Pulsed Gas Injection for Signal Enhancement in Residual Gas Analysis under Ultrahigh Vacuum Conditions

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Introduction

Residual gas analyzers (RGAs) are the standard tool for vacuum diagnostics and leak testing in a range of applications, from semiconductor fabrication facilities to particle accelerators and vacuum furnaces. However, they sample the vacuum continuously without pre-concentration, and sensitivity is set directly by the instantaneous partial pressure. Under ultrahigh vacuum (UHV) conditions, the number of molecules can be very small, making it intrinsically hard to detect trace-level leaks against the background. Dedicated helium leak detectors already exploit a related technique: admitting gas to a turbomolecular pump's (TMP) foreline rather than its high-vacuum inlet [1,2] allows helium to reach the spectrometer more easily, collecting that foreline gas before release [3] increases sensitivity by several orders of magnitude. The issue of working with RGAs under UHV conditions is still being discussed [4]. This work presents an extended version of this principle, where the general connection between the vacuum chamber and the RGA is a TMP with a valve to accumulate gas for pulsed release and multi-species analysis.

Methods

We connected the RGA through a TMP to a UHV system, with a valve in between. The system now consists of just one vacuum chamber with an integrated RGA. Closing the valve under UHV conditions lets the TMP accumulate the residual gas in a small volume. Opening it releases the accumulated gas as a concentrated pulse into the RGA ion source. Using a helium test leak as a model trace source, we quantify the resulting gain simultaneously for H_2, He, (H_2O,) N_2, O_2 and CO_2 as a function of accumulation time.

Turbopump	Pfeiffer HiPace 80
Analyzer	Hiden HAL-series quadrupole RGA
Valve	Swagelok ALD3 diaphragm valve
Accum. volume	126 cm^3
Accum. Times (t_a)	5, 20, 60, 150, 360 s
Species monitored	H_2, He, N_2, O_2, CO_2

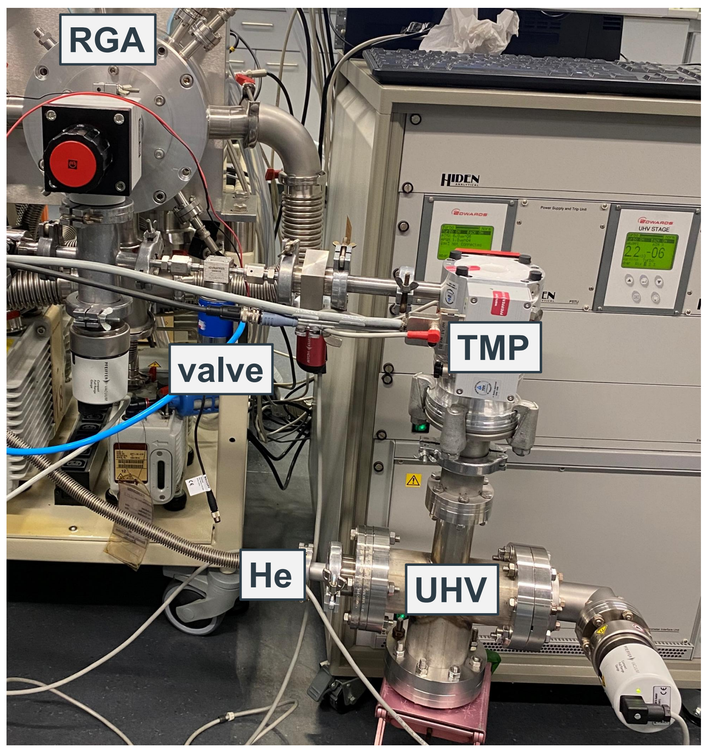
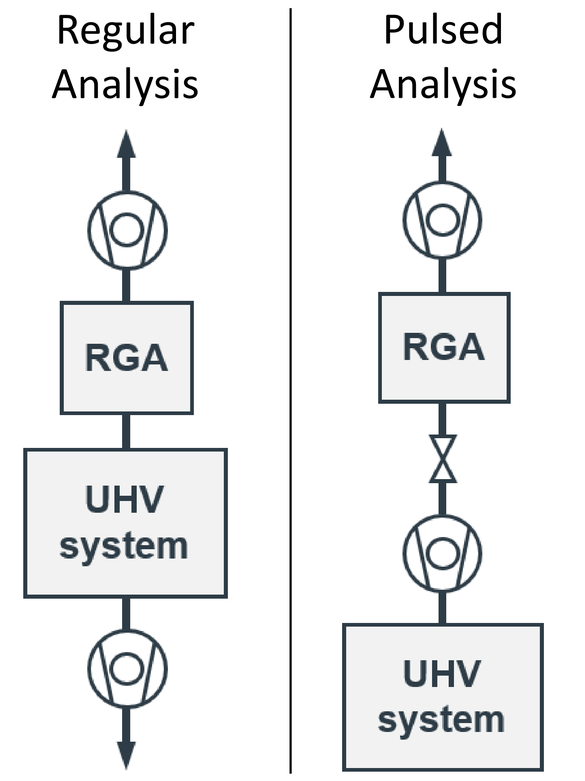


