Detection of Plasma Ions by Coupling a High Resolution TOF-MS at Minimum Distance to EUV-light Focus Point.

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Introduction

For a better understanding of extreme ultraviolet (EUV) induced chemistry in a surrounding gas phase consisting of hydrogen, a high-resolution time-of-flight mass spectrometer (TOF-MS) is employed to detect ions generated in the EUV beam path. Some of the important requirements were:

- The **shortest possible distance** between EUV plasma focus and actively sampling entrance of the TOF-MS.
- An **ion source** inside TOF-MS, which can transfer the ions from the plasma region to the flight tube (Native Ion mode, **NI**), while also providing electron ionization (**EI**) functionality.
- A **coupling stage** with very clear boundaries and a geometry that can easily be adapted to multi-physics simulation models for validation purposes.
- Operation of the MS at an EUV beam line with focused radiation at a wave-length of 13.5 nm without source gases influencing the hydrogen atmosphere.

Methods

EUV-HIEX → Interface filter → Coupling stage → Ion source → TOF-MS | Hydrogen

EUV high-intensity exposure (EUV-HIEX) setup for 13.5 nm (TOS, RWTH Aachen).

- discharge-produced Xe plasma EUV source
- beam conditioning system to focus radiation
- spot size: 60 µm, typical power: 400 µW

Spectral purity filter based on SiN/Zr layer system.

- max. transmission of 42% at 13.5 nm
- spectral purity > 100.000

The coupling stage consists of ultra-high vacuum stainless steel ConFlat (CF) parts.

- rotational symmetry design
- gas inlet and turbo-molecular pump (TMP) connection
- heaters for baking at 120° C
- volume about 1 liter

Custom built ion source (Physical Chemistry, University of Wuppertal). Provides

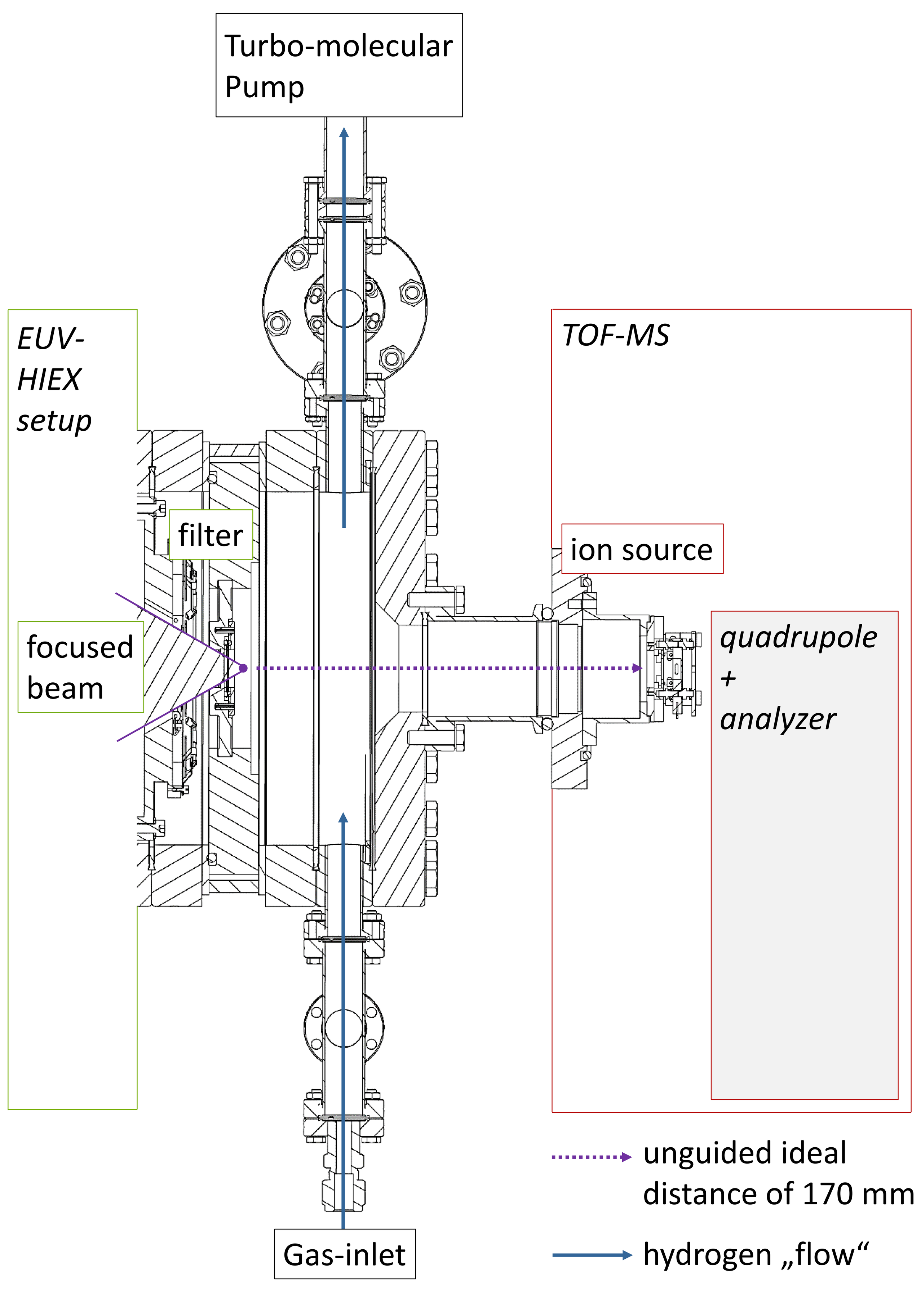
- electron ionization (EI) mode
- transmissive mode for native ion (NI) sampling

