Development and Characterization of Pulsed Ion Sources Coupled to oaTOFs

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Introduction

The application of pulsed ion sources in combination with orthogonally accelerating time-of-flight mass spectrometers (oaTOF-MS) may render the performance of such systems unfavorably, when the ion source is not synchronized with the oa-stage. Spectra are then recorded at high repetition rates (kHz range) by the MS even though no ions have been ejected by the ion source ($\rightarrow$ reduction in sensitivity and increase in background noise). If i) high mass resolution, and ii) sampling of individual full mass spectra in the kHz regime are required, oaTOFs are the mass analyzers of choice. Synchronization of the ion source with the oa-stage enables time-resolved characterization of the ion source and ion-molecular gas-phase processes. In this work, resonance enhanced multiphoton ionization (REMPI) of nitrogen monoxide (NO) was performed [1] to characterize this synchronization method for further application in pulsed plasma dynamics studies.

Experimental Set Up and Methods

Gas Supply

400 ppm NO in N_2 (Messer Industriegase GmbH, Bad Soden, Germany) are fed into a vacuum chamber via a gas chromatography (GC) capillary.

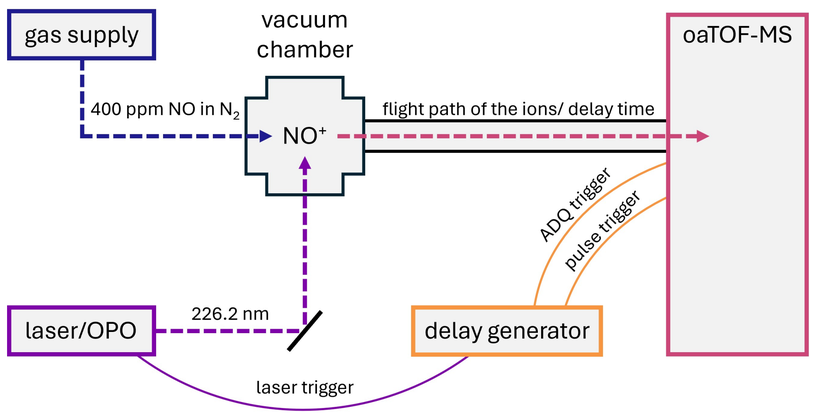

Fig. 1: Schematic overview of the experimental setup

Ionization

A Nd:YAG pumped optical parametric oscillator (OPO) laser system (NT342 Series, EKSPLA, Vilnius, Lithuania) resonantly ionizes NO at 226.2 nm via (1+1) REMPI ([A(v=0) $\leftarrow$ X(v=0)], pulse duration: 5 ns, repetition rate: 10 Hz). An electrode has been placed in close vicinity to the ionization region, to which voltages can be applied.

Ion Detection

For ion detection, the vacuum chamber is coupled to a high resolution oaTOF-MS (LTOF, Tofwerk AG, Thun, Switzerland).

Synchronization

The LTOF is synchronized with the laser system using the trigger out signal of the Pockels cell driving unit. The time interval between the laser pulse and the push pulse of the oa-stage of the LTOF as well as the data acquisition is adjusted by a delay generator (81150A, Keysight Technologies, Santa Rosa, USA).

Simulation Results

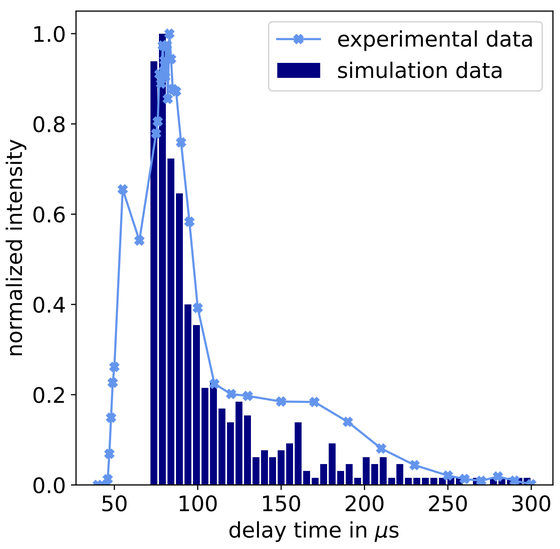

Fig. 2: Comparison of experimental results with IDSimF simulations

- The simulations were performed using the Ion Dynamics Simulation Framework (IDSimF) [2].
  It is an open source software written in C++ that contains various models and programs for the simulation of ion trajectories.
- Ion density: 4E14 particles/m^3
- Acceleration of the ions is caused by space charge forces.
- High level of agreement between experimental and simulation results

