Multistage Transversal Modulation Ion Mobility Spectrometry: Towards a High Transmission and High Resolution IMS for trap-type MS

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Summary

• Introduction:
  – The problem: IMS-MS pulsed vs continuous
  – The solution: TMIMS (principle of operation)
  – Objectives of the development
  – TMIMS Background
  – Engineering Requirements

• New concept: TMIMS ladder

• Results

• Conclusions
IMS-MS pulsed vs continuous output.

**Ion Mobility ($K$):**
- Collision cross section.
- Shape of the molecules
- Conformation of proteins

**Current IMS – MS systems in the market**
- Pulsed output of ions (Drift Tube IMS, Travelling Wave IMS):
  - Peaks duration in the millisecond scale
  - Only compatible with fast MS
  - Careful integration required

- Commercialized systems integrate IMS and MS in a single system
  - Not modular
  - **Expensive systems**
  - Limited to Q-TOF

To expand IMS possibilities to all kind of existing MS → IMS with continuous output of ions
TMIMS: principle of operation

- TMIMS provides continuous output of ions

Uniform electric fields:

- Velocity \( \rightarrow \) Trajectories:
  \[ u = KE_0 \]
  \[ v = KE_1 \sin(\Omega t) \]
  \[ x = KE_0 (t - t_0) \]
  \[ y = 2 \frac{KE_1}{\Omega} \sin \left( \frac{\Omega}{2} (t - t_0) \right) \sin \left( \frac{\Omega}{2} (t + t_0) \right) \]

- Distance to the outlet slit
  \[ y = 2 \frac{KE_1}{\Omega} \sin \left( \frac{\Omega l}{2KE_0} \right) \sin \left( \Omega t - \frac{\Omega l}{2KE_0} \right) \]

- Selection criterion:
  \[ K = \frac{\Omega l}{2 \pi E_0} \]

- G. Vidal de Miguel, "Method and apparatus to produce steady beams of mobility selected ions via time-dependent electric fields", 61/211,111 (USPTO)
Objectives

  - Eurostars program.
  - IMS-Orbitrap \(\rightarrow\) IMS continuous output

- Goal: pre-commercial TMIMS
  - Add-on architecture (modular)
  - Can be coupled with existing API-MS
  - Can be coupled with existing Ion Sources

**Diagram:**

- **Ion source** → **TMIMS** (pre-filters ions according to their mobility) → **Mass Spec**
TMIMS Background

Developed TMIMS prototype, performs:
- IMS pre-filtration
- IMS-IMS pre-filtration

Previous prototypes demonstrated the viability of the technology
Still need to be improved to meet final user requirements

Engineering requirements

- Drastic reduction of the inlet voltage (from 16kV to 0V)
- Improved transmission (up to 10-20%)
- Cost
- Size
- Robustness
- Desolvation of ions
- Maximum intensity that the TMIMS can handle
- Overtones and secondary peaks must be eliminated
Summary

• Introduction
• New concept: TMIMS ladder
  - Principle of operation
  - Cell design
  - Assembly
• Results
• Conclusions
TMIMS ladder, principle of operation.

- Each stage operates with a fraction of the total voltage.
  - Simplified High Volt. Requirements.

- Ions are sequentially filtered.

- Desolvation and space charge effects affect only first stages.
  - Improved robustness

• G.Vidal de Miguel, “Transversal Modulation Ion Mobility Spectrometer with reduced voltage and improved robustness and resolving power”, USPTO
Theoretical considerations (1/2).

