Very Long Path Length Ion Mobility Separations using Structures Lossless Ion Manipulations


Pacific Northwest National Laboratory
Some approaches for potentially achieving very high resolution ion mobility separations

- Separation over long path in dense gas/fluid; challenges: large voltage drop required, difficulty in combining with MS
- Separation in very low temperature fluid; challenges: design complexity, maintaining uniform temperature over useful volume
- Extended residence time Differential Mobility separations (e.g. FAIMS); challenges: large ion losses, slow scan speed
- Separation in flowing (or expanding gas); challenges: maintaining highly stable gas flow, limited separation space and dynamic range
- Separation in cyclic path devices; challenge: limited separation space
- Separation over very long path lengths; challenges: space and cost needed for long path device, large voltage drop required
Structures for Lossless Ion Manipulations (SLIM)

One of many SLIM electrode arrangements......

DC to Guard electrodes for ion confinement
RF to central ‘rung’ electrodes for ion repulsion from surfaces

DC guards RF/DC rungs DC guards

Central electrode optional DC steps to e.g. drive ion drift

Guard electrode RF +/- rung electrode Guard electrode

See Wednesday Poster by Tolmachev et al., WP 485

Garimella et al., JASMS, 25, 1890 (2014)
A traveling wave SLIM IMS variation

• Existing data shows IMS performance can approach drift tube designs, and theory suggests Resolution \( \propto \) (drift path length)^{0.5} with good separations achievable over significant mobility range*

• Attraction: voltages applied independent of drift path length

• Question: can a SLIM implementation provide good resolution?

• 2\(^{nd}\) question: can the SLIM implementation be simplified?

• 3\(^{rd}\) question: can the design be made compact?

• 4\(^{th}\) question: ..........

Initial traveling wave IMS SLIM electrode design evaluated

#RF strips, #rows DC electrodes (12,11)

5 mm PCB gap
Elevated DC to 4 of every 8 electrodes in each of 11 rows incremented in single electrode steps 

Sequence = 11110000
Transmission (%)

Board spacing: 5 mm gap
Guard 15 V, TW amplitude 30 V and speed 84 m/s

Lossless ion transmission from ~m/z 200 to 2500

Sandilya Garimella
Direct measurement of ion current in SLIM IMS module

Board spacing: 5 mm
Guard 15V, TW amplitude 30 V and speed 84 m/s

See Monday Poster by Hamid et al.; MP 137
TW speed effect on IMS resolution

Sequence = 1110000

Resolving power ~35

See Monday Poster by Hamid et al.; MP 137
Good agreement between experiment and simulation

Resolution

Travelling Wave Frequency (kHz)

m/z 922 and m/z 622

Experiment

Simulation

m/z 922 and m/z 622
Comparison of 30 cm TW SLIM with conventional TW IMS

<table>
<thead>
<tr>
<th>TW SLIM (30 cm)</th>
<th>Synapt G2-TWIMS* (25 cm)</th>
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<tbody>
<tr>
<td><strong>P</strong> = 4.0 Torr N\textsubscript{2}</td>
<td><strong>P</strong> = 2.6 Torr N\textsubscript{2}</td>
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<td><strong>TW speed</strong> = 89 m/s</td>
<td><strong>TW speed</strong> = 650 m/s</td>
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<tr>
<td><strong>TW amp.</strong> = 30 V</td>
<td><strong>TW amp.</strong> = 40 V</td>
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Liulin Deng

A few of the TW sequences examined in SLIM modules

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30 V

10000000

11000000

11100000

11110000

11110000

11110000

11111000

11111000

11111100
Effect of TW sequence on IMS resolution for 6,5 arrangement with 5 mm board gap

TW sequence
TW speed = 84 m/s
amp. = 30 V
TW amplitude effect on IMS resolution

TW speed = 84 m/s

Resolution ($R_{622-922}$) vs. TW amplitude (V)

Sequence = 11110000
Some other SLIM electrode arrangements explored
IMS performance for a 6,5 electrode arrangement

#RF strips, #rows DC electrodes (6,5)

30.5 cm
Effect of SLIM board gap on R for 6,5 linear path arrangement

TW Speed (m/s) vs. Resolution

- 5 mm gap
  - Resolution = 9.8

- 3 mm gap
  - Resolution = 11.2

- 2 mm gap
  - Resolution = 9.3

TW amplitude = 30 V
Effect of SLIM board gap on R for 6,5 multi-turn path arrangement

TW amplitude = 30 V

- 5 mm gap: Resolution = 10.8
- 3 mm gap: Resolution = 11.6
- 2 mm gap: Resolution = 9.8
Resolution for straight vs. multi-turn path arrangements

See Monday Poster by Hamid et al.; MP 137
Simple electrode arrangement for turning corners

Ion trajectories calculated for 3 mm gap, TW amplitude = 30 V, speed = 84 m/s

Start

3,2 electrode arrangement

RF-

RF+

Guard DC

Guard DC

DC TW electrodes
The long or winding roads towards higher resolution
28 M path SLIM IMS module incorporating ~60,000 discrete electrodes
Initial evaluation of long path length SLIM IMS-MS

- ~65% efficiency for ion transmission through long path module
- Guard electrode spacing between tracks too narrow; ions jump paths at turns* under conditions needed for separation
- Refined design developed
Take 3 long path (14 M) SLIM design

TW Electrode dimensions: 0.43 mm width x 0.91 length; 0.13 electrode gaps
Initial results....much optimization to come

TW: 86 m/s, 11 110000, 25 V
Guard: 12.5 V
RF: 842 kHz, 220 V_{pp}

R = 33
A good separation is often not enough

Fast switching of selected ion packets to different path previously demonstrated (Webb et al, Anal. Chem., 86, 9169; 2014)

Trapping and accumulation of selected packets from multiple separations (see Tuesday Poster by Tsung-Chi Chen et al.; TP 074)

Our plan: Capture entire separations in a large array of traps, with intensity dependent number of accumulation steps for each trap (i.e., AGC) to increase dynamic range

Goal: Enable ‘read out’ of the entire separation, or any selected fractions, at any speed, to any MS platform type

Screen shot of ion trajectory simulation; ions of three different mobilities first separated and shown fractionated into three different traps, stored, and selected (green) for transfer to MS
Acknowledgements

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