The single-ion detection efficiency of two types of electron multipliers is provided for incident energies reaching 10 keV. Absolute efficiencies above 90% were measured for a discrete dynode electron multiplier (DDEM), in response to Ar$^+$ ions and protons, above an energy of 5 keV. The efficiency to detect protons is consistently higher than that of Ar$^+$ ions, due to a higher secondary electron emission yield. For a channel electron multiplier we have measured a similar maximal detection efficiency for Ar$^+$ ions; though strongly varying across the detector surface.
1. Introduction

The absolute efficiency of single ion counting is an important parameter in many experiments. An example is the simultaneous detection of ion clusters along a charged particle track [1-3], applied to nanodosimetry. One of the most important prerequisites for such ion cluster measurements is the exact knowledge of the single ion detection efficiency. The available literature data [4-6] on efficiencies of electron multipliers (EM) to ions of 1 - 10 keV, are reported exclusively for channel electron multipliers (CEM). The CEM results for protons, which have been summarized in a review by Macau et al. [4], show a significant spread in efficiency (10 to 40 % at 1 keV and 50 to 80% at 10 keV). The relative efficiency for positive ions (H⁺, H₂⁺, ³He⁺, He⁺, Ar⁺ and Ne⁺) have been investigated by Burrows et al [5], which also found the counting efficiency to be independent of the charge state of He ions. Fricke et al. [6] investigated the absolute efficiency of a channel type multiplier in the energy range of 4 - 15 keV for H⁺, He⁺, Ar⁺, Kr⁺, and Xe⁺ ions.

Despite their simplicity, high gain and low background, CEMs have many drawbacks, namely: variation of the efficiency across their input aperture, strong dependence of the gain upon particle flux above 10³ - 10⁴ ions per second and the appearance of secondary pulses due to ion feedback. The more recent discrete dynode electron multipliers (DDEM)[7], that have a uniform input sensitivity and are designed to withstand large beam intensities, seem to be promising devices for ion counting applications.

This work has been motivated by the necessity to precisely study the absolute ion detection efficiency of the DDEM devices, prior to their application to nanodosimetry. The results are compared to those obtained with a CEM.

2. EXPERIMENTAL TECHNIQUE

Two types of electron multipliers were investigated: discrete dynode multipliers, type DM205IG manufactured by ETP [7] and a channel-electron multiplier type Philips B719BL [8].

Mass-selected, slightly defocussed, proton and Ar⁺ ion beams, were obtained from an ion gun system G-1 (Colutron Research Corporation). The experimental setup is shown in figure 1. It has a double collimator system (C1, C2), a Faraday cup (FC), a secondary electron suppressing electrode (SE) and the electron multiplier (EM) under study. The collimator consists of two cylinders (C1, C2) with 1 mm diameter orifices. The configuration of the collimators and additional shields, was designed to reject scattered ions. The Faraday cup, mounted on a movable rod, can be placed in the beam (“in” position), or removed (“out” position). The collimator geometry is chosen in a way to limit the maximal possible diameter of the beam, below the apertures of both the Faraday cup and the electron multiplier. The suppressing electrode, maintained under a negative potential, was added to repel the secondary electrons from the collimator and the Farady cup. The system was operated under a vacuum of 0.6-2·10⁻⁵ Torr, obtained with a turbomolecular pump. A solid state
electrometer, Keithley 610C, was used for Faraday cup current measurements.

Figure 1: Schematic view of the experimental set up for efficiency measurements. C1,C2- collimator system, SE- suppressing electrode, FC- Faraday cup, EM- an electron multiplier.

Standard pulse shaping and counting electronics was used for the pulse counting mode.

Due to the large difference in the resistances of the voltage divider chains of the investigated EMs (i.e. 3.3 MΩ for the DDEM and 100 MΩ for the CEM), which places a limit on the maximal beam intensity without loss of gain, two different methods for efficiency measurements have been applied.

The absolute efficiency of the DDEM was measured in a direct way: the ion beam current from the Faraday cup and the count rate of the pulses from the EM (Faraday cup in “out” position) were measured in turn, typically 5 - 10 times. The ratio of these values for consecutive measurements were used for evaluation of ion counting efficiency.

The counting efficiency of the CEM was evaluated by comparing its count rate with that of a previously evaluated DDEM. In this case, the CEM was mounted in place of the FC, on the movable rod. For each investigated ion energy, the ratio of count rates of the CEM (“in” position) to that of the DDEM (CEM in “out” position), were measured in turn, 5 to 10 times.

The intensity of the ion beam during the measurements was on the order of 0.04 - 0.4pA (corresponding to 3·10⁵-3·10⁶ ions/sec). In the high flux measurements, the electronics’ dead-time was 50 nsec. The repetition of the measurements was required due to an observed drift in the ion beam intensity which was seen to be on the order of 10% over a set of measurements. However the results of the current and counting mesurements were seen to maintain a constant ratio throughout this drift.

