Electron Multipliers
for 2000 and Beyond

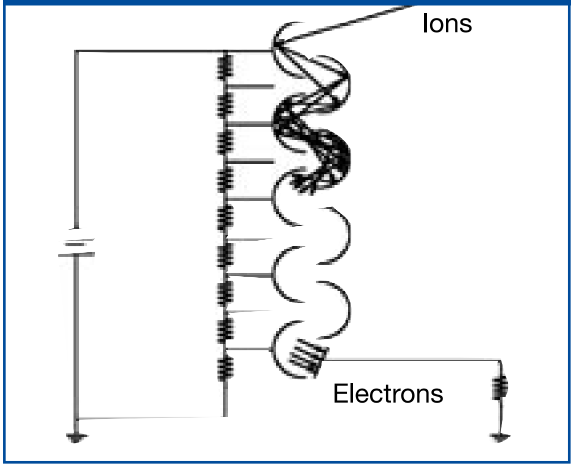
Discrete-Dynode Technology Comes Of Age

Electron multipliers have been widely used as detectors of charged particles and high-energy photons in analytical instrumentation for over thirty years. Their basic function of detection and amplification of very small signals remains virtually unchanged since the beginning. Modern computer design techniques, however, as well as advancements in materials and manufacturing have enabled development of extremely sensitive yet rugged devices vital to the performance of today's mass spectrometers and other analytical instruments.

THE NEED FOR DEVELOPMENT

The first electron multipliers used in mass spectrometers consisted of a number of discrete stages or dynodes, usually fabricated from beryllium-copper (BeCu) alloy.[1,2] Each dynode stage acts as a separate amplifying element; the total number of stages determines the maximum gain of the device. A bias voltage is applied to accelerate the secondary electrons down the dynode stages via a discrete resistor chain (see **Figure 1**). This configuration allows devices to handle large linear output currents that are necessary in many applications. BeCu was used because of its good secondary emission properties; however, it has the disadvantage of being unstable when exposed to atmosphere. Early detectors performed well as long as the instrument was kept under vacuum, but elaborate precautions were necessary when the instrument was vented (when changing filaments or columns in GC-MS instruments, for example) to minimize degradation of performance. In addition, early designs were inefficient both in their ability to collect all of the ion signal from the analyzer and in the amplification process itself. Sensitivity was relatively poor and fabrication of devices with high gain for pulse-counting applications was difficult.

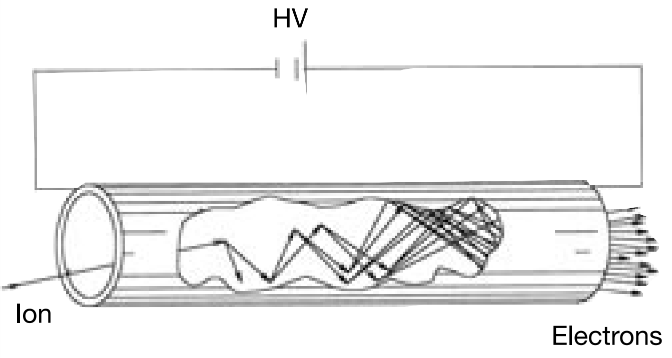
Figure 1 - Discrete-dynode electron multiplier



Channel electron multipliers (CEMs) were developed in the late 1960s and introduced to commercial scientific equipment in the mid-1970s. CEMs consist of a glass tube fabricated from a lead-silicate glass having the properties of secondary electron emission and, when appropriately processed, electrical conductivity.[3]) Secondary emission occurs from a thin silica-rich (SiO_2) layer on the surface of the glass tube. These devices integrate the resistor-divider network with the "continuous"-dynode stages (see **Figure 2**) and thus can be made very compact. They have the additional advantages of high gain capability and of being reasonably stable when exposed to atmosphere, which made them preferable to the BeCu devices. Until recently, CEMs have dominated the mass spectrometer electron multiplier market.

The major problems with CEM detectors are their relatively low linear output current capability and often-erratic performance from device to device. Recent products have sought to address these problems through development of higher conductivity materials and depositing the lead-silicate glass on a monolithic ceramic substrate or even encapsulating a glass tube within a ceramic housing. While the latter two solutions have the advantage of being very compact, CEMs still suffer from saturation effects leading to nonlinear output. This can be a serious problem when analyzing high concentration samples, or attempting to analyze samples over a wide concentration range without repeated calibration of equipment. In addition, the glass material used in these devices is difficult to process consistently. Each batch of glass may have slightly different properties, which requires continual monitoring and changes to process parameters. This can result in wide variability between devices.

Figure 2 - Continuous-dynode electron multiplier



ADVANCED DISCRETE-DYNODE DETECTORS

ACTIVE FILM Multipliers™ are the latest development in electron multiplier technology. Taking advantage of new design techniques, advanced materials research, and the inherent advantages of discrete-dynode geometry, new devices are capable not only of integrating the advantages of both older BeCu devices and CEMs, but also of providing total performance impossible to obtain with older technologies.

One of the most significant advances in recent detectors is the incorporation of specially processed aluminum oxide (Al_2O_3) materials as the active, secondary emissive surface. Al_2O_3 has superior secondary emission properties as well as the advantage of being absolutely air-stable and extremely resistant to corrosive atmospheres. This, combined with advanced computer design techniques, has facilitated development of detectors able to take full advantage of modern instrument capabilities.

