Optimizing the Microchannel Plate Detector Assembly to Improve Time-Of-Flight Mass Resolution

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Overview:

Purpose:

To increase the resolution of mass spectrometer instruments by improvement of the microchannel plate based ion detector regarding:

- Detector time response to an incoming ion arrival -- especially for FWHM, with equal rise and fall times.
- Jitter in the ion arrival time due to flatness of the active surface or distortion as a result of mounting.

Methods:

Layout of the conical anode was modified to conform more closely to 50 ohm impedance. The structure of the assembly was modified to take advantage of the speed inherent in the microchannel plate design. The goal was to make faster, and approximately equal, rise and fall times with minimal FWHM. Flatness of the channel plate chevron detector surface was improved.

Results:

In testing with an ion source applied to the detector, the response time was improved for FWHM and rise time as compared to the currently available microchannel plate detector:

	Current technology	Improved result	Unit
Rise time	300	**104**	pS
FWHM	450	**173**	pS

In a time of flight mass spectrometer, it was possible to achieve the resolution was substantially increased in comparison with the currently manufactured bi-polar detector (photomultiplier based).

	Current technology	Improved result	Unit
Mass 118	5113	**12554**	Da
Mass 223	6091	**15530**	Da

Introduction:

Microchannel plate detectors have been the detector of choice for ion applications due to their sensitivity and speed. But to increase instrument resolution, the time response of the detector needs to be improved to allow a higher precision in measurement of the arrival time. Additionally, the slow speed of heavy ions requires better control of the flatness of the microchannel plate detector.

To significantly improve the existing microchannel plate detector, it is necessary to consider the errors caused by the following issues:

- The error in arrival time of the ion due to the non-flat surfaceof the microchannel plate. The error can be caused by the mounting of the plate in the detector housing, a warping of the surface once mounted, or the depth of the channels themselves.

Introduction (continued):

- As an ion is detected, the microchannel plate causes the release of approximately 200,000 electrons that depart from the channel output pore with in 50 pS or so. But, the electron acceleration and overall travel time causes the detected electron waveform to slow down considerably.
- In the application of ion detection, the trend is toward amplitide readout by a high speed digitizer. The best results are obtained with equal rise and fall time. A long tail on the detected pusle becomes difficult to handle.
- The transition from the detector active diameter (18 mm in the present case) to the diameter of the wire lead inside the coaxial cable needs to transition smoothly with constant, 50 ohm impedance. In the existing design, this transition needs to be lengthened and made more even to avoid loss of signal bandwidth and capacitive loading.

Methods:

Flatness:

The following steps were taken to improve flatness of the microchannel plate:

- The bias angle was changed from 12 degrees from normal to 19 degrees from normal. Such a change reduces the depth that an ion can travel before hitting the side wall from 9.4 um to 5.7 um for the 2 micron pore plates. The error is significantly worse for greater pore diameter – 18.8 um for 4 um plates.
- Surface flatness control has been improved for the 2 micron pore plates with typical variation held to 10 micron over the active region (+/- 5 m).
- The mounting has been changed in the current work to improve fixing of the microchannel plate to the instrument. To accomplish this, a thick plate is used with flatness controlled to 1 um. The input surface of the channel plate is mounted directly to this plate to prevent any additional error in flatness.

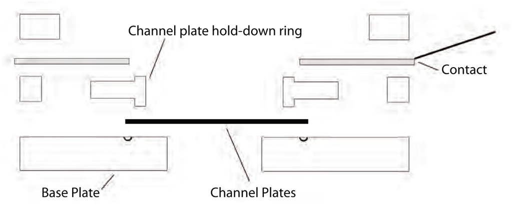


Figure 1. Thick base plate holds plates accurately relative to mounting into instrument.

