

SPECIALLY CONFIGURED HIGH-PRESSURE RESIDUAL GAS ANALYZER FOR MEASUREMENT OF CONTAMINANTS' PARTIAL PRESSURES IN HYDROGEN PLASMA SPUTTERING AND NANOLITHOGRAPHY ENVIRONMENTS



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Abstract

Accurate, quantitative monitoring of trace contaminants in hydrogen-rich environments is essential for controlling processes that govern the lifetime and performance of EUV lithography tools and related plasma-based sputtering studies.

We report a specially configured high-pressure residual gas analyser (HP-RGA) platform for 1–10 Pa H₂ with trace species in the 10⁻⁷–10⁻² Pa range, combining precision gas/liquid dosing, in-situ flow calibration, and calibrated leaks with optimized conductance and pressure control.

The upgraded ion source and secondary electron multiplier settings enable dosing/quantification accuracies better than 5% for gases and 10% for H₂O, with detection limits in 5 Pa H₂ of <0.5 ppm for H₂O and <0.1 ppm for N₂. Uncertainties linked to pump speed and leak calibration are reduced using balanced H₂/N₂ turbomolecular pumping.

These capabilities support studies of metal mirror-coating sputtering and surface chemistry relevant to nanolithography, including plasma-assisted carbon removal, hydroxylation of metal oxides, and polymer outgassing that can modify sputtering via reactive species.

In parallel, we address a key limitation for quantitative HP-RGA interpretation: spectra of H₂/O₂ and H₂/N₂ mixtures show ion signals inconsistent with direct parent-molecule ionization (e.g., formation of N_xH_y⁺ species and apparent O₂→H₂O conversion), demonstrating that ion–molecule chemistry inside closed ion sources can bias inferred partial pressures.

We develop a two-stage COMSOL Multiphysics modelling workflow to identify and quantify these artifacts, using a 0D chemical-kinetics screen to isolate dominant pathways and a 3D particle-based ion-source model that incorporates geometry, operating potentials, space-charge, charged-particle transport, and coupled gas-phase chemistry.

The results show that charge-transfer reactions involving H₂⁺/H⁺ dominate at elevated pressures (≈10⁻²–10⁻¹ mbar in the ionization region) and can enhance ions originating from trace components; for H₂/N₂, reaction channels producing N₂H⁺ at m/z = 29 may interfere with N₂ quantification based on m/z = 28. These results show that ion-source chemistry can introduce deviations in HP-RGA measurements if not properly accounted for.

Together, the calibrated instrument and chemistry-aware modelling provide a pathway to more reliable HP-RGA quantification of H₂O and N₂, enabling improved process monitoring, stability, and lifetime studies for next-generation EUV photomasks and optical mirrors.

