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

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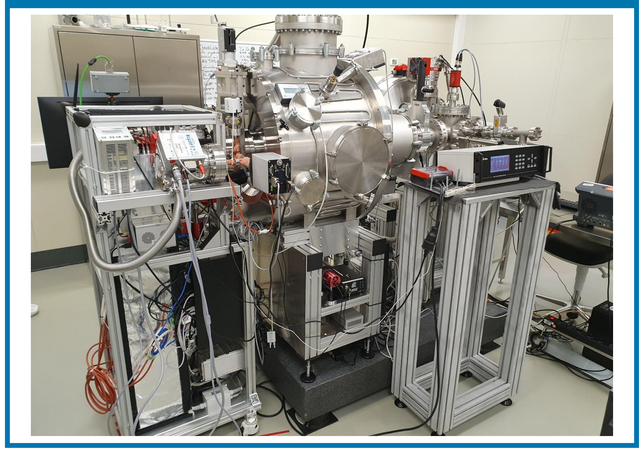
Introduction

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 wavelength of 13.5 nm without source gases influencing the hydrogen atmosphere.

The Setup



Methods

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

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
  - focused spot size of 60 µm
  - typical power of 400 µW
  - typical intensity of 100 mW/mm²

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

Costum built ion source (Physical Chemistry, University of Wuppertal). Provides
- electron ionization (EI) mode
- transmissive mode for native ion (NI) sampling

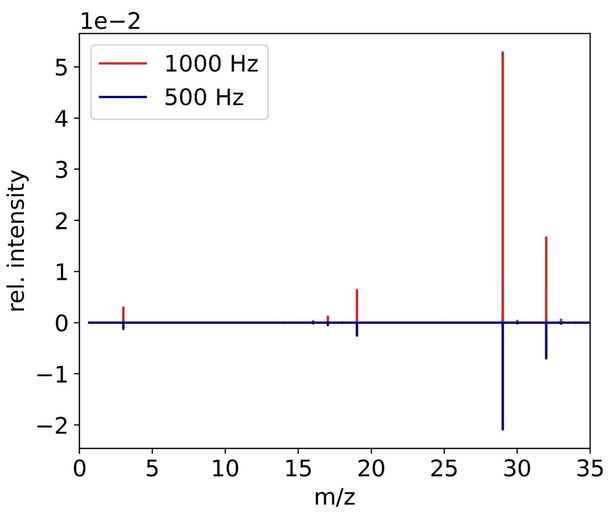
Large time-of-flight mass spectrometer (TOF-MS) (TOFWERK AG, Thun, Switzerland)
- ion transfer quadrupole (100 mm length)
- flight tube length (folded): 2700 mm

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

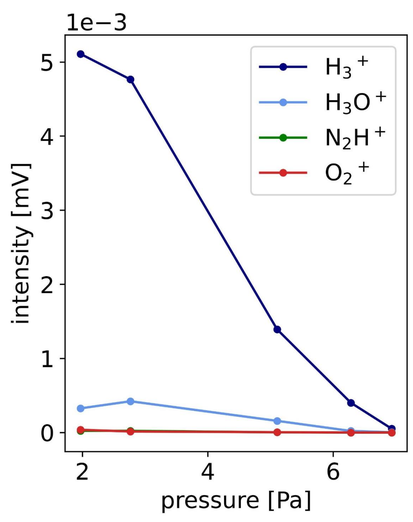
Experimental Results

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

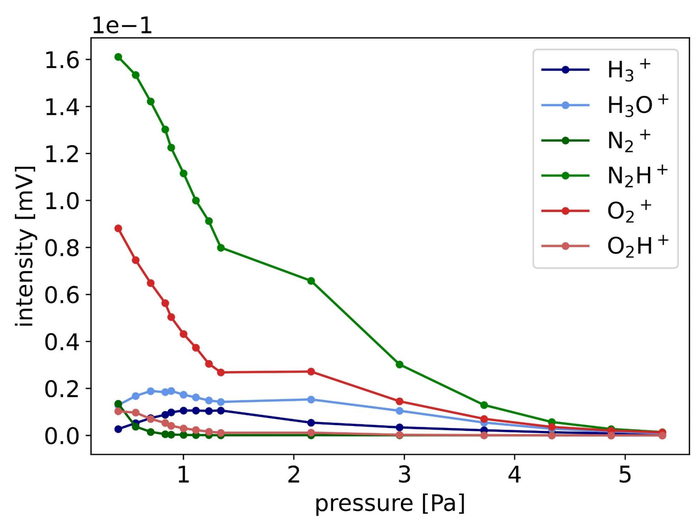
NI mode During native ion sampling from the plasma the dominant species are H_3^+, H_3O^+, N_2H^+, and O_2^+ in addition to OH^+ and O_2H^+.



The signal intensity scales with the EUV pulse frequency; when doubled from 500 to 1000 Hz the signals increase by a factor of 2.5.