Improved edge rate:

The leading edge rise time can be improved by the addition of a grid to the anode structure. The trailing edge fall time is controlled by the capacitance of the anode structure to that grid. This design attempts to get equal rise and fall times as an optimum in mass spec instruments. Then to decide the optimum separation between anode and grid:

$$t_{rise} = 0.8\frac{d}{v} \qquad v = \sqrt{\frac{2\,K.E.}{m}}$$

$$t_{fall} = 2.3\,RC = 2.3 \cdot 50\Omega \cdot \varepsilon_0 \cdot \frac{A}{d}$$

where d=space between grid and anode
v=velocity of the eletrons
K.E.=Kinetic Energy=V·e
m=electron mass
A=active area

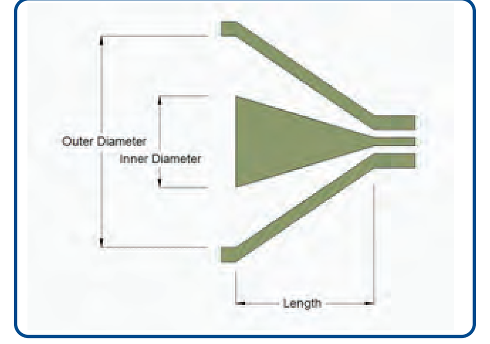
Methods (continued):

Setting these two quantities equal, we get the spacing for optimum timing performance for the usual detector sizes as shown at the right. From this result, it can be seen that the detector will not be able to have the speed of the channel plates if the rise and fall time are equal. The 2 micron pore plates achieve 50pS rise time. But the active area would need to be much smaller if we are to get equal rise and fall time.

Optimum spacing for equal rise and fall times

Active Diameter	Rise time	Fall time	Spacing
18 mm	95 pS	95 pS	2.73 mm
25 mm	131 pS	133 pS	3.76 mm
40 mm	211 pS	211 pS	6.06 mm

Capacitive load:



If the anode does not behave as a transmission line from the face to the exit point, where the signal enters the cable, additional capacitance will be added to the circuit and slow down the fall time. The current design utilizes a conical anode, but the aspect ratio is too short to serve the application at the higher speeds we would like to achieve. This situation was corrected by increasing the length to get an aspect ratio of approximately 1.5 as shown at the left.

Results:

The ideas presented were used to construct a prototype detector. This detector was tested using an ion input source to determine speed of response as shown in Figure 2. This detector was also tested in a commercial TOF Mass Spectrometer having a flight length of 2 meters and bias voltage limited to 4.5 KV so as to confirm the expected improvements to mass resolution. Figure 3 shows the peak at mass 118. Figure 4 shows the resolution at small mass for the new detector in comparison with two optically-isolated detector assemblies, which are now in production.

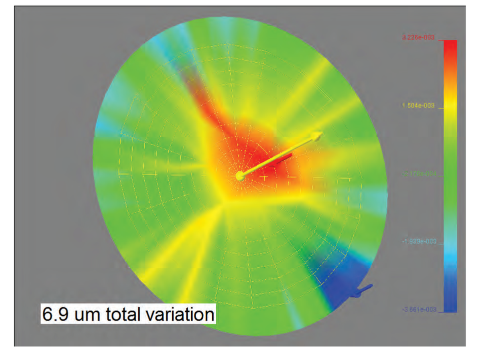


Figure 3: Flatness scan of mounted channel plate, input side.

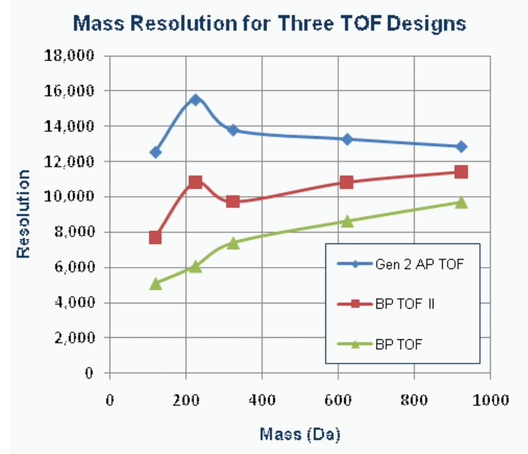


Figure 4. New design is compared to two production assemblies in a TOF Mass Spec instrument at the low mass range.
Flight path length = 2 meters
Acceleration = 4.5 KV
BP TOF refers to bi-polar detectors, based on photomultiplier tubes for optical isolation.