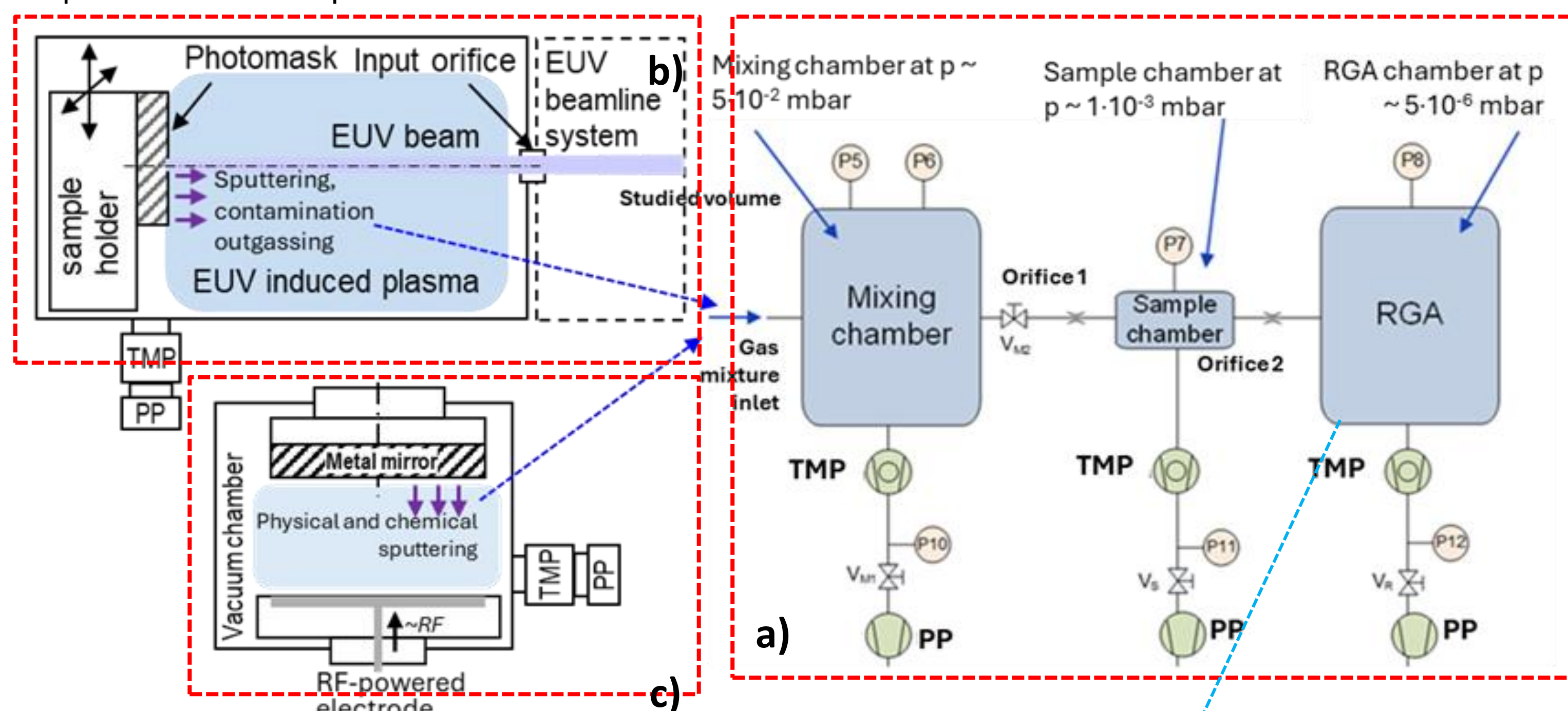


Fig. 1. High pressure RGA with mixing and sample chambers in various plasma sputtering environments: a) RGA concept outline, V - valves, P/PP - pressure gauges/pre-pump, TMP - turbomolecular pumps; b) application illustration: EUV lifetime test of EUV sensitive optical materials in the EBL-2 research facility; c) application illustration: studies of mirror surface resilience to sputtering at various background pressures.

A closed-ion-source Residual Gas Analyzer (RGA) can report biased gas compositions because ionization and subsequent ion–molecule chemistry inside the ion source can convert neutrals into new ionic products before detection.

Two key artifacts:

- protonation in H₂/N₂ mixtures, yielding N_xH_y⁺ species such as N₂H⁺, and
- apparent O₂→H₂O conversion when air is mixed with H₂, which can create large errors in inferred partial pressures and shows poor repeatability.

