Structures for Lossless Ion Manipulations (SLIM) Using Multilevel Elevators and Escalators for Obtaining Ultrahigh Resolution Ion Mobility Separations

Ahmed M. Hamid, Yehia M. Ibrahim, Sandilya V. B. Garimella, Ian K. Webb, Liulin Deng, Gordon A. Anderson, Spencer A. Prost, Jeremy A. Sandoval, Randolph V. Norheim, Erin S. Baker and Richard D. Smith

Biological Sciences Division, Pacific Northwest National Laboratory, Richland, WA 99352

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by Battelle Since 1965

Overview

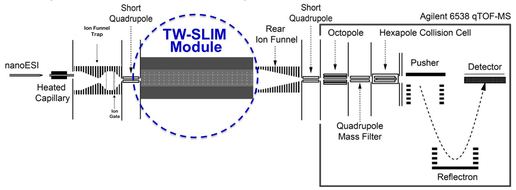
- New SLIM modules allow moving ions in three dimensions (3D), i.e. between different SLIM levels.
- Multilevel SLIM enable longer paths and increased IMS resolution, as well as extended and integrated ion manipulation capabilities.
- Two approaches are presented.

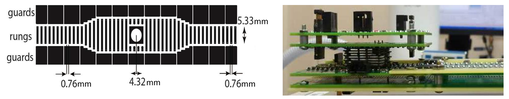
Introduction

- Although extending the drift path length can enhance the mobility-based separation power, conventional drift tube arrangements are ultimately limited by both the high voltages and the size of the drift tube needed.[1] Alternatively, traveling waves can eliminate the need for increasingly high voltage as the drift path increases.[2]
- The speed of an ion packet in a traveling wave (TW) through a buffer gas is dependent on its mobility.
- High-mobility ions slip behind the waves less often than low-mobility ions, and thus move faster than low-mobility ions.[2,3]
- The implementation of a TW IMS approach with SLIM enables lossless ion manipulations and the basis for achieving higher ion mobility resolution.[3]
- We present two new concepts for moving ions between different SLIM levels in a three dimensional device. The new SLIM components, namely the “elevator” and the “escalator”, both enable moving ions between different SLIM levels.

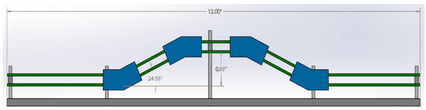
Methods

Experimental setup



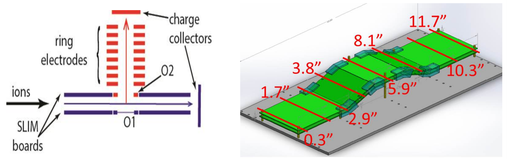


(Left) Schematic diagram of an elevator-SLIM board showing key dimensions (in mm) (Right) A picture of SLIM elevator



Schematic diagram illustrating the components of the TW-SLIM escalator

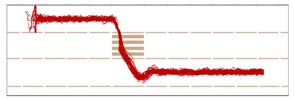
Direct evaluation of ion current transmission efficiency



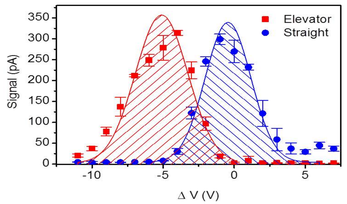
Results

Ion trajectory simulations

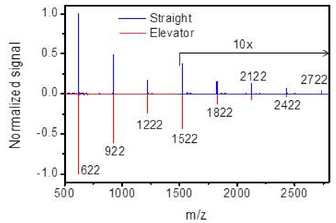
SIMION 8.1 was used for ion trajectory simulations.



SLIM Elevator Transmission

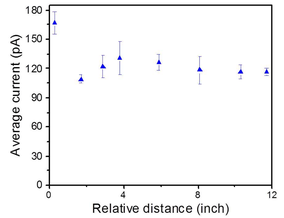


Within a voltage range of 5 V the ion plume can be efficiently and completely steered into the elevator, allowing one IMS peak to be separated from another, enabling the SLIM elevator component to also be used as a switch.