ION OPTICS – DESIGNED FOR EFFICIENCY

Early discrete-dynode multipliers were designed using crude mechanical analogs such as rubber membranes and metal balls. The resultant structures were functional but not very efficient. Design of CEM-based detectors was little better, since the structure of most CEMs is not amenable to the precise geometrical positioning required to maximize ion collection efficiency and signal-to-noise performance.

Over fifteen years of continuous effort have resulted in a sophisticated computer design program specifically targeted at the design and development of electron multipliers. **Figure 3** shows a simulation from the design software depicting the input optics of a typical detector developed for a quadrupole analyzer. Critical parameters incorporated in the design include ion exit energies and angles, as well as the desired mass detection range. Similar calculations are used to optimize coupling between successive dynode stages. Results of the ion/electron optics simulations can then be integrated into standard CAD software to insure the precision and uniformity of the product. **Figure 4** illustrates a plot of detection uniformity over the aperture of a typical ***ACTIVE FILM Multiplier*™.**

Figure 3 - Result of Ion Optics simulation

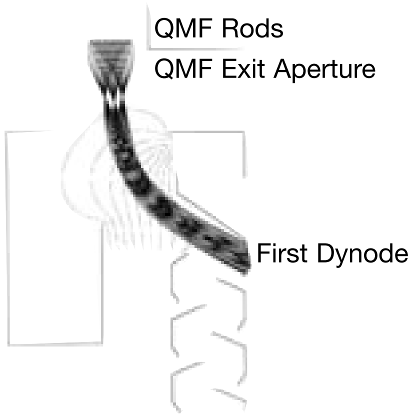
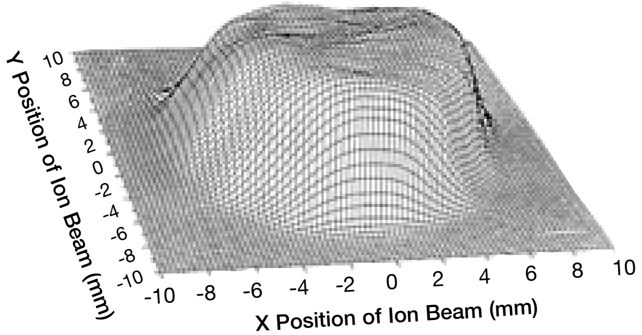


Figure 4 - Multiplier output response as a function of input beam position



DISCRETE BENEFITS

In contrast to CEMs, each element of a discrete-dynode multiplier may be independently optimized to ensure maximum overall device performance. CEMs, because of their inherently integrated structure, often compromise various performance parameters since changing the process to alter one parameter (e.g. gain, resistance, etc.) may affect others as well.

Discrete-dynode electron multipliers may incorporate dynodes of different shapes and materials to optimize performance throughout the detector. For example, special "ion baffle" dynodes are used to eliminate ion feedback (a source of noise) in the high gain section of the device. Also, recent advances have shown that different materials should be used for different stages for best performance.[4]) Important factors to consider in the selection of materials are the electron flux incident on the dynode and the consequent rate of surface contamination (which leads to gain reduction over time). **Table 1** shows results of recent research into the different operational requirements for dynodes used in different locations of the multiplier. [5])

ACTIVE FILM Multipliers™ incorporate dynodes with very large active surface area to achieve maximum lifetime of the detector. All things being equal, the larger the active surface area, the longer the lifetime. In general, discrete-dynode detectors have 4x – 10x the active surface area of a typical CEM detector. **Figure 5** shows a schematic representation of a typical ACTIVE FILM Multiplier optimized for use in a quadrupole instrument.

Table 1 - Dynode operational requirements vs. position

Dynode Position	Important Functional characteristics
First:	High Ion-to-electron conversion efficiency
Front end:	High gain, exposure to low electron flux
Middle:	High gain, exposure to moderate electron flux, increased gain stability required
Output-end:	Maximum gain stability, exposure to high electron flux

CONCLUSION

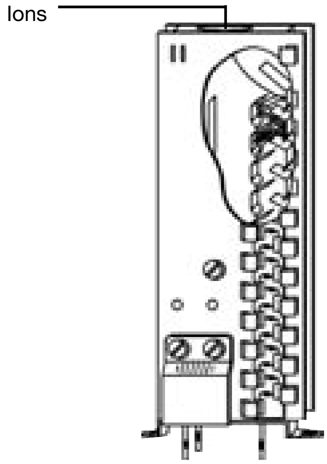
Modern discrete-dynode electron multipliers incorporating Al_2O_3 materials are far superior to the original BeCu devices. They also exhibit significant advantages in sensitivity, dynamic range, and overall robustness over CEM devices which today universally use SiO_2 as the secondary emissive surface.

Discrete-dynode technology allows independent variation of performance parameters to optimize detectors for a given application or instrument. Altering one design criterion (dynode surface area, for example) does not necessarily affect any other, as is frequently the case with CEM-based detectors. Current state-of-the-art detectors can be individually tailored to customer's increasingly demanding specifications.

New research directions are focused on incorporating different materials at different locations of the dynode chain and at further enhancing sensitivity via advanced ion optics and conversion dynode technology. Although current devices outperform their predecessors, the technology is clearly still in its infancy with many advances to come.

REFERENCES

Figure 5 - Typical *ACTIVE FILM Multiplier™*



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5. Hunter, Dr. Kevin L. and Dick Stresau, Breaking the Rules of Traditional Multiplier Design, A Key to Improved Performance, presented at the 2000 Winter Conference on Plasma Spectrochemistry.