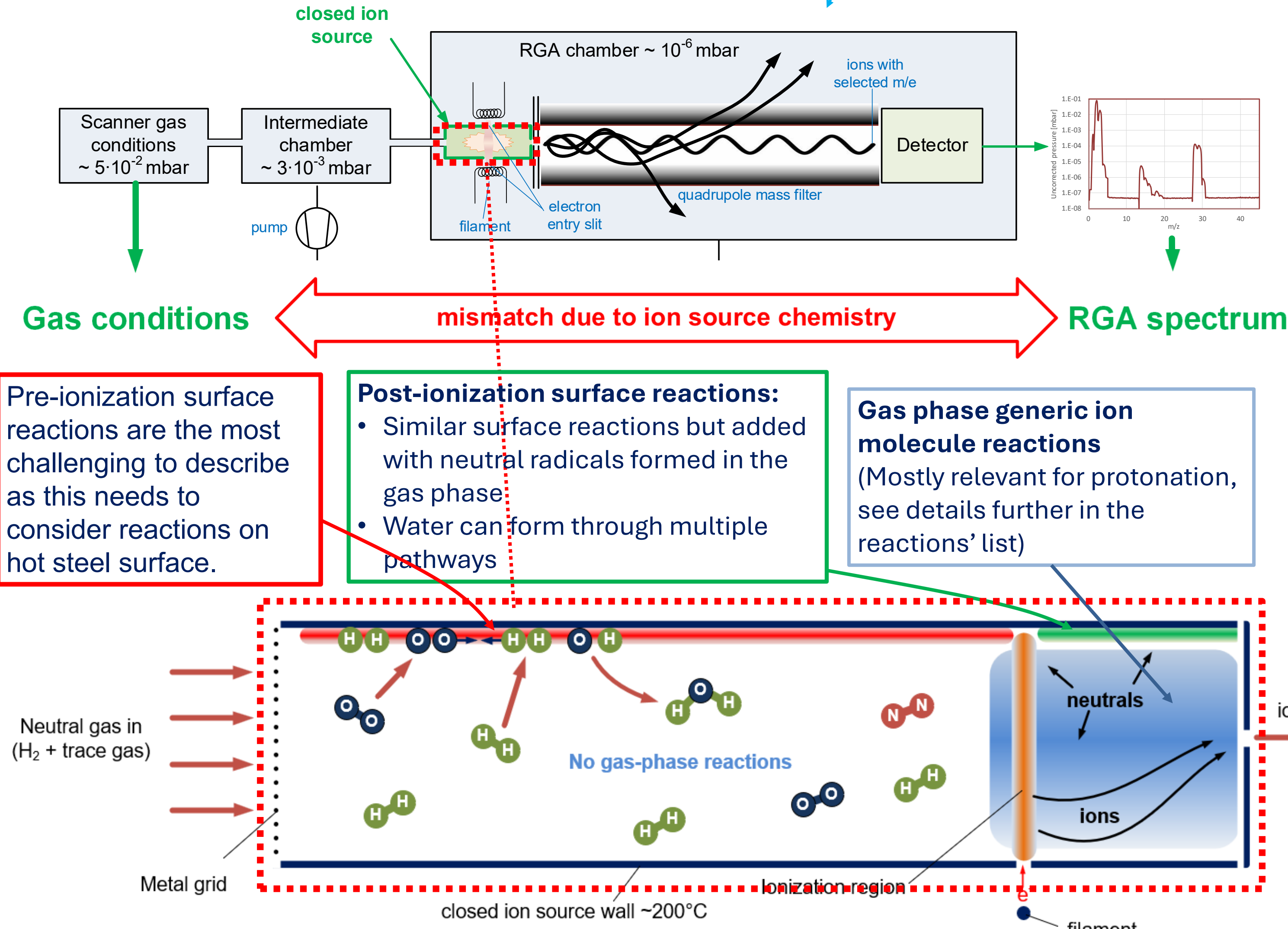


Fig. 2. Detail of the RGA and ion source illustrating chemical reactions taking place in different regions of the closed ion source and key reaction mechanisms.

