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TECHNICAL ARTICLE

EXTENDING THE LIMITS FOR LINEAR ION COUNTING

An Electron Multiplier for High Count Rate Mass Spectrometry

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INTRODUCTION

As a result of current trends in mass spectrometry, ETP is frequently asked for electron multipliers with increasingly higher count rate capabilities. In response to this demand we have developed, and now manufacture, a multiplier capable of linear ion counting to 20MHz and an ultimate count rate capability of 50MHz.

We will begin by discussing the basic characteristics required by a high count rate electron multiplier;describe the performance we've achieved with each of these characteristics; then discuss how they relate to the high count rate capability of the multiplier we have developed.

Four different characteristics stand out as important for achieving high count rate with an electron multiplier:

- The output pulse width and multiplier dead time determine the minimum time interval between any two output pulses from a multiplier. These parameters place an absolute upper limit on count rate.
- Linear response at high output currents - At very high count rates the large associated output current causes a gain shift in the multiplier which results in non-linear response to input ions. This is the mechanism that usually limits the upper count rate for pulse counting multipliers.
- And finally, a narrow output height distribution which is important for optimizing a multipliers detection efficiency and maintaining the system's detection stability.

Usually, a trade-off between these characteristics limits a multiplier's count rate performance. However, the flexibility offered by a discrete dynode multiplier technology has enabled us to make major advances in these areas without compromising other performance parameters.

The techniques that I will describe have been used to achieve high count rate performance for several different versions including multipliers quadrupoles, ICP-MS and magnetic sector systems.

RESULTS

First we'll take a look at the output pulse shape from the multiplier. From figure 1 it can be seen that, at the base line, the pulse is approximately 8 nanoseconds wide. Active film Multipliers have no dead time other than the time required for a pulse to fall below the system's discriminator level. This pulse width represents a basic limit to the pulse pair resolution of the multiplier and hence the upper limit of instantaneous count rate is 125MHz.

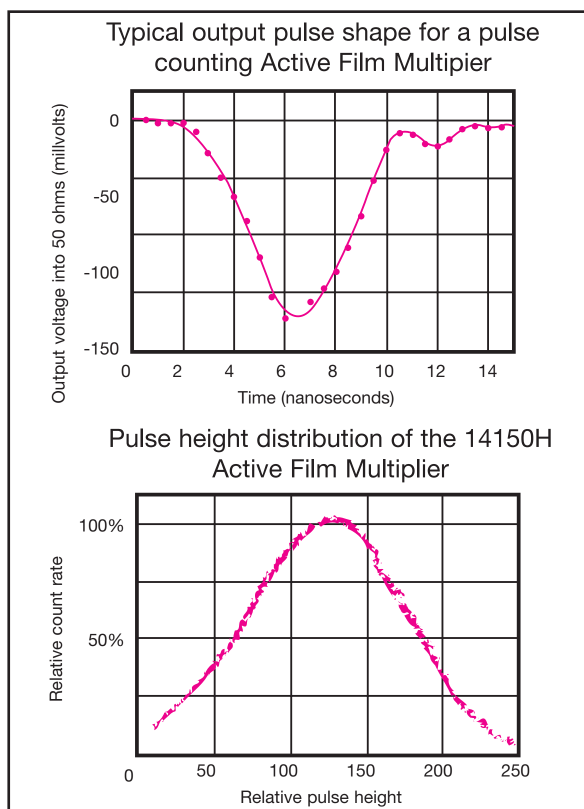

FIGURE 1.

The pulse height distribution shown was obtained from a pulse counting Active Film Multiplier when operated with a high voltage of 2.1 kilovolts, which corresponds to an operating gain of 5 x 10^7. The input ion energy in this case was 2.1KeV. Input ions with higher energy will result in a narrower pulse height distribution. This distribution has a full width at half maximum of 100 percent of the peak position. The narrow distribution leads to a well defined counting plateau enabling stable operation of the counting system.

The presented plateau curve was taken on a cameca IMS-3f SIMS system using a 22 stage Active Film Multiplier. It was taken by turning the mass spectrometer to a selected mass and measuring the count rate as the multiplier's HV was increased. By setting the HV at 2.3KV, just above the "knee" of the curve, the system becomes relatively insensitive to changes in HV or detection electronics and the multiplier is operating at it's peak detection efficiency.

The most obvious difference between the high current Active Film Multiplier and all other multipliers is its linear response at exceptionally high output currents (see figure 3). You will notice that it is very linear with up to 60μAmps of output current and has only 3% variation from linearity at 100μAmps : considerably ten times more than the maximum linear current from a conventional pulse counting multiplier.

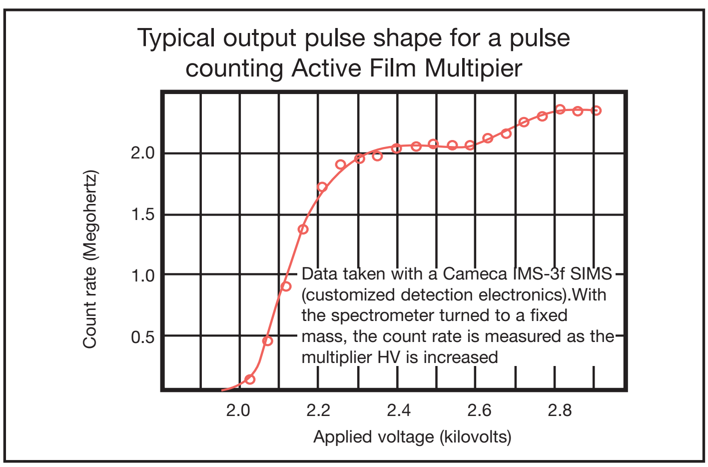

FIGURE 2.