Ion passage criteria:

• One stage

\[ |l_{e_1}/\omega \left[ \sin \left( 2\pi \frac{\omega}{e_1} + \varphi_1 + 2\pi \tau_0 \right) - \sin(\varphi_1 + 2\pi \tau_0) \right]| < dy \]

\[ \left| l(e_2/\omega) \left[ \sin \left( 2\pi \frac{\omega}{e_1} + \varphi_2 + 2\pi \tau_0 \right) - \sin \left( 2\pi \frac{\omega}{e_1} + \varphi_2 + 2\pi \tau_0 \right) \right] \right| < dy \]

• Two stages

\[ \left| l(e_2/\omega) \left[ \sin \left( 2\pi \frac{\omega}{e_1} + \varphi_2 + 2\pi \tau_0 \right) - \sin \left( 2\pi \frac{\omega}{e_1} + \varphi_2 + 2\pi \tau_0 \right) \right] \right| < dy \]

• Three stages

\[ \left| l(e_3/\omega) \left[ \sin \left( 2\pi \frac{\omega}{e_1} + \varphi_3 + 2\pi \tau_0 \right) - \sin \left( 2\pi \frac{\omega}{e_1} + \varphi_3 + 2\pi \tau_0 \right) \right] \right| < dy \]

• ... 

• Lateral displacements are accumulated as ions traverse the ladder.
• Selected ions are sequentially focused at the slits.
• Total resolving power of the TMIMS-ladder equals conventional TMIMS with the same total voltage.

• G.Vidal de Miguel, “TMIMS ladder”, USPTO
Theoretical considerations (2/2).

- Inlet slit defines the width of the ion beam.
- Outlet slit defines maximum allowed deflections.
- Intermediate slits are broadened to improve transmission.
  - Ions are discarded only at the outlet slit.
  - Losses through intermediate slits are minimized.

• G.Vidal de Miguel, “TMIMS ladder”, USPTO
Final design:
- TMIMS ladder: 6 stages

- TMIMS ladder
  - Low Peak-to-Peak voltage
  - Reduces HV System size and cost
- Elongated envelope facilitates coupling with commercial IS
- Flow distribution (opposite direction to ions):
  - Keeps the analysis area clean of vapors
  - Helps to desolvate ions
- Resistive capillary:
  - compensates for the voltage drop.
  - enables maintaining a grounded inlet
Cell Assembly

Basic architecture and materials:
- TMIMS Ladder made of Satinless Steel and ceramics
- PEEK external insulator
- Aluminium external heating and housing

Compatible with:
- Thermo Mass Spectrometers
- Thermo Ion sources:
  - The Cell can be heated up to 200 C to facilitate desolvation.

Adjacent module:
- Provides oscillating voltages.
- Adjacent to the Cell to minimize capacitive loads.
TMIMS ladder control

Adjacent module
- Provides oscillating voltages.
- Adjacent to the Cell to minimize capacitive loads

Ion source

Control module
- Provides DC voltages.
- Temperature control
- Gas flow control

TMIMS Cell

MS
Summary

• Introduction
• New concept: TMIMS ladder architecture
• Results: Shape of the spectra.
• Conclusions
TMIMS Stages, one by one:
Coordination of the ladder:
Coordination of the ladder:
Effect of the deflector voltage
Space charge
Summary

• Introduction
• Requirements evaluation
• Architecture
• Results
• Conclusions
Conclusions & future work:

• Resolving power:
  • Very preliminary tests (a week following integration) showed a resolving power of 30:
    - Deflector voltage: **1.5 kV**. (7 times lower than the previous prototype)
  • The **predicted Resolving power is 60**:
    - An optimization of the phase and the electric field of each stage is required.

• **Cost:**  • **Low cost** power electronics can be used to control the TMIMS ladder.

• Robustness & compatibility:
  - The system seems to be robust against space charge (more tests planned),
  - Robustness against partially solvated ions will be evaluated next.

• **Grounded inlet**, which facilitates coupling with regular ion sources.
  - The resistive capillary seems to work normally,
  - The transmission still requires optimization and characterization.

• **Continuous output** eases coupling with pre-existing MS: **IMS for Trap & Orbitrap**
Conclusions & future work:

• We are reducing the cost of the TMIMS.
• This will enable users to purchase an add-on IMS cell for their MS.
  - Compatible with standard Ion Sources,
  - Compatible with LC,
  - Compatible with pre-existing Mass Spectrometers.
Many thanks!

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