Large time-of-flight mass spectrometer (TOF-MS) (TOFWERK AG, Thun, Switzerland)

- ion transfer quadrupole (100 mm length)
- flight tube length (folded): 2700 mm

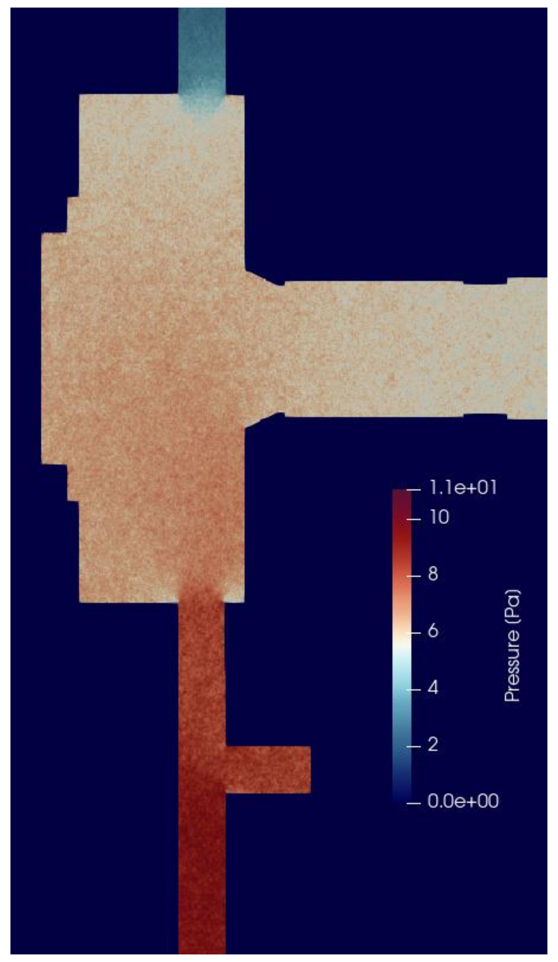
Hydrogen 7.0 by NM Plus 300 (Vici DBS, Schenkon, Switzerland). **Gas flows** by mass flow controllers (MKS Instruments, Berlin, Germany).