3. Results and discussion

The optimal operating conditions of the electron multipliers are deduced from the pulse counting curves as a function of the applied voltage, shown in figure 2. The data for the DDEM shows a plateau which extends from about 2000V. An operation voltage of 3000V was chosen for the DDEM in all subsequent measurements.
Figure 3: Absolute efficiency of a DM205IG electron multiplier for Ar+ ions and protons as a function of their incident energy. Vacuum: 5·10⁻⁵ Torr.

In the case of the CEM, the counting characteristic shows a plateau between 1500V to 2000 V. A similar behavior was reported by the authors of [9], at operating pressures of 10⁻⁵ – 10⁻⁶Torr, though in our case, at 2·10⁻⁵ Torr, the efficiency plateau was more pronounced. This can be explained by better performance of the CEM, and also by the fact, that the dead-time (in this case 390 nsec), introduced by the pulse counting electronics, possibly suppresses the counting of a large fraction of secondary ion feedback pulses. However, at a voltage exceeding 2500V the feedback phenomenon still persists, reflected by the observed increase in the counting rate. The operating voltage corresponding to the end of the plateau (2000 V) was chosen for the efficiency measurements.

It is a known fact that there is a variation of efficiency across the input aperture of the CEM, as shown in figure 3. The efficiency measurements of this multiplier were performed with the ion beam impinging on the outer part of the CEM entrance cone (as shown by the arrow), yielding therefore the maximal expected efficiency. For
broad beam experiments, the efficiency should be averaged over the CEM area.

The results of the absolute maximal local efficiency of the CEM, as deduced by comparison with that of the DDEM, are shown Table I.

<table>
<thead>
<tr>
<th>Ion energy [keV]</th>
<th>1</th>
<th>2</th>
<th>6</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDEM efficiency</td>
<td>32±1%</td>
<td>70±1%</td>
<td>91±2%</td>
<td>97±1%</td>
</tr>
<tr>
<td>Ratio of the efficiencies of CEM to DDEM</td>
<td>1.04±0.01</td>
<td>1.03±0.06</td>
<td>1.02±0.07</td>
<td>0.97±0.02</td>
</tr>
<tr>
<td>CEM absolute efficiency (at its edge, see text)</td>
<td>33±1%</td>
<td>72±4%</td>
<td>93±7%</td>
<td>94±2%</td>
</tr>
</tbody>
</table>

Table I: Maximal local counting efficiency of a CEM B719BL for Ar+ ions.

The measured absolute ion detection efficiency curves for the DDEM are shown in figure 4 for both protons and Ar+ ions. It is expected that the detection efficiency for other ions, lighter than Ar+, would fall in between these two curves. Over all the incident ion energy range, it is seen that the efficiency to detect protons is higher than that of Ar+ ions, consistent with similar measurements performed by Burrous [9]. This is due to higher secondary electron emission yields induced by the protons at the relevant incident energies; this higher yield is reflected in the pulse height spectra shown in figure 5. For an incident ion energy above 5keV, the detection efficiency of Ar+ ions increases above 90%, while that of protons approaches unity. It should be noted that the efficiency results presented in figure 4, for a given DDEM, were reproduced within the systematic errors, for a second unit of an equal type.

![Figure 4](image)

Figure 4 Relative counting efficiency of channel electron multiplier Philips B719BL as a function of the incident beam location across the entrance cone.

4. Conclusions

We have presented the absolute counting efficiencies of a discrete dynode electron
multiplier (DDEM), ETP-DM2305IG, for protons and Ar\(^+\) ions, and a channel electron multiplier (CEM), Philips-B719BL, to Ar\(^+\) ions, in the energy range 1 to 10 keV. The efficiencies of both multipliers vary from about 44\% for 1 keV, 80\% for 3 keV and 95\% for 6keV Ar\(^+\) ions. Higher efficiencies were recorded, using the DDEM, for protons in the low energy range, due to higher ion-induced secondary electron emission yields. The CEM has shown a non homogenous response over it’s sensitive area.

The DDEM was found adequate for single ion counting, providing fast pulses at large ion flux. Its operation with ions accelerated above 7keV, ensures a detection efficiency close to unity.

Acknowledgements

This work was partly supported by a US National Medical Technology Testbed grant (No. DAMID 17-97-2-7016) and a European Commission grant (No. FI4P-CT96-0044). S. Sh. was partly supported by the state of Israel, Ministry of Absorption and the Center for Absorption of Scientists. A. B. is the W. P. Reuther Professor of Research in the peaceful uses of Atomic Energy.

References

1. S. Shchemelinin, A. Breskin, R. Chechik, P. Colautti, R. W. M. Schulte

3. S. Pszona, J. Kula and S. Marjanska, “Ion cluster spectra at nanometer track length from alpha particles and electrons” *in press*


7. ETP Scientific Inc., 7 Midstate Drive, Auburn, Massachusetts 01501-1886, U.S.A.