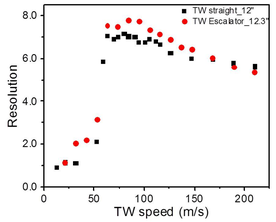
The mass spectra collected for the straight and the elevator paths have similar *m/z* ranges (600-2700). The similar mass spectra indicate a relatively sharp ion plume turn into the elevator for the *m/z* range observed. However, minor differences in transmission have led us to explore alternatives, such as the “ion escalator”.

TW-SLIM Escalator Transmission



The measured ion currents indicate essentially lossless ion transmission through the TW-SLIM escalator module between the two TW-SLIM levels illustrating the efficient transmission of ion beam among TW-SLIM levels using a TW escalator.

Traveling wave speed effect

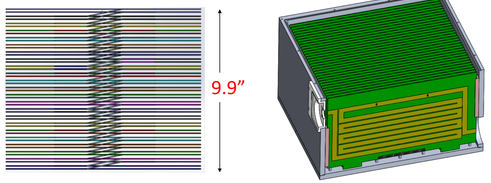


$$R_{622-922} = \frac{t_{922} - t_{622}}{(\Delta t)_{average}}$$

t: Arrival Time measured at the center of the peak (ms)
Δt: Full width at half height (ms)

The straight (12”) and the escalator (12.3”) TW-SLIM modules provided similar IMS separations. Therefore, ions can be transported through the TW escalator 3D design without significant losses in the sensitivity or IMS resolution.

TW-SLIM City



Conclusions

- Two new concepts for moving ions between two levels of SLIM modules were evaluated for forming 3D structures: the SLIM elevator and TW-SLIM escalator.
- Ion simulations and optimization of the fields inside the elevator indicated ions could be efficiently transmitted in a straight path or steered into the elevator.
- Ion mobility resolution obtained using the TW-SLIM escalator module was comparable to that obtained for a straight module, indicating that resolution wasn’t lost as the ions moved between SLIM levels.
- The elevator and escalator pave the way for development of more complex multilevel SLIM devices.
- Multilevel SLIM can be utilized for many applications, such as performing different ion chemistries (e.g. in different gases) on different levels, as well as for extended ion paths for other manipulations, and for achieving much higher ion mobility resolution.

Acknowledgments

Portions of this work were funded by the NIH National Institute of General Medical Sciences (8 P41 GM103493-10) and by the U.S. Department of Energy (DOE) Office of Biological and Environmental Research Pan-omics Program at Pacific Northwest National Laboratory (PNNL) and performed in the Environmental Molecular Sciences Laboratory (EMSL), a DOE national scientific user facility on the PNNL campus. PNNL is a multiprogram national laboratory operated by Battelle for the DOE under contract DE-AC05-76RL01830.

References

1. Merenbloom, S. I.; Bohrer, B. C.; Koeniger, S. L.; Clemmer, D. E. *Analytical chemistry 2007*, 79, 515-522.
2. Giles, K., Wildgoose, J.L., Langridge, D.J., Campuzano, I.: A method for direct measurement of ion mobilities using a travelling wave ion guide. *International Journal of Mass Spectrometry*. **298**, 10-16 (2010).
3. Hamid, A. M.; Ibrahim, Y. M.; Garimella, S. V.; Webb, I. K.; Deng, L.; Chen, T.-C.; Anderson, G. A.; Prost, S. A.; Norheim, R. V.; Tolmachev, A. V.; Smith, R. D. Analytical chemistry 2015, 87, 11301-11308.

Career Opportunities: For openings in the Integrative Omics Group at PNNL please visit http://omics.pnl.gov/careers

CONTACT: **Ahmed M. Hamid, Ph.D.**
Biological Sciences Division
Pacific Northwest National Laboratory
E-mail: ahmed.hamid@pnnl.gov

www.omics.pnl.gov