Coupling Stage



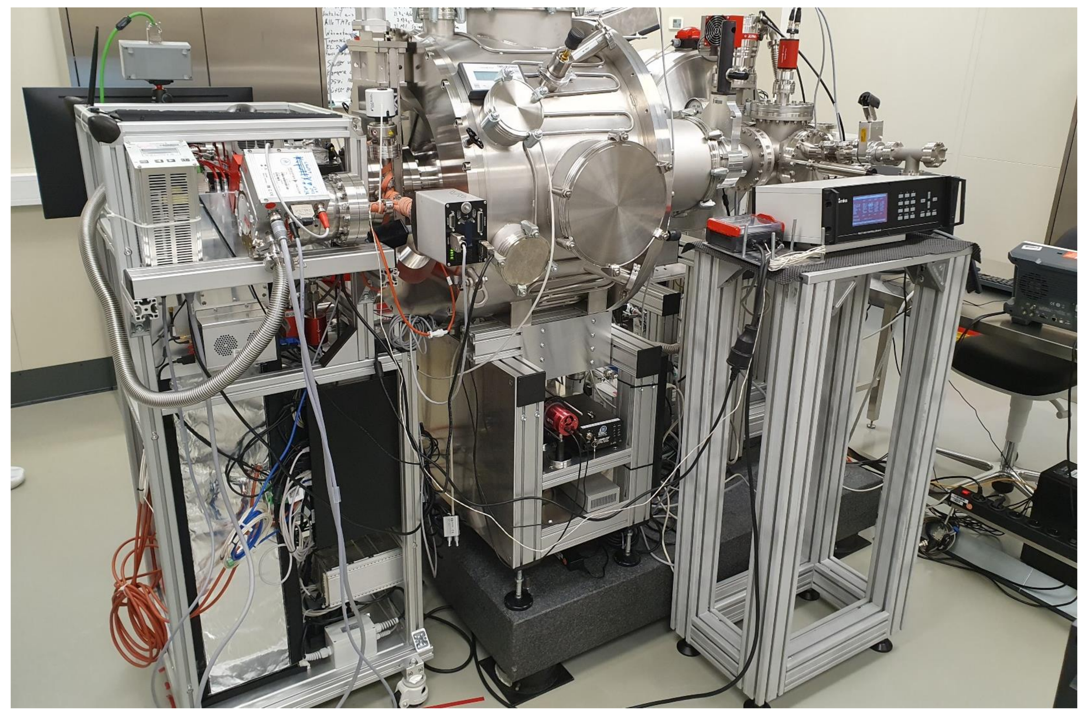
Simulation

The **pressure distribution** in the coupling stage appears homogeneous, whilst a clear pressure offset is given between the inlet and the TMP by a factor of two[1]. Furthermore, the **ion velocity** in the EUV focus position is congruent to the one-dimensional Maxwell-Boltzmann distribution.



[1] SPARTA program package, S. J. Plimpton et. al, Physics of Fluids, 31, 086101 (2019)