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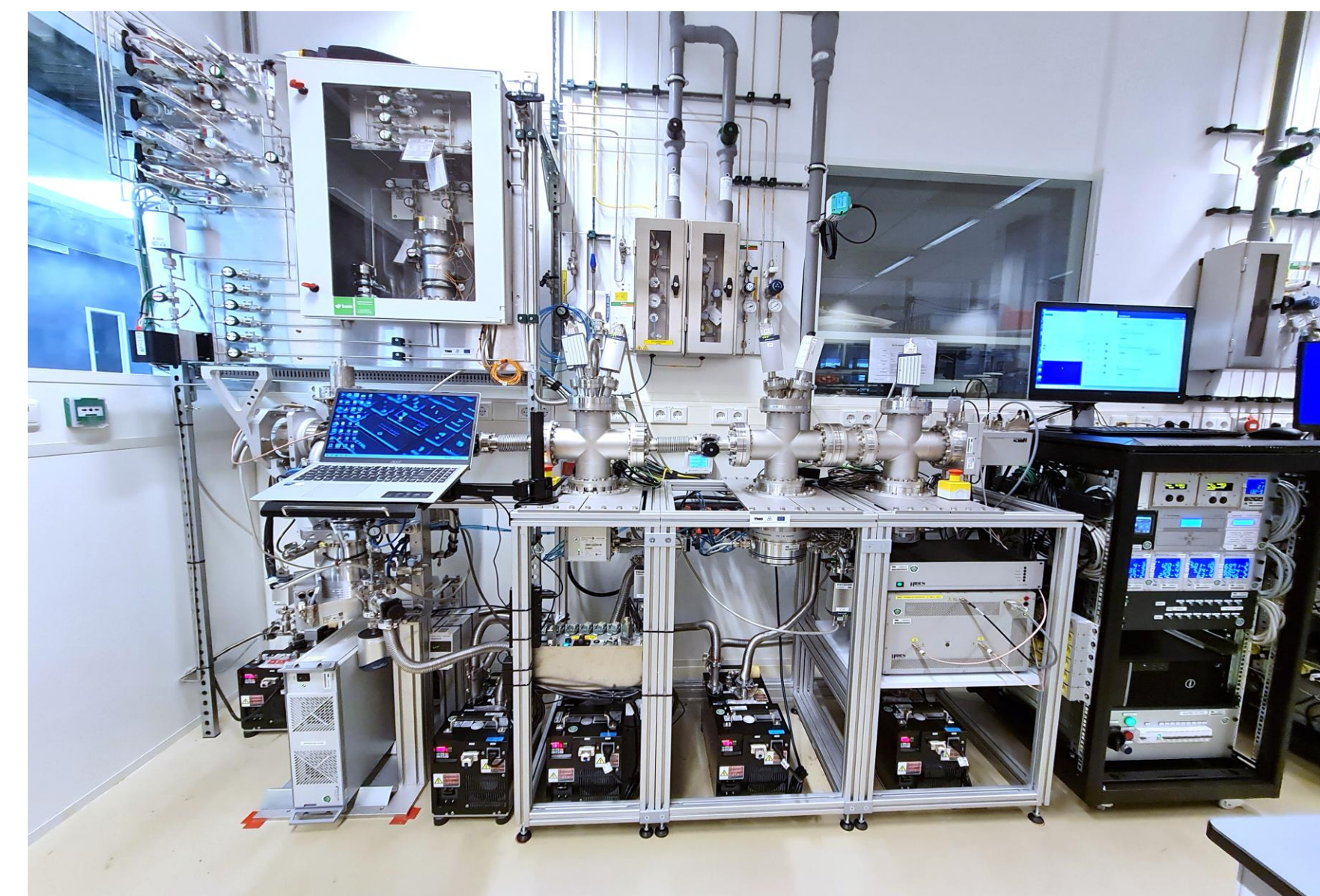


Fig. 3. Experimental setup including the high pressure RGA system.

Why this consideration is important?

- Lifetime stability is not sufficient
- Simulation results do not fit RGA experimental data
- Dynamic range of ionizer is not sufficiently broad to extract scaling laws from experiments.
- Electron induced particle release measurement configurations may have low reproducibility

Objective: Investigate and quantify the chemical processes occurring within the RGA.

Methodology:

