High Dynamic Range Ion Detection Using Channel Electron Multipliers

Paul Mitchell, Stephen Ritzau, Ph.D. and Lenny Erickson, PHOTONIS USA, Sturbridge, MA

PHOTONIS | INDUSTRY | SCIENCE | MEDICAL

Overview:

Purpose:

Channel electron multipliers (CEMs) have widespread use in mass spectrometers due to their high sensitivity and small size. However, the voltage gradient inside the channel is not stable at high output current, limiting the dynamic range.

- CEMs are well suited to the addition of discrete-dynode sections to permit higher current output levels.
- The overall size of the detector can remain physically small, while extending the dynamic range of the instrument.
- The combination of a six-channel CEM and the enlarged dynode active area will lengthen the operating life of the detector, when compared to a single channel CEM.

Methods:

The improved design is based on combining a six channel CEM with a new three stage electron multiplier having discrete sections with circular symmetry. Each discrete dynode section is biased separately, preventing the voltage redistribution and gain loss at high output currents that occurs with the CEM alone. The surface area of the electron multiplier was increased substantially to lessen the influence of gain-spoiling contamination during use in mass spectrometers.

Results:

- The linear range is extended beyond the range of the CEM by the amount of gain included in the added stages of discrete dynodes.
- The life expectancy is improved by use of a large active area on the last stage, made possible by the circular symmetrical electron optical layout of the dynodes.
- The size remains small since most of the gain is achieved in the compact spirals of the six-channel CEM.
- The added stages of discrete dynode elements do not compromise the speed of response.

Introduction:

CEM with Discrete Dynodes:

Previous work by Laprade, Cochran and Labich[1] has shown the improved linearity performance of hybrid MCP and CEM-based detectors. In 1997, a two-stage MCP-dynode detector demonstrated linear output current capability in excess of 120 µA.

Later work performed by Laprade and Cochran[2] produced two-stage analog and pulse-counting CEMs utilizing materials processing changes in the fabrication of the reduced silicate glass. (Figure 1) The analog CEM design demonstrated a linear output current approaching 100 µA. The pulse-counting version provided a maximum count rate capability of over 10 million counts per second.

Introduction (continued):

Figure 1. Two-stage analog CEM (PHOTONIS model 5778).

A problem occurs when the current at the anode end becomes large enough to influence the bias voltage gradient within the channel. If a large current flowing inside the pore is diverted by secondary emission into the vacuum space and ultimately out of the pore and onto the anode, the voltage gradient will drop at the output region and cause a nonlinear result.

The linear range of the CEM is limited to 10 to 15 percent of the current flow created by the bias voltage because of the inability to limit the voltage change along the length of the channel. The present approach is to reduce the resistance of the channel. As the bias current flow increases, more heat generation will occur and ultimately limit the maximum linear range to a few tens of microamperes.

In this paper, we present a solution to this problem in which discrete dynodes are used to increase the gain and the maximum operating current achievable. This approach is effective because each step of the multiplication process is biased separately with a robust voltage source. The linear range of the modified CEM detector is increased by the level of gain added by the discrete dynodes.

Methods:

The technical challenges are to:

- Address the limited gain from secondary emission in a demountable dynode set;
- Focus the electrons exiting at wide angles and energies from the CEM;
- Avoid large structures in order to maintain the small footprint.

Secondary Emission:

In keeping with a limited increase in operating voltages, the discrete dynode approach is constrained to three dynodes. The added gain should extend the useful, linear range by about ten times or approximately 100 µA of output current. The materials used should have good stability against the higher operating current. The gain per stage needs to be 2.2 times with as little loss in collection as possible.

Figure 2 shows results for various sputtered materials as well as native oxide of aluminum. While it is clear that the first trial needs improvement, more information concerning gain and life will be needed to select the best material.

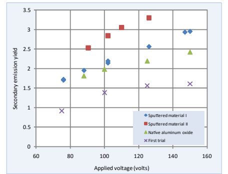


Figure 2. Secondary emission yield of candidate materials for dynodes.