Fig. 1 — Laboratory setup at the Hiden RGA.



Results

During accumulation, the isolated volume between the TMP and the valve traps the helium derived from the leak, resulting in a fall in the downstream signal by almost an order of magnitude, while the levels of H_2, N_2, O_2 and CO_2 barely change. Opening the valve releases the trapped gas in a short, concentrated burst: a rapid increase limited by the opening of the valve and the response of the RGA, followed by a slower decrease as the volume empties and the system returns to steady-state flow. The other species only rise slightly. For a few seconds, the helium signal has a high intensity.

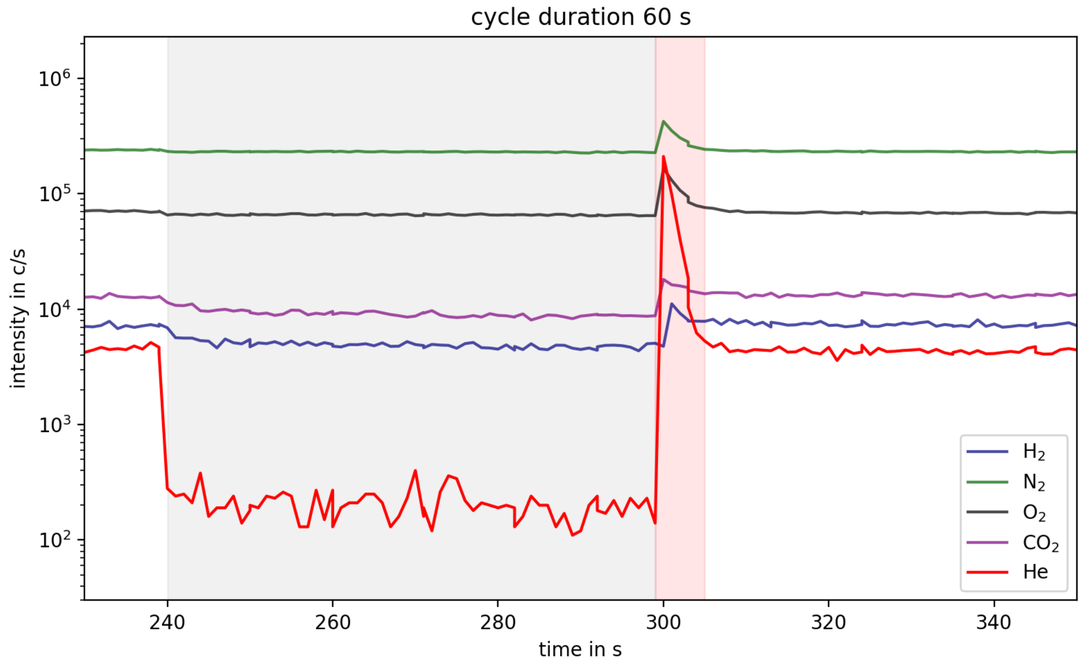


Fig. 2 — Ion chromatogram of all five species over a 60 s cycle. Grey: accumulation (valve closed) - He drops ~10× as it is trapped upstream. Red: release (valve open) - a sharp He spike appears; H_2/N_2/O_2/CO_2 rise only slightly.