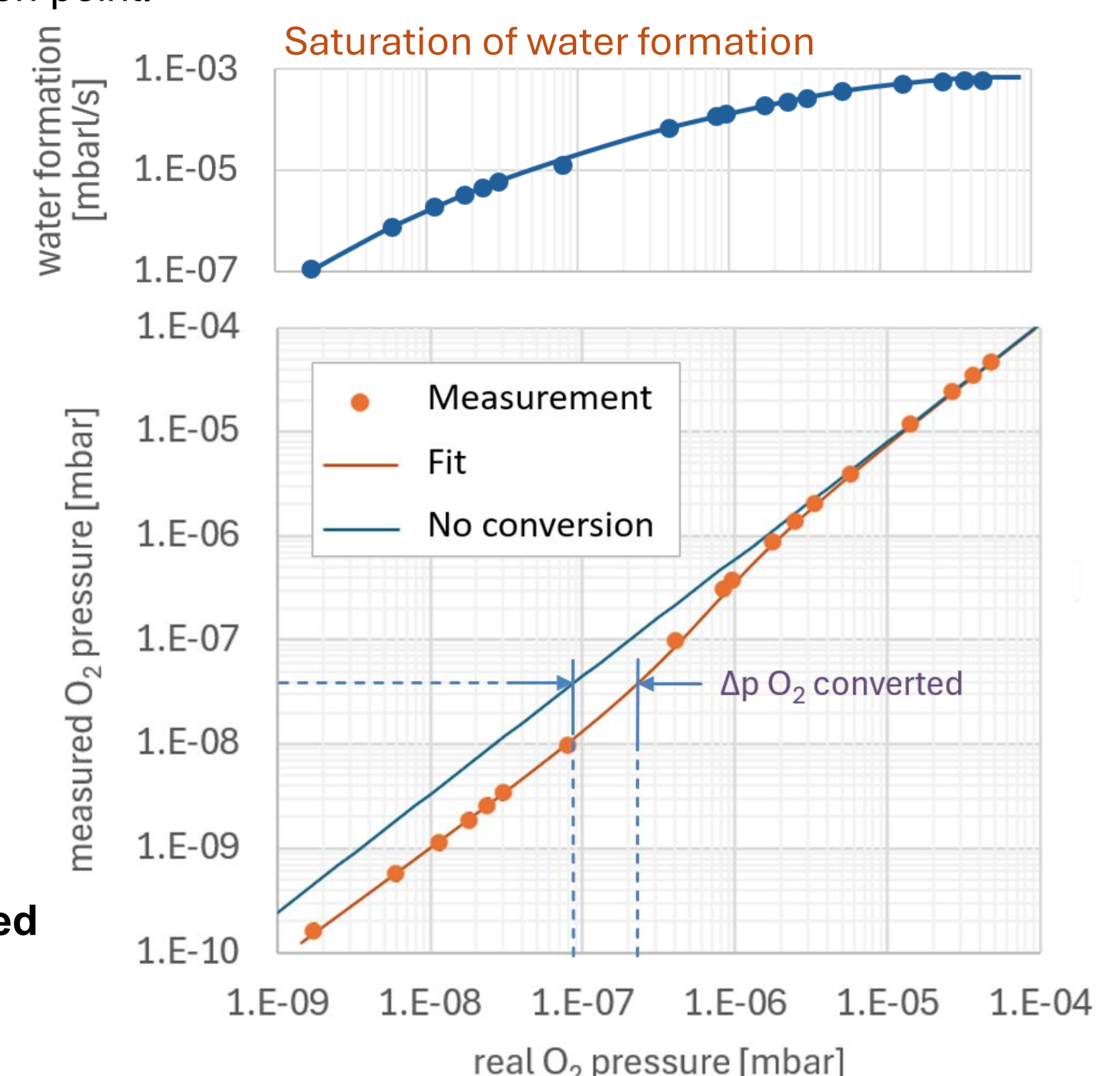
- Determine the relationship between actual and measured partial pressures
- Analyze RGA spectra to identify and quantify active chemical species

Experimental findings:

- The RGA readings differ from the expected values for a scenario with no chemical conversion.
- This difference indicates the degree of oxygen conversion into water.
- At low partial pressures 60–80% of the O₂ is converted to water
- As oxygen concentration increases, the fraction of converted oxygen decreases, suggesting water formation reaches a saturation point.

- Scanner gas conditions are measured with a High-pressure Residual Gas Analyzer with closed ion source
- Ideally the detected ions represent scanner gas composition
- However, reactions in the ion source alter the gas composition

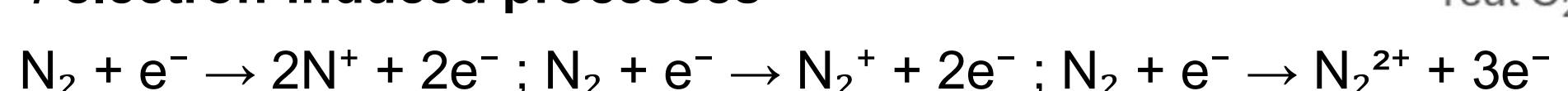
Fig. 4. Measured O₂ pressure illustrating O₂ conversion into water. Anticipated readings (blue curve) suggest no chemical conversion.



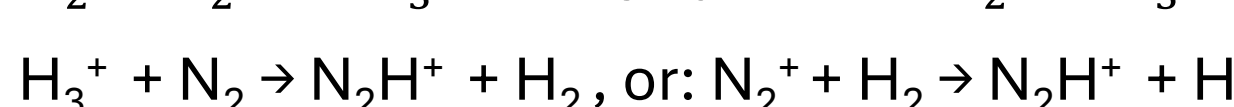
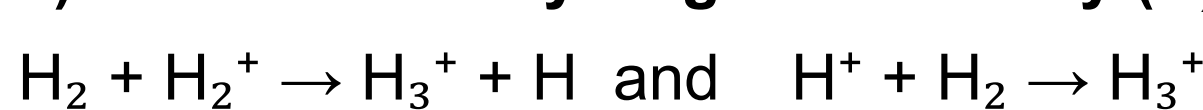
Key chemical reactions mentioned

