Miniature Ion Detectors for Mass Spectrometers Help Move Laboratory Analysis into the Field

a report by
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Mass spectrometers are analytical instruments that can be used to identify unknown materials in mixtures with concentrations as low as one part per billion. Mass spectrometers have three main components, which are listed below.

- An ionisation source for converting the analyte material into charged particles.
- The mass filter for sorting the resultant ions by mass.
- The ion detector that provides an amplified signal that the instrument electronics use to determine mass and abundance.

Once relegated exclusively to the research community in the laboratory environment, mass spectrometers have proven useful in a wide variety of everyday applications. Today, mass spectrometers are used in a variety of disciplines.

- Medical diagnostics (lung and blood testing).
- Determination of pesticide levels in canned foods.
- Water quality evaluation.
- Mining (mineral analysis).
- Volcano eruption prediction.
- Drug discovery.
- Homeland security applications.

It would be fair to say that everyone has benefited from the development of modern mass spectrometers.

Easy to use, truly field-portable mass spectrometers have been the dream of industrial hygienists, forensic pathologists, law enforcement officials, geologists, first responders and a host of others interested in moving laboratory quality analysis into the field location.

Although much progress has been made in reducing room-sized instruments to bench-top size, most portable instruments today would be best described as transportable. Designers of truly field-portable mass spectrometers face three challenges – how to reduce the size, weight, and power consumption without sacrificing performance.

BURLE Electro-Optics has made significant progress in meeting these challenges with the introduction of a variety of miniature ion detectors

When Size and Weight Count

A typical discrete dynode multiplier used in bench-top instruments is over 100mm tall, weighs in at over 35g and consumes over 300mW. *Table 1* provides size and weight comparisons for various detectors.

BURLE has introduced an entirely new generation of miniature ion detectors based upon microchannel plate (MCP), Spiraltron™ and Channeltron® technology (see *Figure 2*). These developments can revolutionise field portable mass spectrometers. These detectors are now available for instrument designers and can be optimised for particular applications.

MCP-based Detectors

An MCP is a solid state electron multiplier consisting of millions of independent, continuous, single channel electron multipliers all fused together in a rigid two-dimensional array. With channel densities up to 10 million channels per square centimetre, these are among the highest pixel density devices known to man. These devices are sensitive to a wide variety of charged particles and electro-magnetic radiation including ions, electrons, X-rays, UV photons and accelerated neutrals.

These high gain, low noise devices incorporate a wafer-like structure that makes them ideal for custom-designed detectors for portable mass spectrometers. MCPs can be machined in any shape or size ranging 3–200mm. MCPs can be cascaded in stages in order to produce single ion gains ranging from 10 to 10^8. MCP detectors incorporate anode structures to collect the output charge. These detectors can be used in both analogue and pulse-counting modes of operation. Detection efficiency, dynamic range, power consumption and noise rejection are but a few areas that can be optimised. MCP detectors are well suited for use in high magnetic fields and under poor vacuum conditions (up to 10 milli-Torr with special hardware). Power

Figure 1: Comparative Sizes of Electron Multipliers

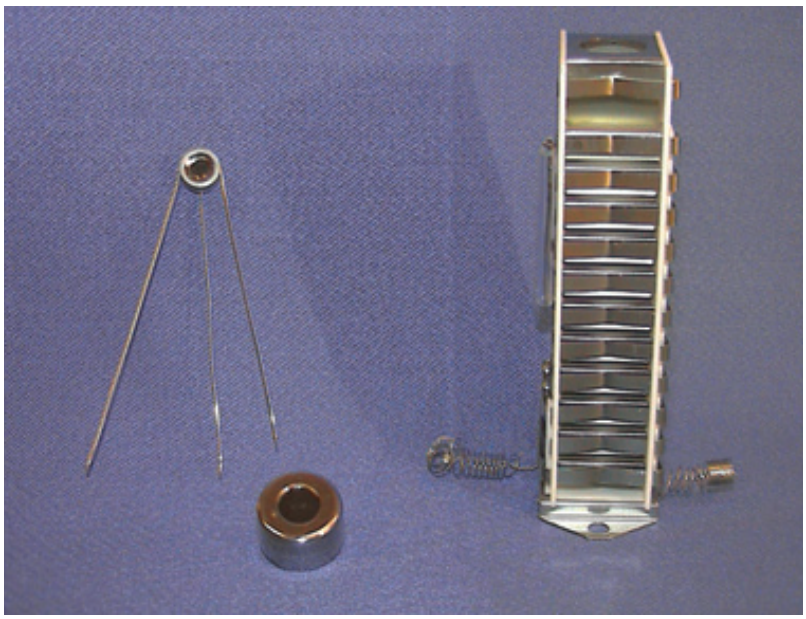


Figure 2: Miniature Ion Detectors Illustrate the Wide Variety of Miniaturisation that has Already been Achieved