Gain factor $G(t_a) = I_{peak}(t_a) / I_{baseline}$

I_{peak}: max. transient ion current after valve opening, depending on t_a.
$I_{baseline}$: steady-state current with the valve continuously open.

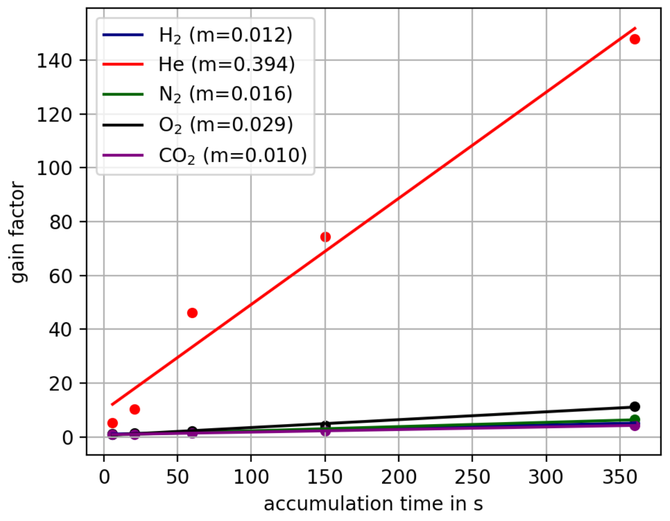


Fig. 3 — Gain factor G vs. accumulation time t for all five species. He grows linearly, reaching G≈148 at 360 s. H_2/N_2/O_2/CO_2 stay below G≈12.

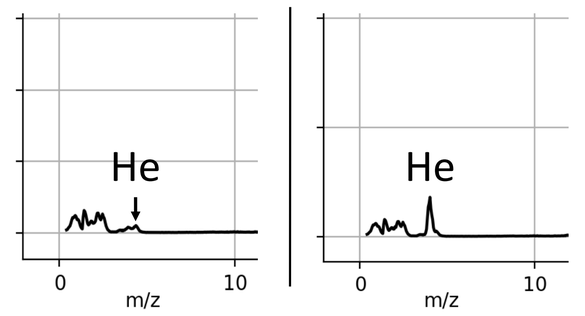


Fig. 4 — Excerpt of the spectrum. Left: regular analysis with a barely noticeable He-peak. Right: pulsed analysis with 20 s accumulation time and clear visible He-peak.

148× gain for He-peak signal with t_a = 360 s compared with continuous sampling

< 12× gain for background species H_2, N_2, O_2, CO_2 within the same accumulation time

As the helium trend is linear across the entire tested range, the gain can be easily adjusted by changing the accumulation time. Doubling the time roughly doubles the achievable enrichment, and no hardware changes are required. As the background species remain almost constant, this directly improves the He-to-background ratio, making accumulation time the simplest way to increase detection sensitivity. This enables much smaller amounts of residual gas to be detected than with regular analysis, without expensive equipment.

Acknowledgment

The generous support from the institute for pure and applied mass spectrometry (ipaMS) at University of Wuppertal, Germany, is gratefully acknowledged. Moreover, the financial support within the 14AMI project funded by the BMBF (16MEE0370) and the EU-CHIPS JU(101111948) are gratefully acknowledged.

References: [1] Briggs, US Patent 3,690,151 (1972) – [2] Handke, US Patent 5,131,263 (1992) – [3] Verheyden et al., Vacuum 21, 519 (1971) – [4] Marshall et al., Vacuum 241, 114668 (2025)