCP to a 2 μm diameter pore / 19° bias angle MCP improved the mass resolution by ~15% for masses of 1000-3000 Da.
- The flatness of a mounted MCP is determined by the hardware and the design ogf the detector. Proper designs can routinely produce detectors with input surface flatness values <15 μm over 25mm diameter areas.
- Improperly designed or assembled hardware can distort otherwise flat MCP.