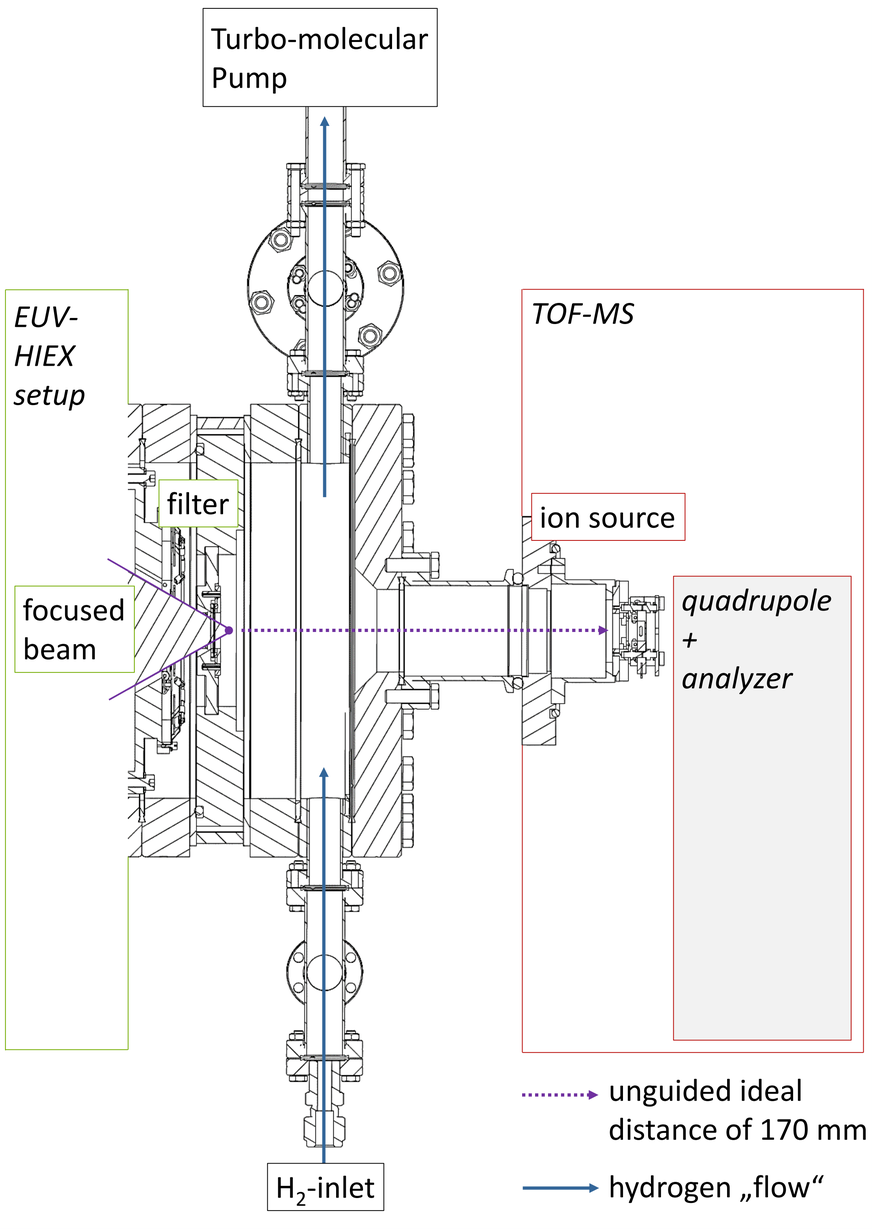


The signal intensity of all species decreases with rising pressure. This is observed in pure hydrogen…

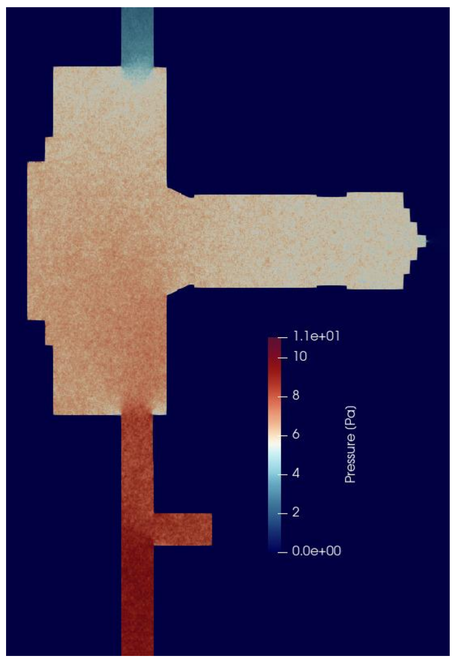


… and in air-spiked atmospheres.

The Coupling Stage

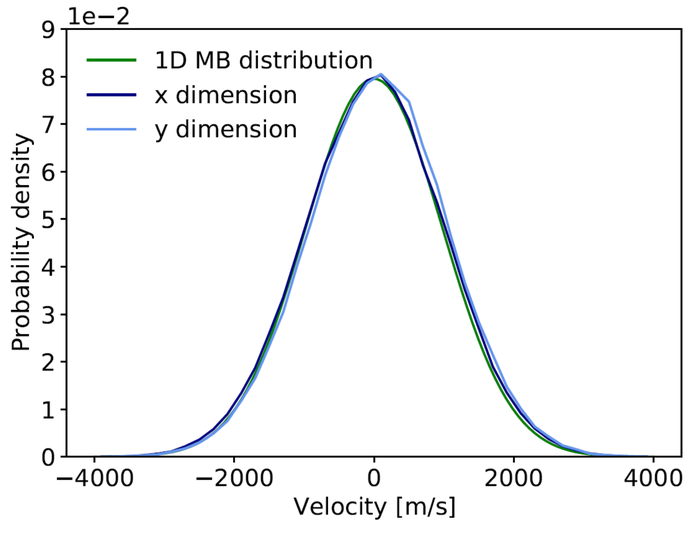


Simulation Results



The **pressure distribution** in the coupling stage appears homogeneous, whilst a clear pressure offset is given between the inlet and TMP by a factor of 2. Furthermore, the **ion velocity** in EUV focus position is congruent to the one-dimensional Maxwell-Boltzmann distribution (1D MB).

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



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 as opposed to
- In **EI** mode the TOF-MS acts like a residual gas analyzer because native ions probably vanish in the flood of EI ions 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 in the system is surprising at first sight **but** occurred at other EUV attachments from the group. It could be caused by floating surfaces in the plasma area or by volume recombination, even though the pressure region is uncommon for the effect[1].

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.

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

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