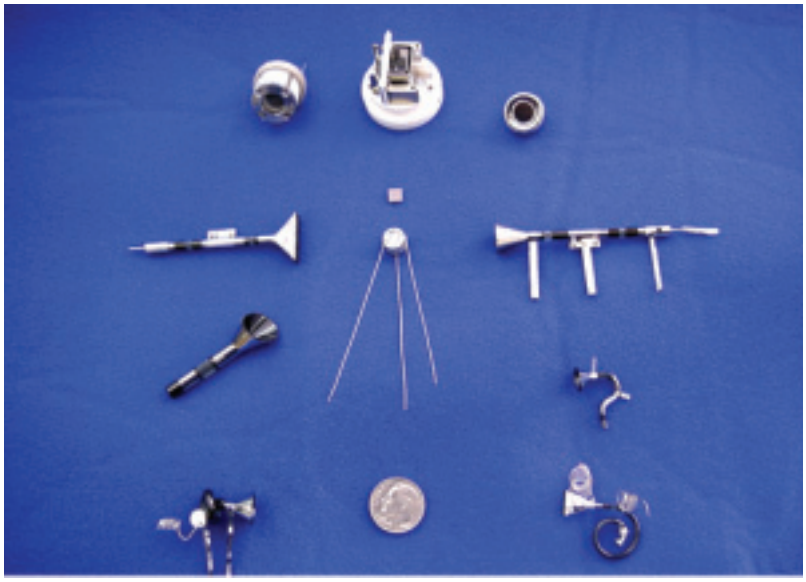


Table 1: Summary of Dimensional and Weight Information

Detector Type	Weight (grams)	Height (mm)
3 x 3mm MCP	0.016	0.2
Mini Channeltron®	0.51	12.5
Quantum™ MCP Detector	1.39	7.8
Spiraltron™	2.6	65
Microtron™	4.59	9
Mini TOF	10	15
MAGNUM®	26	35
RGA	25	25
Discrete Dynode Multiplier	35	100

consumption generally scales with detector size, decreasing as the detector gets smaller. The Quantum™ microchannel plate detector is the smallest ion detector ever built, measuring a mere 8mm in height (see *Figure 3*).

Time-of-flight Mass Spectrometry

Time-of-flight is the fastest growing mass spectrometry technique today. This technique separates ions of various masses by precisely measuring the amount of time it takes to traverse a fixed distance. This technique has become popular with instrument designers because it is not mass limited like ion trap and quadrupole instruments, and therefore is well suited for biological applications, incorporating large molecule samples. In addition, low-cost high-speed digitisers are now widely available along with very fast ion detectors incorporating microchannel plates. Ion detectors utilising small pore MCPs typically produce a single ion pulse width of less than 400ps (see *Figure 5*) When used in conjunction with high speed digitisers, the ions need not traverse great distances in order to be separated sufficiently for analysis.

To the instrument designer, this is a great windfall. High-speed, small detectors that are tolerant of operation in poor vacuum conditions enable the use of short flight tubes (cm, not meters) inside small vacuum housings at relatively poor vacuums. This results in a smaller, lower-cost vacuum system. Smaller vacuum systems consume less energy, and therefore further contribute to the portability of the instrument.

Miniature Channeltrons®

Miniature Channeltrons®, Spiraltron™ and Magnum® electron multipliers have continued to be reduced in size without sacrificing performance. These compact ion detectors are well suited for use in quadrupole, ion trap and magnetic sector mass spectrometers.

Miniature Channeltrons® are single-channel electron multipliers that can be formed in a variety of shapes and sizes. The cone collection area may be formed in a round (preferable for ion trap and quadrupole instruments) or rectangular shape for sector instruments. The gain of these ion detectors is adjustable up to 5 x 10^7 and can be operated in either analogue or pulse-counting modes. Miniature Channeltrons® operate well in vacuum conditions up to 5 x 10^{-5} Torr (see *Figure 6*).

Spiraltron™ electron multipliers consist of six independent multiplier channels twisted together and fed by a single collection cone. Collection cones may