Methods (continued):

CEM Electron Output:

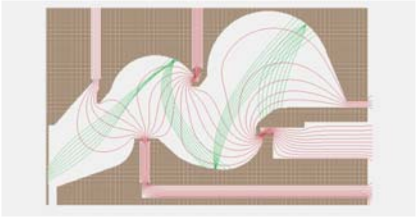
The output pattern of the CEM was imaged on a phosphor screen and measured for angular distribution as shown in Figure 3. The angle of the higher energy electrons is 45 degrees with respect to the axis and shows in the figure as "hot spots". Such high energy electrons leaving the six-channel CEM would be difficult to focus. A new structure was needed to accommodate these electrons.

Figure 3. Image of electron output of CEM showing grouping of the six-channel pattern.

Discrete Dynode Structure:

It was decided to solve this problem by creating donut-shaped structures with an interlocking technique – similar to the standard, linear-focused shape used in photomultiplier tubes[3]. Instead of having a linear extension, the shape was made circular. A slice of the dynode set is shown in Figure 4.

Figure 4. Radial slice of the new dynode configuration with the axis along the lower edge. Potential lines are shown using 100 volts per stage using red lines. Electron trajectories are shown using green lines starting at the exit point of the CEM at the left and moving to the anode at the right. Note the large active surface at the last dynode that will extend operating life.



By utilizing a shape with circular symmetry, the collection efficiency of the electrons leaving the CEM can be much improved. This is aided by surrounding the exit pores with deflectors. In addition, the circular shape allows the final dynode to be significantly larger to increase life expectancy without compromising the overall size of the assembly.

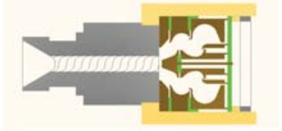
Results:

The ideas presented here were used to make a trial detector assembly using a standard CEM (PHOTONIS Magnum® 5902) with aluminum dynodes cut according to the electro-optical result from Figure 4. The configuration is shown in Figure 5.

Results (continued):

The green box in Figure 5 represents the circuit board that holds the bias resistors and de-coupling capacitors. There are plans for two bias voltages to be used for normal operation – a voltage for the set of dynodes and another voltage for the CEM.

Figure 5. Overall layout of CEM with three stages of discrete dynode multiplication showing the CEM in grey and outer and inner focus pieces followed by dynodes one through three. Overall size of the trial piece is 44.3 mm by 22.8 mm.



The detector was operated in vacuum with ion and electron sources to measure gain and linearity. It was found that the gain with the trial unit was low but enabled some initial measurements. It was found that dynode shapes taken from the electron optical study were quite accurate – only the deflector voltage needed adjustment of 5 volts down at 400 volts.

The next steps will include the measurement of linearity and stability against high currents and over extended operating time.

Conclusions:

The principle difficulties encountered in getting significantly larger output current from the CEM has been solved by:

- Adding three discrete dynodes to the structure;
- Incorporating a new dynode structure to gain surface area without size increase.

Figure 6. View of second dynode surrounded by the third dynode with the CEM and dynode one removed.

Future work will center on:

- Measuring the linearity and life time data;
- Adjusting the CEM length to match the required gain;
- Selecting the secondary emissive surface for best gain and life.

References:

1. Laprade, Cochran and Labich (1997). *Performance Characterization of a High Dynamic Range Hybrid Detector for Inductively Coupled Plasmas Mass Spectroscopy (ICPMS).* Galileo Corporation (USA). Presented at ASMS 1997, Poster 1523P.
2. Laprade and Cochran (1998). *A High Dynamic Range, Single Channel Electron Multiplier for Mass Spectrometry Applications.* BURLE Electro-Optics (USA). Presented at Pittcon 1998.
3. Flyckt and Marmonier (2002). *Photomultiplier Tubes: Principles and Applications.* PHOTONIS.

Acknowledgements:

The authors greatly appreciate the support of the production and engineering staff at PHOTONIS who helped our progress in this work.