Experimental Results

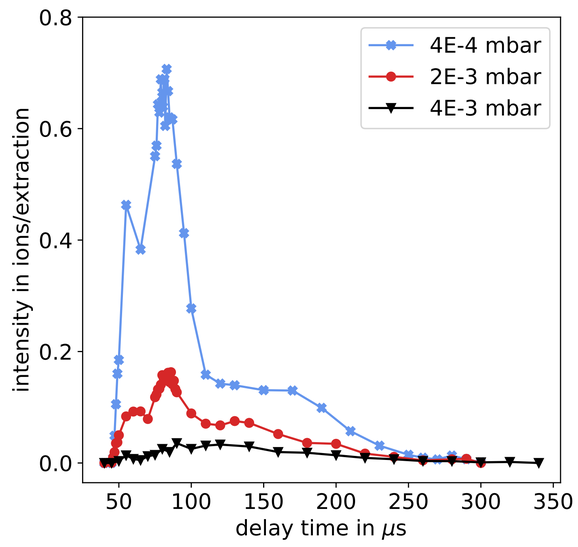

Fig. 3: Detected ions as a function of the delay time at different pressures

- Maximum detected ions per extraction at a delay time of 70 μs
- Over a flight distance of 22 cm, a delay time of 70 μs corresponds to a speed of about 3000 m/s and thus a kinetic energy of 1.5 eV.
- Kinetic energy for the fastest ions: about 3.5 eV
- When the background pressure in the chamber is increased, fewer ions are detected, and the average velocity of the ions shifts to longer times.

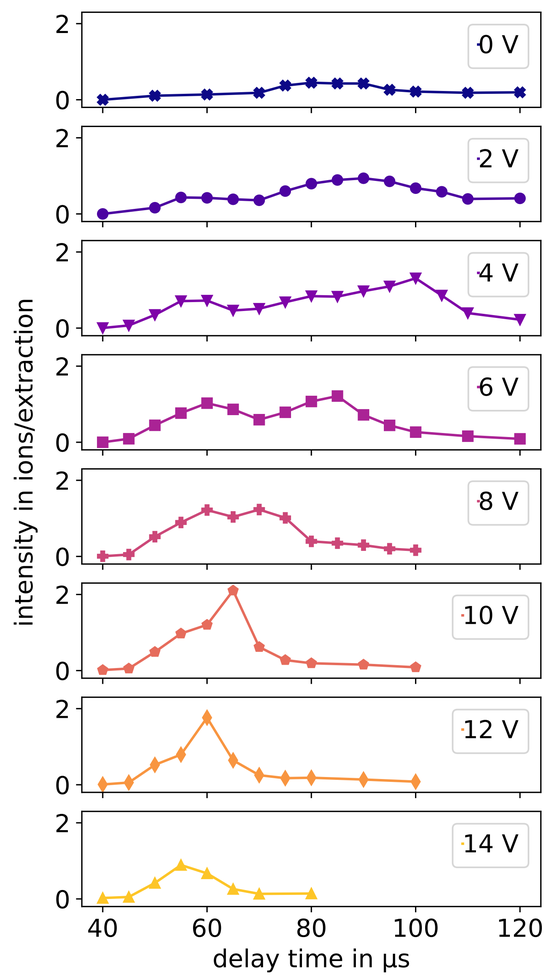

Fig. 4: Effect of ion accelerating on the arrival times

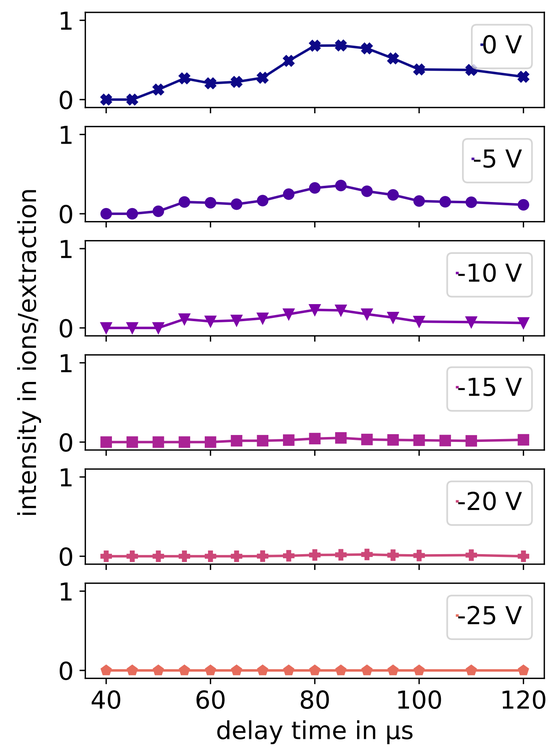

Fig. 5: Effect of ion decelerating on the arrival times

Ion Accelerating:

- Applying a pushing potential to the electrode

Ion Decelerating:

- Applying a drawing potential to the electrode

Conclusion and Outlook

Conclusions:

- Successful synchronization of a pulsed ion source and an oaTOF-MS
- Simulations with IDSimF are in good agreement to the experimental results

Outlook:

- Application of this synchronization method for pulsed plasma ion sources
- Time-resolved characterization of different pulsed plasma ion sources

Acknowledgment

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References

[1] R. M. Garnica, M. F. Appel, L. Eagan, J. R. McKeachie, T. Benter, *Anal. Chem.* **2000**, *72*, 5639–5646.

[2] IDSimF, ion dynamics simulation framework, `https://idsimf.readthedocs.io/en/latest/`.