Figure 4

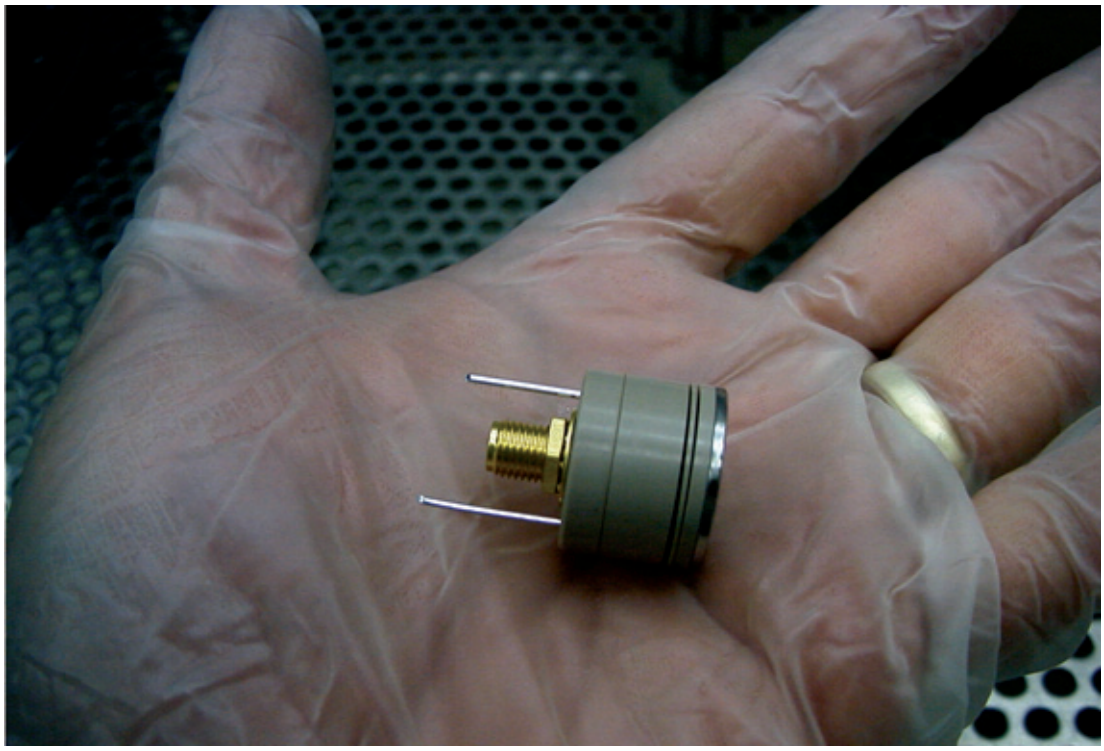
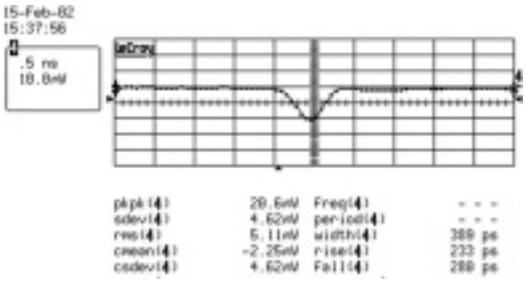


Figure 3: The Quantum™ Detector

Figure 5: Single Ion Pulse



be produced in any shape or size in order to optimise the collection efficiency.

Spiraltron™ electron multipliers can operate at gains in excess of 10^8 while producing less than one count per second noise. These electron multipliers demonstrate long lifetimes attributed to the generation of secondary electrons from the surface area of six channels instead of just one. Spiraltrons are capable of producing significantly higher linear output current (analogue operation) and linear count rate (pulse-counting mode) than conventional-sized single channel electron multipliers. These ion detectors also tolerate poor vacuum conditions and operate well to 5 x 10^{-4} Torr (see *Figure 7*).

MAGNUM® electron multipliers are a further refinement of the Spiraltron™ technology. The MAGNUM® also utilises the six-channel architecture to produce performance benefits similar to the Spiraltron™ products.

MAGNUM® electron multipliers are designed as rugged replacement cartridges that any end user can replace. The cartridge design enables the ion optics of the instrument to be reused throughout the lifetime on the instrument saving thousands of dollars in replacement costs (see *Figure 8*).

Conclusion

The ion detector is no longer the limiting factor in miniaturising field-portable mass spectrometers. BURLE has developed a complete line of miniature electron multipliers and they are in use today. Utilising single piece construction methods for Magnum® and Spiraltron™ have facilitated the development of an entire family of small, light weight multipliers that can be used in miniaturised mass spectrometers. These compact devices produce full-scale performance at a fraction of the size, weight and power consumption.

MCP-based detectors that have been reduced in size by as much as a factor of 10 are manufactured.

Figure 6: Miniature Channeltron®

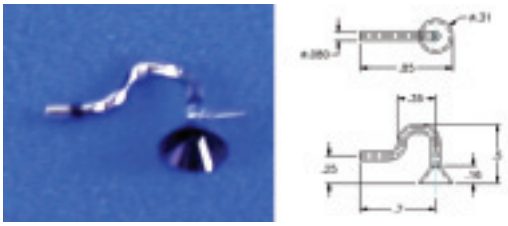


Figure 7: Spiraltrons™

Figure 8: MAGNUM® Electron Multipliers

The development of fastener-free assembly technology has facilitated the reduction in size and assembly time. Miniature MCP detectors operate well in magnetic fields, making them the ideal detector for small magnetic sector mass spectrometers.

Miniature time-of-flight detectors are produced that offer the improved temporal resolution at a fraction of the size and power consumption of standard detectors. This new generation of detectors can operate in poorer vacuum conditions, leading to miniaturisation of the vacuum systems and reduced vacuum pumping requirements. The high temporal resolution of this detector enables shorter flight tubes to be used, which in turn reduces the requirements on the vacuum system, enabling lower cost and more energy-efficient vacuum pumps to be used. Coaxial detectors (centre hole) further serve to reduce the size of the vacuum system by locating the ion source behind the detector.

Miniaturisation of electron multipliers is an enabling technology for miniature mass spectrometers. A complete line of miniature detectors has been introduced by BURLE Electro-Optics and is available for immediate introduction into the next generation of miniature mass spectrometers. ■