As with all electron multipliers the maximum output current with linear response is directly related to the multiplier bias current - the current that flows through the multipliers internal resistance from the high voltage supply. The flexibility of a discrete dynode multiplier's internal resistance enables the use of very low resistance values. As a result it draws very high bias currents and is linear with very high output currents. Here the total internal resistance of the multiplier is 3.3 MegoHms.

These are analog measurements and so relate to average multiplier output currents. The second horizontal scale at the bottom of the High Current response graph shows the equivalent output count rate for a multiplier operated at a gain of 5 x 10^7. Note that at this gain, the deviation from linearity occurs at a count rate of around 15 Megahertz and the maximum count rate that the multiplier is capable of delivering is around 60 Megahertz. This closely matches the High Count Rate Response data taken with a Cameca SIMS system.

For some applications it is advantageous to operate well below the "knee" of the plateau curve. The reduced multiplier gain will result in less output current for an equivalent count rate. This will, in effect, shift the lower, horizontal scale of this graph to the left. It will enable a higher count rate before the multiplier becomes non-linear. In this way lower detection efficiency can be traded for higher count rate capability. A 70 volt decrease in the multiplier's operating voltage would have its gain, double its linear count rate limit and only decrease its detection efficiency by 10 to 20%. An added benefit from operating in this mode will be a longer operating life for the multiplier.

The High Current Count Rate Response curve shoes data taken with a Camaca IMS-3f SIMS using the high current Active Film Multiplier. (The Cameca system's detection electronics were customised to improve its count rate capability).

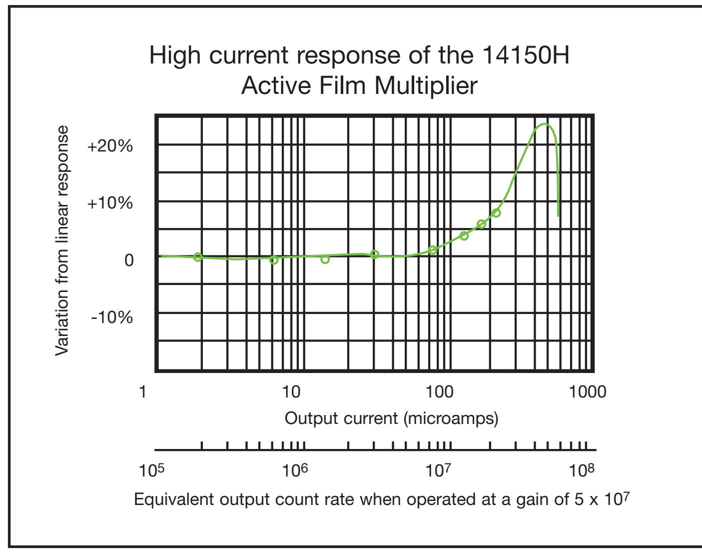

FIGURE 3.

The ratio of ^{28}Si to ^{30}Si was measured for a range of count rates. ^{30}Si was used to monitor the ^{28}Si ion input rate. (^{28}Si has approximately 30 times the abundance of ^{30}Si). Variations in the measured isotope ratio indicate a variation from linearity resulting from the higher ^{28}Si count rate. The data shows that the multiplier is, in fact, very linear with a count rate to about 20MHz.

The upper curve shows the measured isotope ratio before correction for the system dead time. The lower curve is the same data corrected for a total system dead time of 13 nanoseconds as follows:

$$\frac{N_{M28}}{N_{M30}} = \frac{\left\{\dfrac{N^1_{M28}}{1-N^1_{M28}t}\right\}}{\left\{\dfrac{N^1_{M30}}{1-N^1_{M30}t}\right\}}$$

N_{MX} - Actual rate of mass X

N^1_{MX} - Measured rate of mass X

t - Total system dead time

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The initial flat section of the corrected curve indicates that the Active Film Multiplier is responding linearly out to approximately 20 megahertz. At this point there is an increase in multiplier's response. This corresponds to the DC over-response at high currents as seen on the High Current Response Curve. It has the effect of moving the operating point on the plateau curve from just below the "knee" to the top of the pulse counting plateau. Thereafter the multiplier over-responds by approximately 15% until it reaches 45 Megahertz.

CONCLUSION

The high current Active Film Multiplier provides a major advance for ion counting systems where high count rates are important. Linear response to 20MHz demonstrates an order of magnitude increase in counting performance over conventional pulse counting multipliers. The multiplier's unique combination of high count rate capability and narrow pulse height distribution offer exceptional performance for high count rate applications.

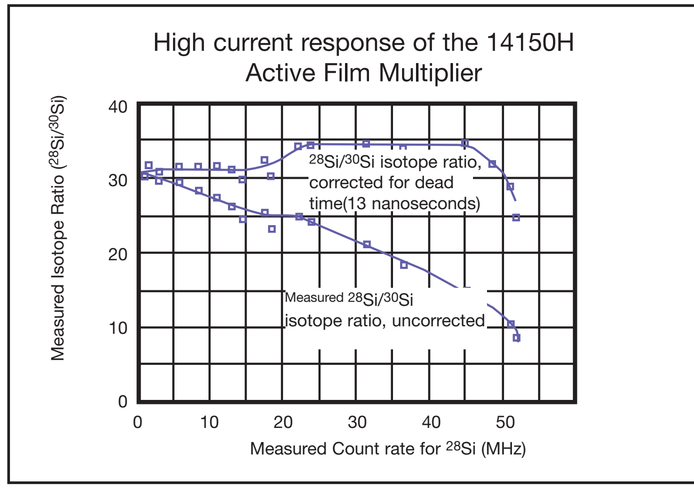

FIGURE 4.

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