



The Development Of An Improved Electron Multiplier For Mass Spectroscopy Applications

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Electron multipliers are used in a wide variety of analytical instruments to detect weak signals from ions, electrons, and UV photons. These analytical instruments include Gas and Liquid Chromatography Mass Spectrometers (GC or LC MS), Matrix Assisted Time of Flight Mass Spectrometers (MALDI-TOF), Residual Gas Analyzers (RGA), Electron Spectroscopy and Scanning Electron Microscopy (Auger and SEM). These machines are designed to assist in the identification of unknown materials, in some cases detecting contaminants down to the parts-per-billion level. The most common type of detector is the Channel Electron Multiplier (CEM). The engineers at Burle Electro Optics have developed a new electron multiplier (MAGNUM® Electron Multiplier) which provides significantly improved performance by increasing linear output current, reducing noise, and increasing detector life.

BACKGROUND

The development of electron multipliers can be traced to the discovery that some materials will give off significant numbers of secondary electrons when bombarded with high energy charged particles. Physicists quickly began to fabricate analytical instruments using detectors with multiple collision stage devices incorporating treated metal surfaces (dynodes) in order to modestly amplify (factors of 3 - 10) the weak signals.

In the 1950s, engineers at the Bendix Research Labs in Ann Arbor Michigan (later Galileo Corp., now BURLE Electro-Optics, Inc.) began experimenting with the use of alkali doped lead glass as the multiplication surface. Hailed as a significant breakthrough at the time, these materials, unlike the discrete dynodes of the time, maintained their secondary electron emission properties even when cycled to atmospheric pressure, a scenario which would render treated metal dynodes useless. These devices quickly evolved from parallel plate continuous multipliers, known as magnetic electron multipliers (MEMs), in which a magnetic and electric field was used to advance the cascading electrons to the anode, to a conductive lead glass tube, eliminating the need for the magnetic field.

Modern day devices are known as Single Channel Electron Multipliers (SCEMs), with Channeltron™ the most widely recognized brand name. Figure 1 illustrates the variety of models available today.

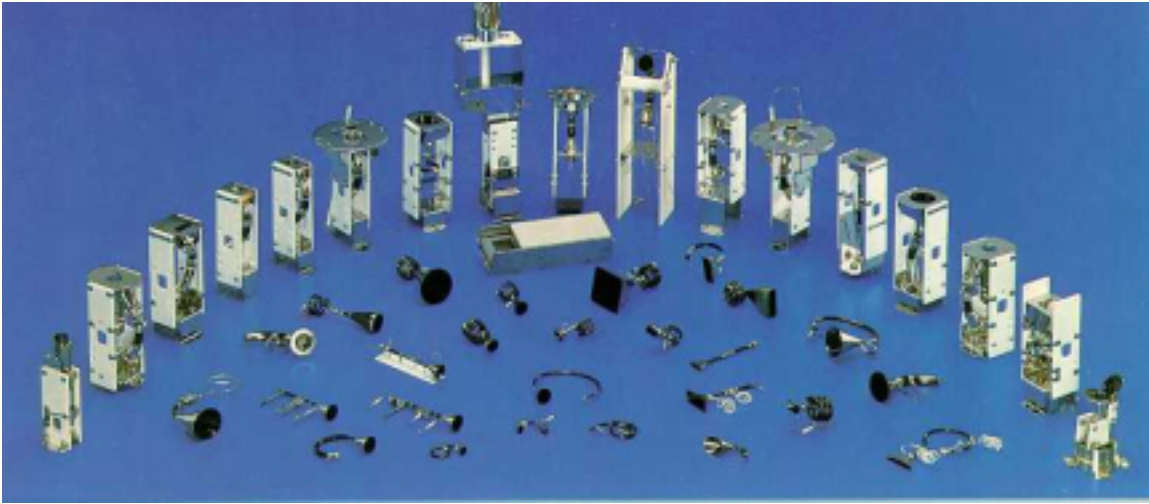


Figure 1 - A wide variety of Channeltron® Electron Multipliers are available from Burle Electro-Optics

PRINCIPLE OF OPERATION

In a typical application for an electron multiplier, a charged particle or energetic photon will impinge upon the input surface of the multiplier causing several secondary electrons to be ejected into the vacuum space. Alkali dopants within the emissive layer lower the work function of the surface leading to increased secondary emission. As the secondary electrons travel down the channel, they will repeatedly collide with the channel wall, producing still more secondary electrons. The electrons are accelerated towards the anode end of the channel by the ever increasing positive potential within the channel produced by the resistive lead glass layer beneath the emissive layer. This process will be repeated until the resulting cloud of electrons exits the channel and is collected by the anode. (See Figure 2)

Varying the voltage across the device will both alter the electron trajectory and the number of secondary electrons produced per strike. In this manner, the gain of the device can be infinitely varied. Proper biasing of the device can result in a single ion, impinging on the input side of the device, producing up to 100,000,000 electrons at the anode.

