Raising the Bar on Electron Multiplier Operation at Elevated Pressures

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Abstract

Electron multipliers offer exceptional amplification properties with unsurpassed low noise behavior but traditionally these detectors have been restricted to high vacuum environments. The ability to expand the use of these types of detectors to high pressure applications provides an opportunity for weight, cost, and power reduction for existing instrumentation. Further, it may serve as an enabling technology for applications where low signals need to be measured at high pressure.

This work explores the boundaries of electron multiplication for amplification at pressures above 1 x 10^{-4} torr. Using gain, voltage and dark current measurements in differing multiplier geometries, the maximum operating pressure as a function of voltage and detector gain is presented. In addition, we examine how parameters such as gas density, path length and spiral channel configuration combine to determine the conditions under which an electron multiplier can be operated.

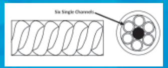
Introduction

The increasing interest in high pressure applications has resulted in the need for small ion detectors capable of operating without sophisticated vacuum pump technology. PHOTONIS USA has developed a miniaturized channel electron multiplier that can deliver high performance at pressures up to 10^{-2} torr.

The MegaSpiraltron™ detector is a physically small, robust ion detector that can achieve high gain while maintaining low noise. These detectors have a compact, durable design and are only 1.35” long and 0.6” in diameter making them an excellent choice for portable instrumentation.

The multi-channel configuration provides a six-fold increase in surface area compared to single channel electron multipliers leading to longer life. The internal spiral structure facilitates low noise performance by significantly reducing the ion feedback typically generated from the high concentration of residual gas molecules in high pressure environments.

The spiral section of the detector consists of six single channels which are twisted – barber pole fashion – around a solid center. This geometry results in effectively six times the output surface area and, in addition, allows a straight channel geometry since the curvature preventing ion feedback is accomplished internally. This dramatically increases detector life and dynamic range. In addition, the number of spiral turns per inch can be varied.



The ability to operate in poor vacuum was determined by measuring the background noise or dark current at various pressure intervals. The operational condition was considered valid when the dark current was in the 10^{-12} amp range. Once the dark current reached the 10^{-6} amp range, the multiplier was considered to be inoperable under the test conditions.

Background

Although channel electron multipliers are known for their rugged and compact physical characteristics, high pressure operation is not restricted to these multipliers. Previous work has shown that microchannel plate based ion detectors operate quietly under high pressures.

The MCP based detector for an XPR RGA instrument shown in Figure 1 routinely operates between 10-30 millitorr at a gain of 5,000. The 25 mm, 5 micron pore Chevron with a metal anode read-out has also demonstrated the ability to operate at elevated pressure.

Figure 2 shows the background noise as measured in counts per second as a function of pressure demonstrating that the microchannel plate detector can operate effectively up to 1 x 10^{-2} torr.

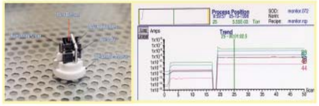


Figure 1. XPR Microchannel Plate Detector and Signal Output at 5.5 Millitorr

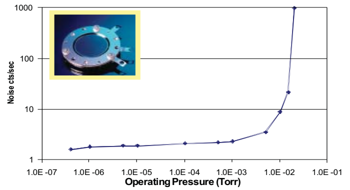


Figure 2. Five Micron Pore Chevron MCP Detector Noise as a Function of Pressure

Experimental Procedure

The MegaSpiraltron detector was characterized in a vacuum test chamber equipped with a BOC Edwards turbo-molecular pump. Vacuum measurements were made using both a BOC Edwards WRG-SL wide range gauge and a Granville-Phillips series 275 convectron gauge. Gain measurements were obtained at 10^{-7} torr with positively charged residual gas ions generated by an electron gun. A Bertan model 2005-03 high voltage power supply was negatively biased and connected to the detector input. The signal was collected and analyzed using Canberra Genie 2000 v.3.1 Spectroscopy software and Multiport II Multichannel Analyzer.

For the elevated pressure measurements, the detector anode was connected to a Keithley model 485 picoammeter to determine the dark current. The chamber pressure was increased using a Granville-Phillips Model 203 precision variable leak valve to introduce dry nitrogen. The convectron and wide range gauges were located adjacent to the detectors being tested.