Results (continued):

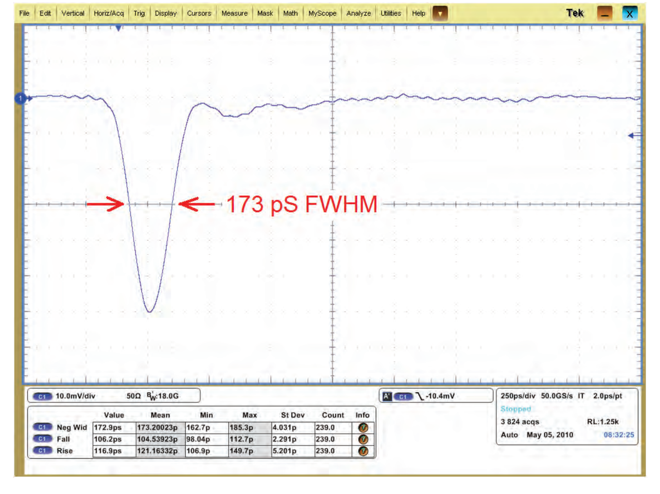


Figure 2. Averaged output from single ion input. Rise time = 104 pS, fall time = 121 pS and FWHM = 173 pS. Ringing frequency is 3.6 GHz with less than 7% amplitide.

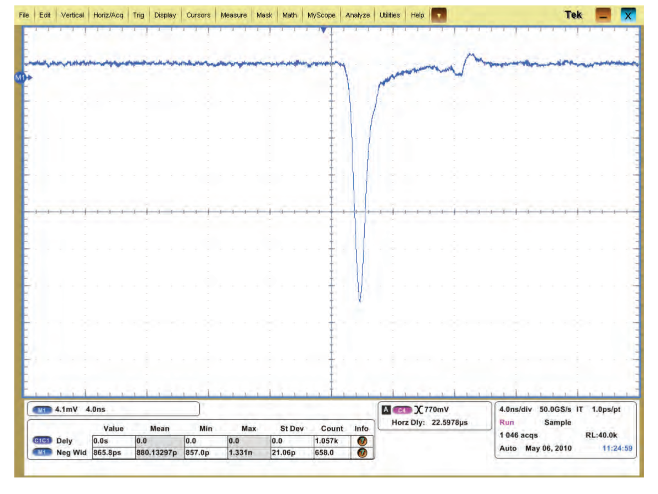


Figure 3. Scope trace shows averaged output from TOF Mass Spec at mass 118 Da. The mean FWHM is 880 pS having a flight time of 22.6 uS. The corresponding resolution becomes 12,544. The reflection of the high speed waveform is due to the vacuum interface connector.

Conclusion:

An ion detector based on microchannel plates has been designed having significantly higher speed and flatness. Test data shows that the response time has been reduced by a factor of two by careful design of the cone section and inclusion of the anode grid. Additionally, by placing the channel plates directly on a thick mounting plate, flatness of the overall assembly can be well controlled. From these changes, we can see:

Rise time improves from 300 pS down to 104 pS in channel plate detectors
Resolution improves from 5113 to 12554 at mass 118 Da

Future work will make these improvements available for other detector sizes. We also hope to improve the sensitivity and dynamic range of the microchannel plate approach to ion detection.

References:

1 G.Beck, Rev. Sci. Instrum., Vol. 47, No. 7 July 1976
2 K. Oba, et al, IEEE Transactions on Nuclear Science, Vol. 33, No. 1, February 1986

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