There are, however, several factors which limit the use of the CEM: output current; detector life; and noise. The maximum linear output current which the device can produce is limited by the charge stored within the channel wall and the recharge time of the channel. The channel can be modeled as an RC (resistor/capacitor) network and once the channel gives up the stored charge, it must be replenished by current flowing in the conductive layer. The larger the quantity of charge depleted during the multiplication process, the longer the effective dead time of the channel.

Unfortunately, electron multipliers have a limited life. Multiplier lifetime is an important performance parameter. It is common for multiplier gain to decrease with usage, requiring periodic voltage adjustments to bring the gain back up to the instrument sensitivity requirement.

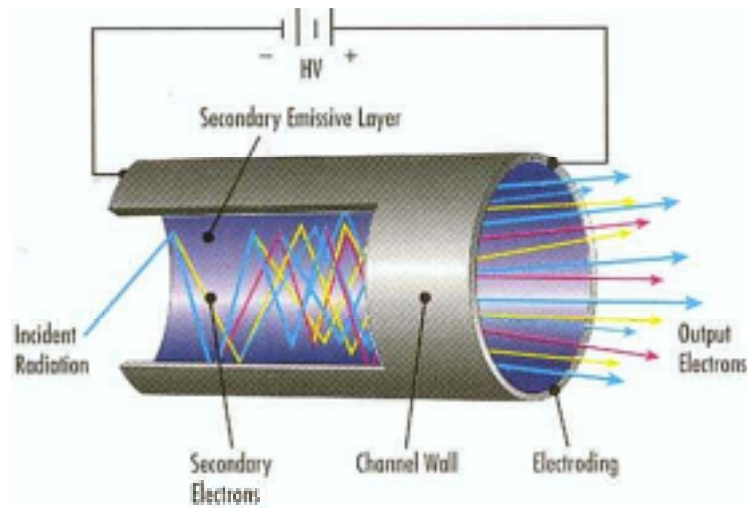


Figure 2 - The Multiplication Process in a Channel Electron Multiplier

Eventually the voltage can not be increased further, necessitating the replacement of the multiplier. In most instruments, multiplier replacement requires the machine to be off line for between 4 - 24 hours. Today, most instruments require the multiplier to be changed at intervals ranging between 3 months to 2 years depending on the application.

Consequently, long multiplier life, resulting in less frequent detector changes, is a very desirable characteristic. The initial detector gain also has an effect on the ultimate life of the multiplier. If the initial gain is comparatively high, the voltage required to operate the instrument will be proportionally lower. This lower initial voltage setting allows the instrument a much greater range in which to compensate for the subsequent, inevitable decline in detector gain.

Multiplier fatigue, characterized as a reduction in gain with use, has two principle mechanisms. The first is caused by radiolytic damage to the emissive surface from the constant bombardment by secondary electrons. The degradation comes in the form of depleted alkali from the emissive surface and in some cases the emissive surface will be sputtered away altogether. The damage is proportional to the amount of charge extracted from the channel per unit area. Consequently, increasing the effective channel area will increase detector life.

A second mechanism for multiplier fatigue is coating of the secondary emissive surface by contaminants within the vacuum environment. The cleanliness of the environment tends to vary by application and analytical technique.

Finally, the detector signal-to-noise ration may limit the ability to detect low level signals. Ion feedback is a significant contributor to detector noise. Ion feedback occurs when a residual gas molecule within the multiplier channel becomes ionized from the electric field. The resultant ion will then be accelerated in the opposite direction of a secondary electron, eventually colliding with the channel wall. If the ion has attained sufficient energy prior to collision, it will yield secondary electrons upon impact with the channel

wall. The liberated secondary electrons will then cascade down the channel and produce an output signal which is not based upon any true input event.

NEW DEVELOPMENTS

Higher dynamic range, lower noise, lower cost, and reduced size, in addition to the ability to operate in poorer vacuums, are just some of the requirements of the analytical instrument industry.

A revolutionary new multiplier has been developed by Burle Electro-Optics to meet the challenge of current and future instrument designs. The MAGNUM® Electron Multiplier™ (Figure 3) consists of six helical multiplier channels tightly wound about a central axis. The six channels are connected on the input side of the device by a single, integral collection cone. The six multiplier channels feed a single anode, which collects and integrates the charge from the channels into one output signal. (Figure 4).



Figure 3- MAGNUM® Electron Multiplier

This multiplier is fabricated from a glass preform which is twisted while simultaneously being drawn to the final dimensions. This intricate process yields the solid glass blanks which are then machined to produce the integral cone and final envelope configuration.

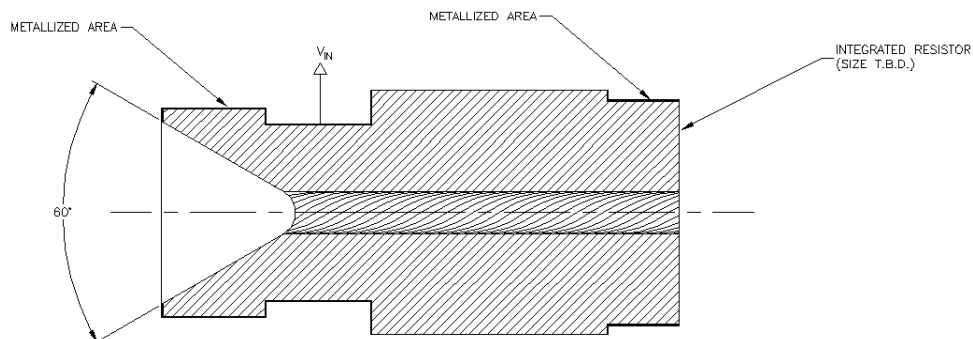


Figure 4- MAGNUM® Electron Multiplier Cross Section

This unique manufacturing process means that this multiplier can be produced far more economically than conventional multipliers.

The aspect ratios used for the six channels are numerically similar to other Channeltron® products and therefore a gain/voltage curve with a steep slope is achieved. The tight radius of curvature used in the spiraling of the six channels helps prevent the onset of ion feedback, enabling the multiplier to operate in poor vacuums at reduced noise levels. In addition, the spiraling of the channels enables the proper aspect ratio channel to be packaged in a shorter or lower profile device. Winding the channels about a central core also enables the multiplier to be operated on axis, enabling instrument designers to make considerably smaller (less expensive) vacuum housings. The large integral cone collector ensures that all the available signal ions are collected.

The MAGNUM® has two characteristics which improve the linear output current and dynamic range performance. First, the Magnum® produces gain with six channels, not the conventional single channel. As a result, the total charge drawn from each individual channel is reduced, therefore raising the maximum linear output current level. Additionally, the MAGNUM® incorporates a special Extended Dynamic Range (EDR) feature which effectively causes the channels to recharge at a rate nearly 10 times faster than conventional devices. Figure 5 demonstrates the actual, measured difference in the maximum linear output current produced by the MAGNUM® versus similar single channel devices.

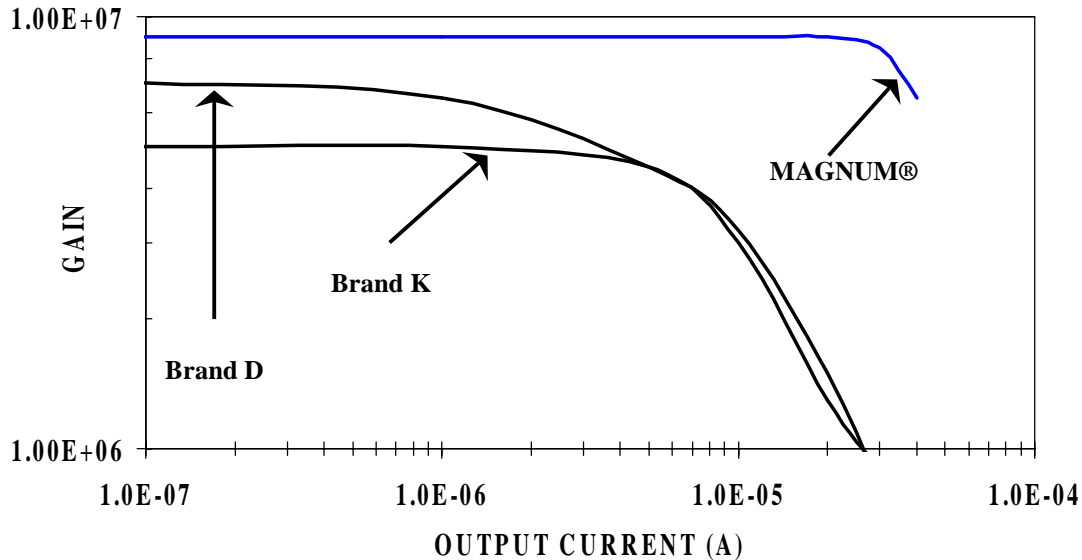


Figure 5- Linear output current comparison

The background noise produced by the MAGNUM® is also quite low, due to the use of proprietary glass forming techniques and the efficient suppression of ion feedback noise

by the extreme channel radius of curvature inherent in the spiral design (Figure 6). The spiral design also enables the detector to tolerate poor vacuum conditions.