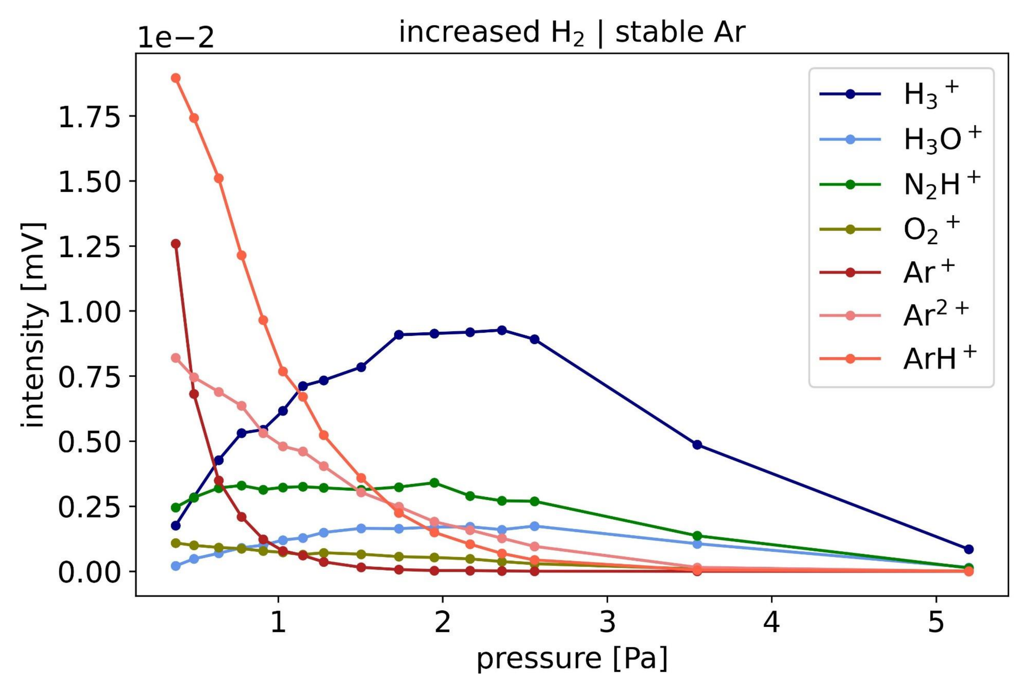
The Setup



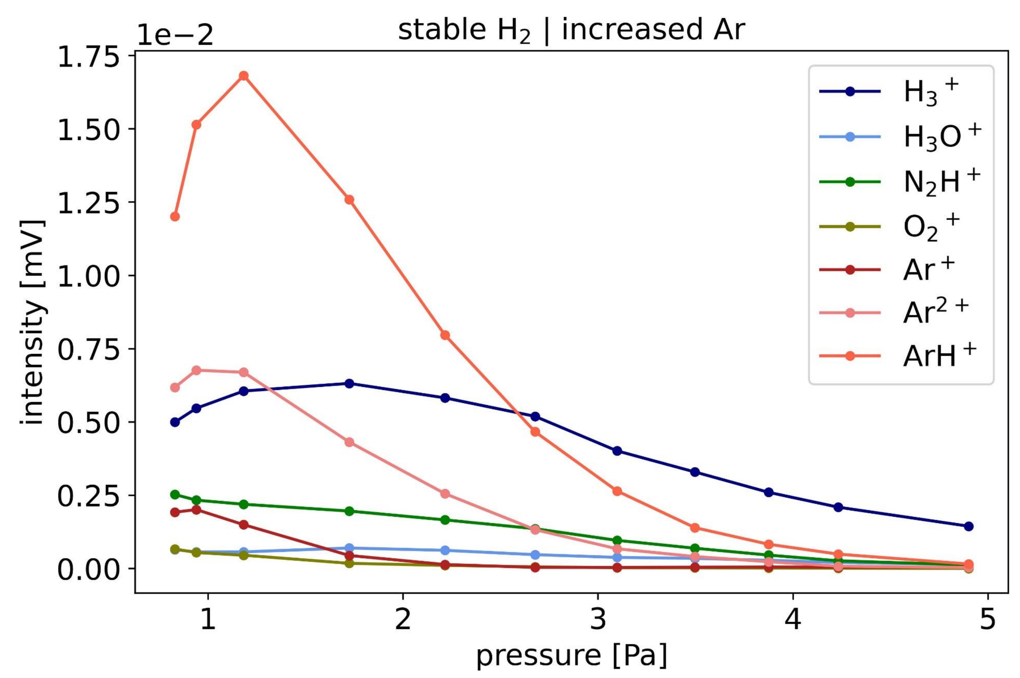
Experimental Results

EI mode Using electron ionization, the resulting spectra reflect the neutral species composition present in the gas matrix (H_2^+, Ar^+, Ar^{2+}), air-related ions (N^+, O^+, N_2^+, O_2^+) water ions (H_2O^+), and a few chemical ionization (CI) products (N_2H^+). No spectral changes are observed when the EUV pulse frequency is varied or turned on/off.

NI mode During native ion sampling from the plasma the dominant species are H_3^+, H_3O^+, N_2H^+, O_2^+, Ar^+, Ar^{2+}, and ArH^+ in addition to OH^+ and O_2H^+. The signal intensity scales linearly with the EUV pulse frequency.



When the hydrogen pressure is increased, the signal intensities of H_3^+ and H_3O^+ peak at 2 Pa and drop afterward. The peak intensities of all the other species only display a decrease as the pressure rises.



When increasing the argon pressure, the signal intensities for Ar^+, Ar^{2+}, and ArH^+ reach a maximum at 1.2 Pa. The signals of H_3^+ and H_3O^+ peak at 1.8 Pa. Towards higher pressures the signal intensities of all the species drop.

Conclusion and Outlook

These first measurements (as part of a long-term campaign) have shown that:

- Exclusively the results in **NI** mode provide information about the ion formation in EUV-induced plasmas
- In **EI** mode the TOF-MS acts like a residual gas analyzer because native ions will not reach the analyzer or become ionized again
- Increasing signal intensity through a higher EUV frequency is traced back to the larger amount of energy present for ionization
- The **decreasing signal intensity** with rising pressure is surprising. It could be caused by non-grounded surfaces in the plasma area or by volume recombination, even though the pressure region is uncommon for the effect[2].

More detailed measurements are necessary to clarify this effect. Furthermore, the influence of a distance variation between the EUV focus position and sampling port will be investigated.

[2] M. A. van de Kerkhof, *EUV-induced Plasma, Electrostatics and Particle Contamination Control*, Eindhoven University of Technology (2021)

Acknowledgment

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