Results

Figure 3 shows the operating voltage of the MegaSpiraltron as a function of pressure. The successful operation indicates that the dark current remained in the 10^{-12} amp range.

As the multiplier voltage is increased, the onset of ion feedback caused the dark current to increase suddenly to several microamps.

At this point, the multiplier was no longer able to function effectively. Thus, a boundary of operation has been established for the MegaSpiraltron detector.

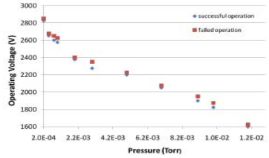


Figure 3. Boundary of High Pressure Operation for the MegaSpiraltron Electron Multiplier

Figure 4 is a comparison of the successful operation of the MegaSpiraltron multipliers of two different path lengths and spiral configurations. The overall length of the multipliers was the same. However, one detector had a channel configuration of 5 spiral turns per inch resulting in a longer path length while the other had 3 spiral turns per inch resulting in a relatively shorter path length.

Data were also collected for a conventional single channel electron multiplier, model 4822 for comparison. It can easily be seen that the maximum operating voltage of the MegaSpiraltron models is significantly higher than that of the conventional curved single channel multiplier.

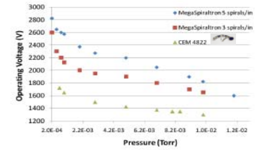


Figure 4. Comparison of Maximum Operating Voltage for MegaSpiraltron Detectors of Different Path Lengths and a Conventional Electron Multiplier

The maximum operating voltage for the higher gain, shorter path length MegaSpiraltron detector was found to be somewhat lower than the longer path length, lower gain MegaSpiraltron detector. When the electric field strength is estimated for these two MegaSpiraltron detectors and plotted as a function of pressure, Figure 5 shows that the relationship is nearly the same. Thus, it appears that a breakdown in the electric field within the channels of the multipliers cannot be eliminated as a factor in determining the high pressure performance.

Results

However, the field strength of the 4822 multiplier with its much longer channel is lower than that of the MegaSpiraltron designs. Since the 4822 detector fails at much lower pressure levels, it suggests that the electric field strength is not the dominant mechanism but may still be a factor.

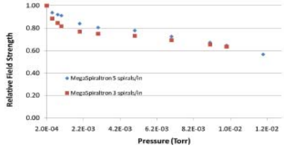


Figure 5. Relative Electric Field Strength for MegaSpiraltron Detectors of Different Path Lengths

Figure 6 illustrates the typical gain curves for the MegaSpiraltron detectors and the single channel electron multiplier. Gain values below 10^6 are extrapolated due to the greater uncertainty in measuring relatively low gain levels. The CEM 4822 is designed for high gain, pulse-counting applications.

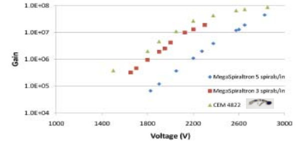


Figure 6. Gain Curves for MegaSpiraltron and Conventional Channel Electron Multipliers

Figure 7 illustrates the gain-pressure relationship for the MegaSpiraltron detectors and the CEM 4822 single channel electron multiplier. It is evident that the MegaSpiraltron detectors can achieve a higher gain at elevated pressures compared to the conventional multiplier.

Further, the MegaSpiraltron detectors exhibit nearly the same high pressure performance despite the difference in path length and spiral configuration. Thus, the gain can determine the maximum safe operating pressure of the detector.

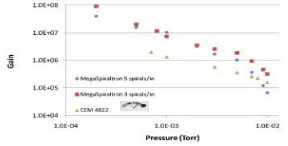


Figure 7. Pressure-Gain Relationship for MegaSpiraltron and Conventional Electron Multipliers

Conclusion

MegaSpiraltron multipliers were characterized in poor vacuum environments demonstrating their ability to operate effectively. This makes them an excellent choice for portable instrumentation and other high pressure applications. The boundaries of successful operation were defined as a function of voltage and gain.

Operation at a million gain can be achieved in a rough vacuum. The performance of the MegaSpiraltron design when directly compared to a traditional channel electron multiplier was significantly better at elevated pressures.

It can be concluded that the channel geometry is the most important factor responsible for the unsurpassed high pressure performance of the MegaSpiraltron detectors. Further, the gain requirement for a given application dictates the pressure region where the multiplier may be successfully operated.

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