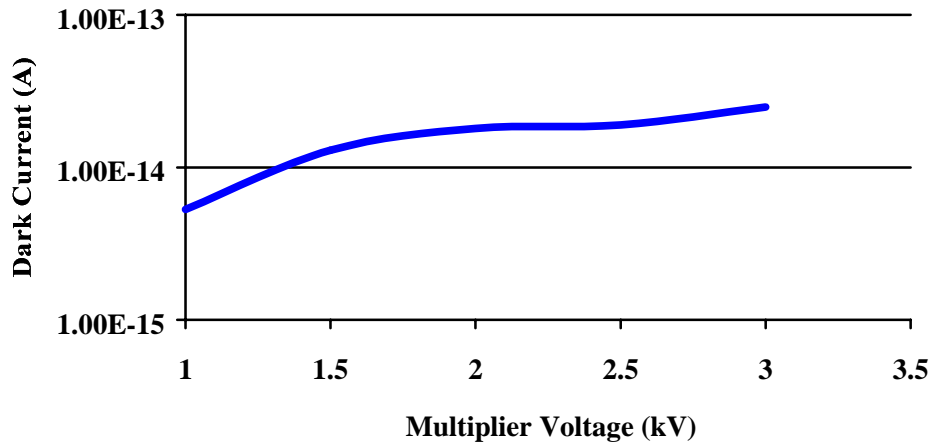


Figure 6 - Typical multiplier noise

Multiplier fatigue characterized as a reduction in gain has also been reduced. Because detector life is proportional to total channel surface area, distributing the extracted charge over six times the area, will yield a proportional increase in the lifetime. In addition, the MAGNUM® provides substantially greater gain at any given voltage (Figure 7). This results in the initial bias voltage setting being lower and the instrument power supply can subsequently compensate for a greater decline in gain before the detector must be replaced. Tests are currently underway in a number of different applications to assess the actual increase in detector life.

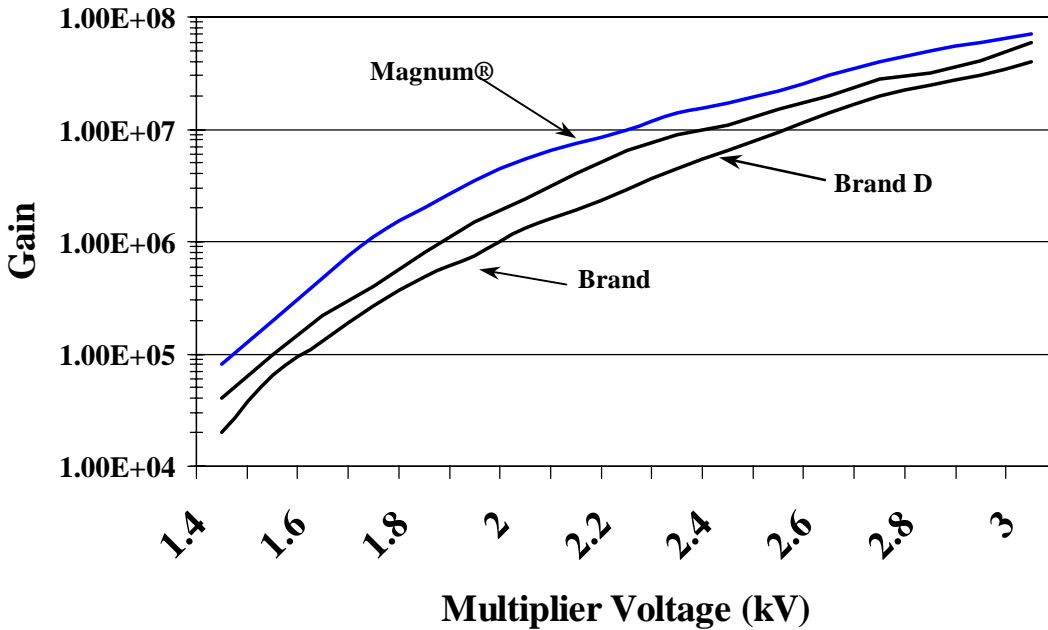


Figure 7 - Multiplier gain comparison

In conclusion, a new style electron multiplier has been developed incorporating a novel multi-channel architecture. This compact device has demonstrated higher gain, lower noise, and superior linear output current capabilities. This device is tolerant of poor vacuum conditions and holds the promise of longer detector life and reduced operating costs. The simplified manufacturing process has resulted in lower manufacturing costs and lower procurement costs for the users. The compact on axis design will facilitate the development of new miniaturized instruments.