Planar DMA: a unique instrument for high resolution nanoparticles analysis below 4 nm and tandem DMA analysis

Mario Armo-González, 1 Irene Carnicero, 1 Rafael Delgado, 1 Sergio Perez, 1 Gary A. Eiceman, 2 Gonzalo Fernández de la Mora, 1 Juan Fernández de la Mora 2 and Rafael Cuesta Barbado 1

1 SEADM S. L., Boeicillo, 47151, Spain / 2 Department of Chemistry and Biochemistry, New Mexico State University, Las Cruces, New Mexico 88003, United States / 3 Mechanical Engineering Department, Yale University, New Haven, Connecticut 06520-8286, United States

Overview

The DMA combines an electric field and a flow field to select a narrow range of electrical mobilities. An optimized version of the P5-DMA connected to an electrometer allowed resolving powers in excess of 100 for an ion mobility of 0.97 cm²/V/s. DMAs, analogously to the quadrupole MS, separate ions in space rather than time, and may be similarly ordered in tandem to filter ions at atmospheric pressure. We have emulated the working principle of the triple quadrupole by placing an atmospheric pressure fragmentation stage (an oven) between two DMAs, resulting in a very high selectivity.

Introduction

SEADM’s planar DMA P5, which operates at supercritical Reynolds numbers, has demonstrated over recent years its capability for high resolving power, in stand-alone or coupled [1] with several Scien and Bruker mass spectrometers. Working with Reynolds numbers of 10¹⁰ and with TAM ion (1 cm²/V/s) as calibration standard, its resolving power was 70-80. While excellent, this resolving power is still below the theoretical value (3), limited by Brownian diffusion.

\[
R^{-1} = \frac{\Delta \log \lambda}{L} = \frac{q_0}{L_{\text{dis}} & Re} \sqrt{\frac{16n_2}{\mu \nu (h + h')}} \tag{1}
\]

Where \(q_0\) is the polydisperse aerosol flow rate, \(L_{\text{dis}}\) is the monodisperse sampling slit length, \(Re\) is the Reynolds number in the separation channel, \(\mu\) is the dynamic viscosity of the gas, \(\nu\) is the Peclet number, \(h\) (1 cm) is the distance between plates and \(h'\) (4 cm) the axial length of the separation cell (distance between inlet and outlet slits).

In this work we improved the laminarization stage of DMA P5, reporting resolving powers as high as 110. We also emulate the working principle of the triple quadrupole by placing an atmospheric pressure fragmentation stage (an oven) between two DMAs, resulting in a very high selectivity.

Conclusions

Planar DMAs are able to reach resolving powers of 110 operating at Reynolds number of 3.3x10¹⁵. Its high transmission and duty cycle make the DMA the ideal instrument for IMS-MS studies.

The short ion transit time in DMAs (~200 µs) facilitates a complete absence of ion fragmentation within the analyser, sidestepping poor fragment resolving power previously observed in IMS² studies. Both parent and fragment ions can accordingly be cleanly resolved via DMA-F-MS. The oven placed between the DMAs provides enough energy to fragment stable molecules.

References


Planar DMA: Single DMA: Methods

**Overview**

The DMA combines a horizontal laminar flow of gas (U velocity) with a vertical electric field between the two parallel plates (4x electric field magnitude), such that ions of different mobilities penetrating through a slit in the upper plate opening out into a fan shape as they drift towards the other plate, whereby only a small range of mobilities is sampled through a second slit in the lower plate and transmitted to the ion detector (electrometer or mass spectrometer).

**Single DMA: Methods**

We used SEADM’s DMA P5-G (Figure 2), with critical dimensions in mm collected in Table 1.

**Single DMA: Results**

<table>
<thead>
<tr>
<th>Theory</th>
<th>DMA-Electrostatic (1 THz)</th>
<th>DMA-MS (Oleic Acid -)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R112</td>
<td>R111</td>
<td>R11</td>
</tr>
</tbody>
</table>

** DMA Voltage (V) **

**Figure 4.** Background subtracted mobility spectra of m/z 281 (Oleic acid). The dashed line is the Gaussian fitting of the three peaks. Dotted line represents the same spectra using a DMA with a resolving power of 30 (hypothetical scenario).

**DMA Voltage difference (V) **

**Figure 7.** Oven temperature dependence of fragment ion mobility spectra in DMA2, with DMA1, transmitting the chloride adduct of the PETN parent explosive.

**Tandem DMA: Methods**

**Figure 5.** Mobility spectrum at the m/z of deprotonated linoleic acid (279 Da).

**Figure 8.** Oven temperature dependence of fragment ion mobility spectra in DMA2, with DMA1, transmitting the chloride adduct of the PETN parent explosive.

**Conclusions**

Planar DMAs are able to reach resolving powers of 110 operating at Reynolds numbers of 3.3x10¹⁵. Its high transmission and duty cycle make the DMA the ideal instrument for IMS-MS studies.

The short ion transit time in DMAs (~200 µs) facilitates a complete absence of ion fragmentation within the analyser, sidestepping poor fragment resolving power previously observed in IMS² studies. Both parent and fragment ions can accordingly be cleanly resolved via DMA-F-MS. The oven placed between the DMAs provides enough energy to fragment stable molecules.