1) Electron-impact ionization

/ electron-induced processes



2) Protonation / hydrogen chemistry (N_xH_y⁺ formation pathway)



3) Water/oxygen-related ion formation (linked to O₂→H₂O artifact)

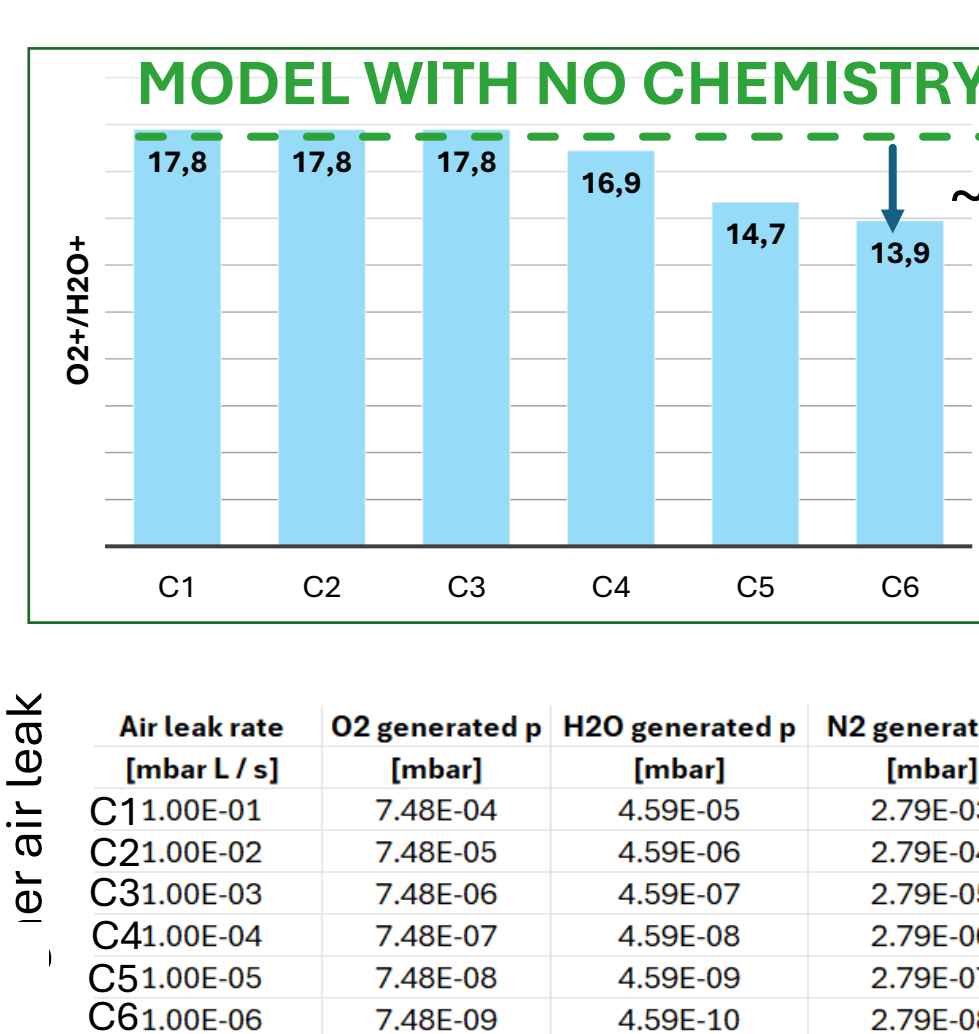
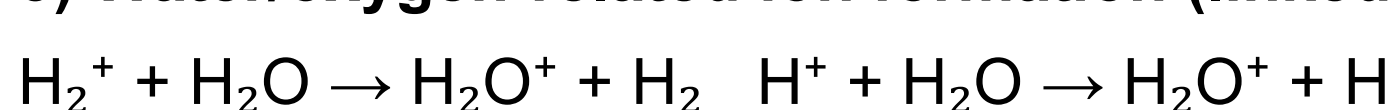


Fig. 5. Example of the simulation: O₂ → H₂O conversion. Maximum “conversion” of 20% observed. Note that this is for the modelling conditions using H₂ + leaked air:

