Efficient Detection for Linear Traps Using a Single Electron Multiplier

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Overview

Purpose: Implement methods for detecting separate ion beams using a single electron multiplier

Methods: Ion optics modeling to ensure efficient capture of primary beam and focusing of secondaries.

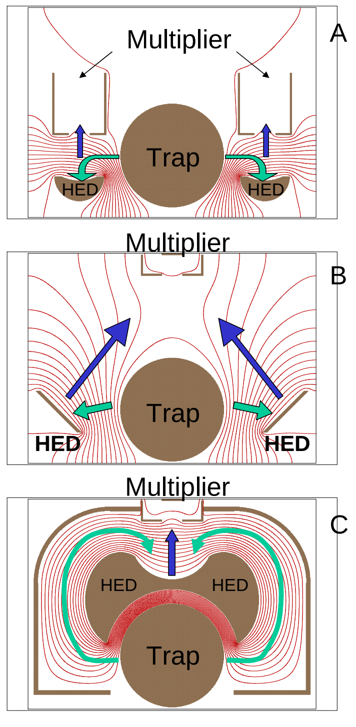
Results: Performance with a single electron multiplier which is indistinguishable from the standard detector configuration.

Introduction

Linear ion traps with radial ion ejection present a challenge in that ions are typically ejected uniformly from both exit slots. Using a single ion detector, at best only 50% of the ejected ions will be detected. To guarantee efficient ion detection, normally separate high energy dynodes and multipliers are placed on each side of the ion trap (Figure 1A) . In addition, each electron multiplier requires an independent high voltage power supply to allow gain matching. These additional components add both expense and complexity to the instrument.

A new design is presented here where ions from separate ion beams can be detected using a single electron multiplier [1]. This can be achieved through one of two methods. The first is the use of two independent high energy dynodes, which are arranged to direct secondaries at a single electron multiplier located above the linear ion trap (Figure 1B). The second is the use of a single high energy dynode which is able to capture primaries from separate ion beams (Figure 1C). A complete evaluation of the configuration with two dynodes is presented here.

FIGURE 1. Standard (A), Dual HED (B), and Single HED (C) configurations. Primary particles are shown in green. Secondaries are shown in blue.

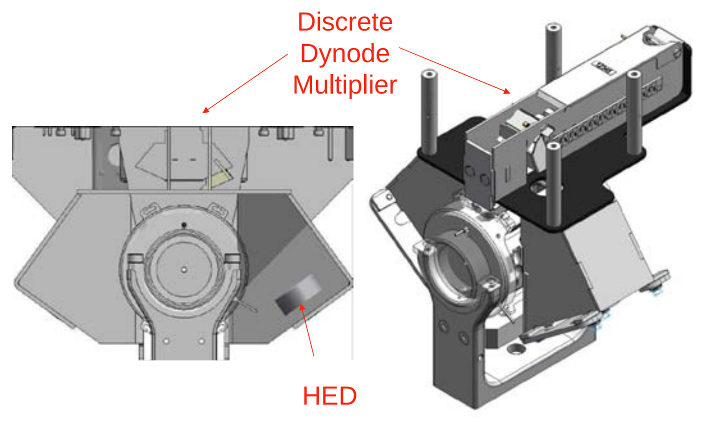


Methods

Initial concepts were developed using Simion^{TM} 3D Version 7.0 (Scientific Instrument Services, Inc.). Further refinements of detailed configurations were performed with a proprietary ion optics modeling program. In all cases, 15 kV was applied to the high energy dynode.

Baseline experiments were performed with an unmodified commercial linear ion trap with radial ion ejection (LTQ XL^{TM}, Thermo Fisher Scientific, San Jose, CA). Tests of the single multiplier concept were done with the same system using a modified top cover and linear trap mount. The top cover was machined to provide additional clearance above the linear ion trap to mount the single electron multiplier. The trap mount was modified to mechanically support the HED's.

FIGURE 2. CAD models of the dual dynode/single multiplier configuration mounted with the LTQ linear ion trap.



Simulations

Simulations of primary ion transfer from the linear ion trap to the HED is shown in Figure 3. The HED must efficiently capture primaries with a wide range of kinetic energies because the ion ejection energy from quadrupole traps is proportional to the RF level at the time of ejection [2]. For all energies examined, capture of primaries was better than 95% efficient from a source aperture of 30 mm x 0.25 mm.

Simulation of the transfer of secondaries from the HED to the multiplier is shown in Figure 4. Transfer of the secondaries in this configuration is challenging because of the much larger distance than normal between the HED and entrance to the multiplier. Using a 13 mm diameter emission zone on the 18 mm O.D. HED, 94% of secondaries can be focused on to a 4mm target area.

FIGURE 3. Simulations of ion transfer from linear trap to HED at (A) 100 eV and (B) 3000 eV.

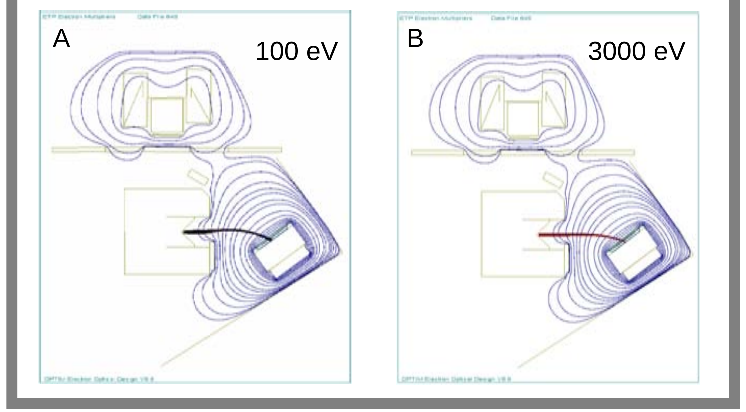
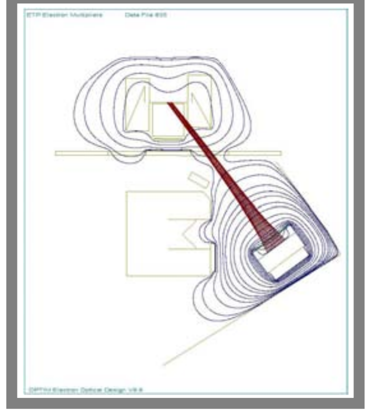


FIGURE 4. Simulation of electron transfer from the HED to the multiplier.



Detection Efficiency

The detection efficiency of this new configuration must be compared to the standard configuration. The simplest method for determining detection efficiency (ions ejected / ions detected) for the two configurations is to inject a know amount of sample and look at the instrument response. Two variables have significant impact on instrument response other than detection efficiency. The first is the multiplier gain, which must be equivalent across all experiments. In this case, a multiplier gain calibration method is employed which typically provides results which are precise to better than 5% [3]. The second variable is the number of ions that are delivered to and ejected from the trap. Due to the significant amount of instrument disassembly and reassembly necessary to switch between configurations, this can be the dominant source of error when attempting to estimate detection efficiency.

A more precise measurement of detection efficiency was required which could compensate for variability in source brightness and ion transfer efficiency. A method was developed based on space charge induced mass shifts. Space charge mass shifts are typically proportional to the number of charges present in the linear ion trap at the moment of ejection. For example, the space charge shift of the 1022 peak (Figure 6A) is dependent on the number of ions of higher mass that are present in the linear trap during ejection.

$$\Delta m = \frac{\overset{\text{ion count}}{n}}{\underset{\text{trap capacity}}{C}} \qquad \overset{\text{signal}}{S} = n\underset{\text{detector gain}}{G}\overset{\text{detection efficiency}}{E} \qquad \Delta m = \frac{1}{\underset{\text{constant}}{CGE}} S$$

FIGURE 6. (A) Example spectrum acquired during space charge mass shift measurements. (B) Plot of space charge induced mass shift versus total signal.

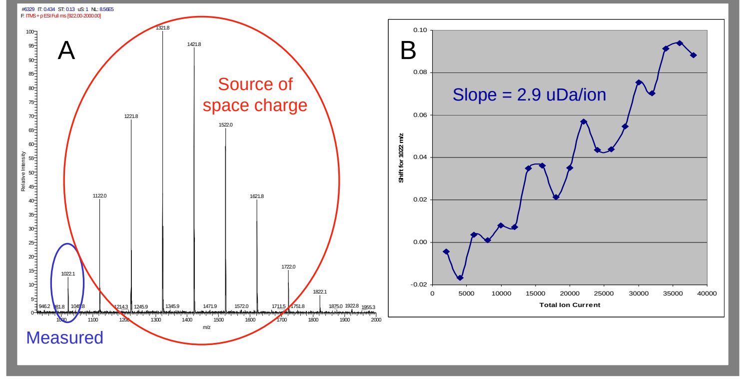
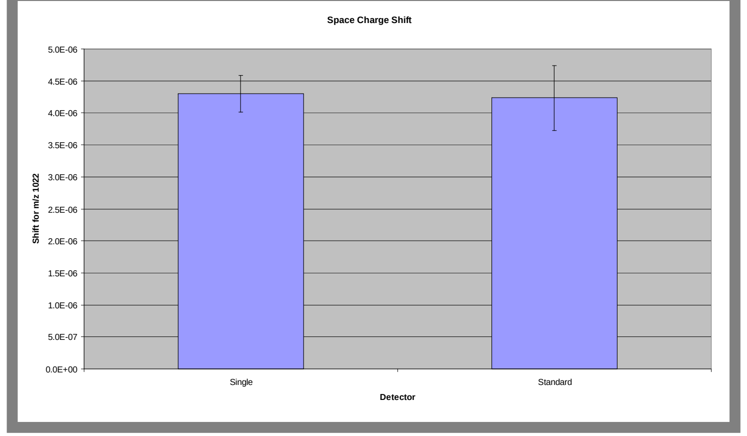


FIGURE 7. Comparison of space charge shifts for the single multiplier detector and standard detector.



If the same linear trap is used for all experiments, then the capacity ***C***, is expected to be constant. The gain ***G*** between the experiments should also be constant. Therefore, the slopes of the shift **Δ*m***, versus signal ***S***, provide a very reproducible indicator of relative detection efficiency ***E***. As shown in Figure 7, the slope for the two configurations is well within experimental variability. This indicates the detection efficiency of the single multiplier configuration is essentially equivalent to that of the standard detector.

Conclusions

The detector configuration with dual dynodes which focus secondaries to a single multiplier located above the linear ion trap demonstrates statistically equivalent detection efficiency to that of the standard configuration with the dual dynode/multiplier pairs located adjacent to the exit slots. This new configuration promises to provide a simpler, more robust detection system, through the elimination of one multiplier and one high voltage power supply.

References

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(3) Schwartz, U.S. Patent 7,109,474, September 19, 2006.

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