Monitoring of volatile vacuum species using remote optical emission spectroscopy

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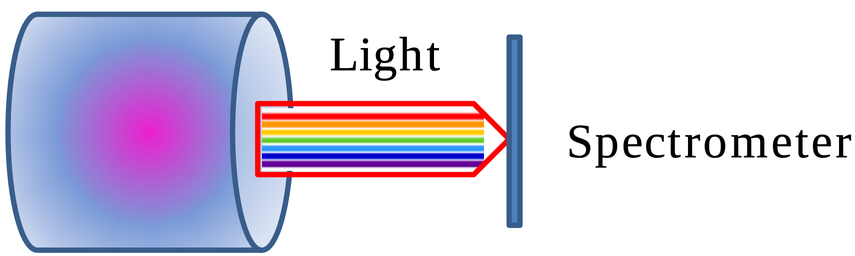
Outline of the talk

- Explanation of the Remote Plasma Emission (RPEM) method
- Gas detection and quantification by RPEM
- Examples of data from ALD, Etching and solvent analysis
- Conclusions

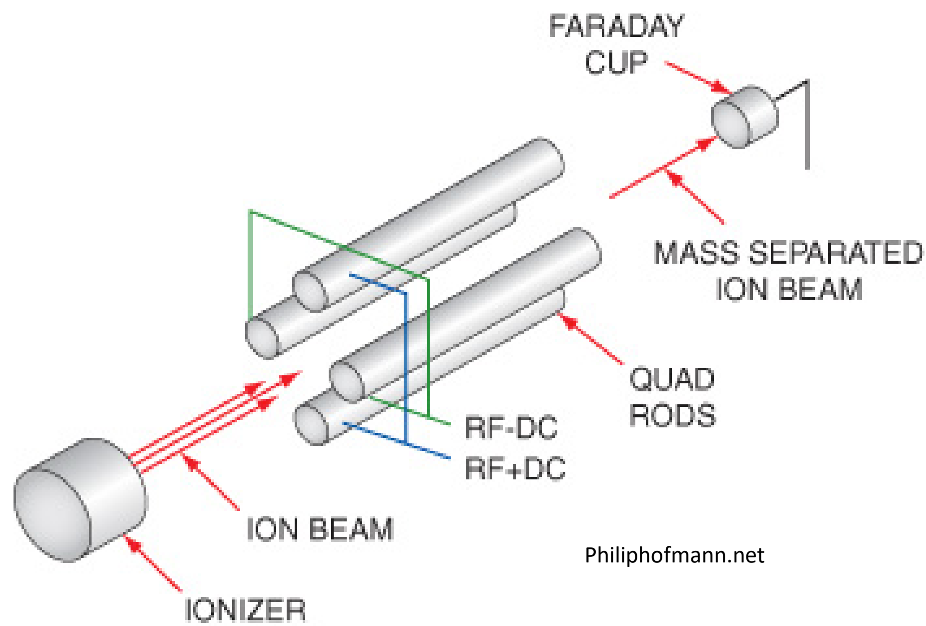
RPGA vs RGA

OPTIX – remote plasma gas analysis (RPGA)
Optical method



Low ppm detection

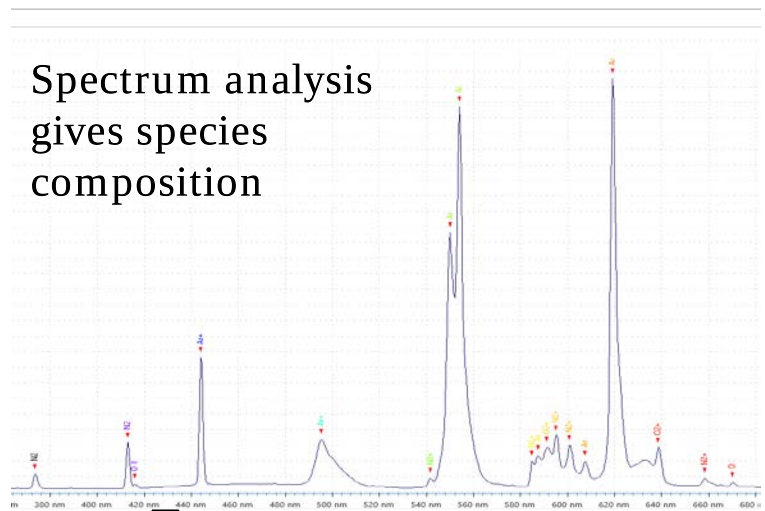
Quadrupole Residual Gas Analyzers (RGAs)



Low ppm detection

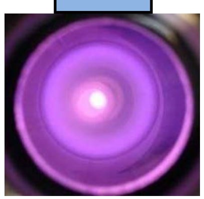
OPTIX Remote Plasma Gas Analysis RPGA

Vacuum process 0.5 to 10^{-6} mbar or with a rotary pump to support atmospheric sensing



Spectrum analysis gives species composition

Wide pressure range remote plasma generator

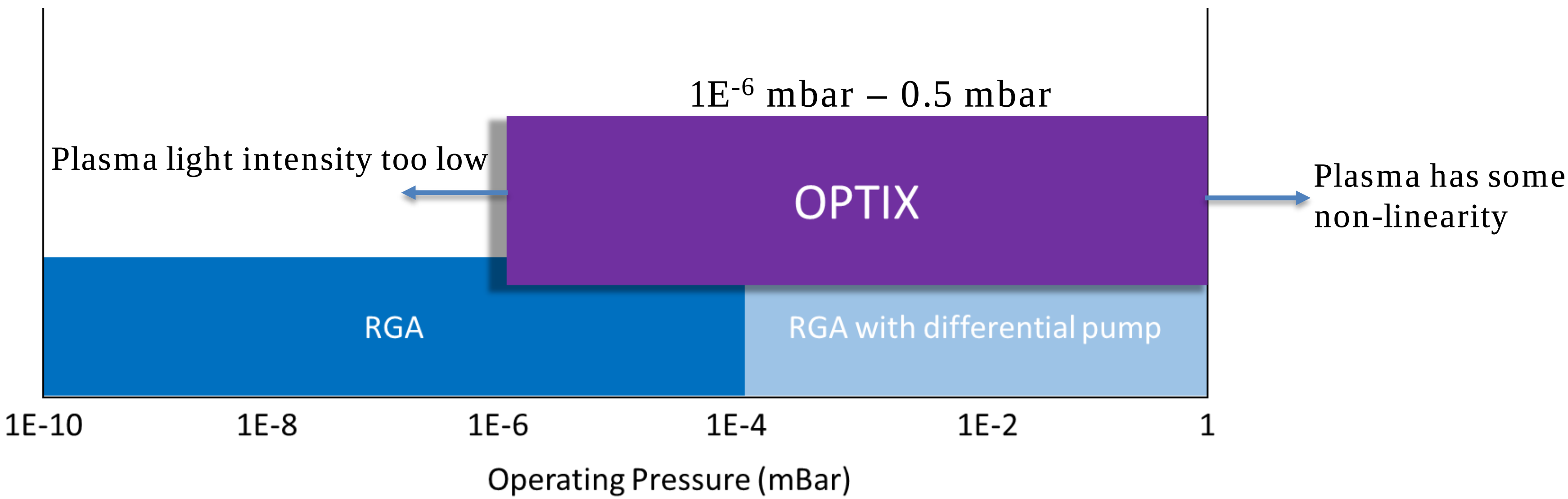


High intensity plasma

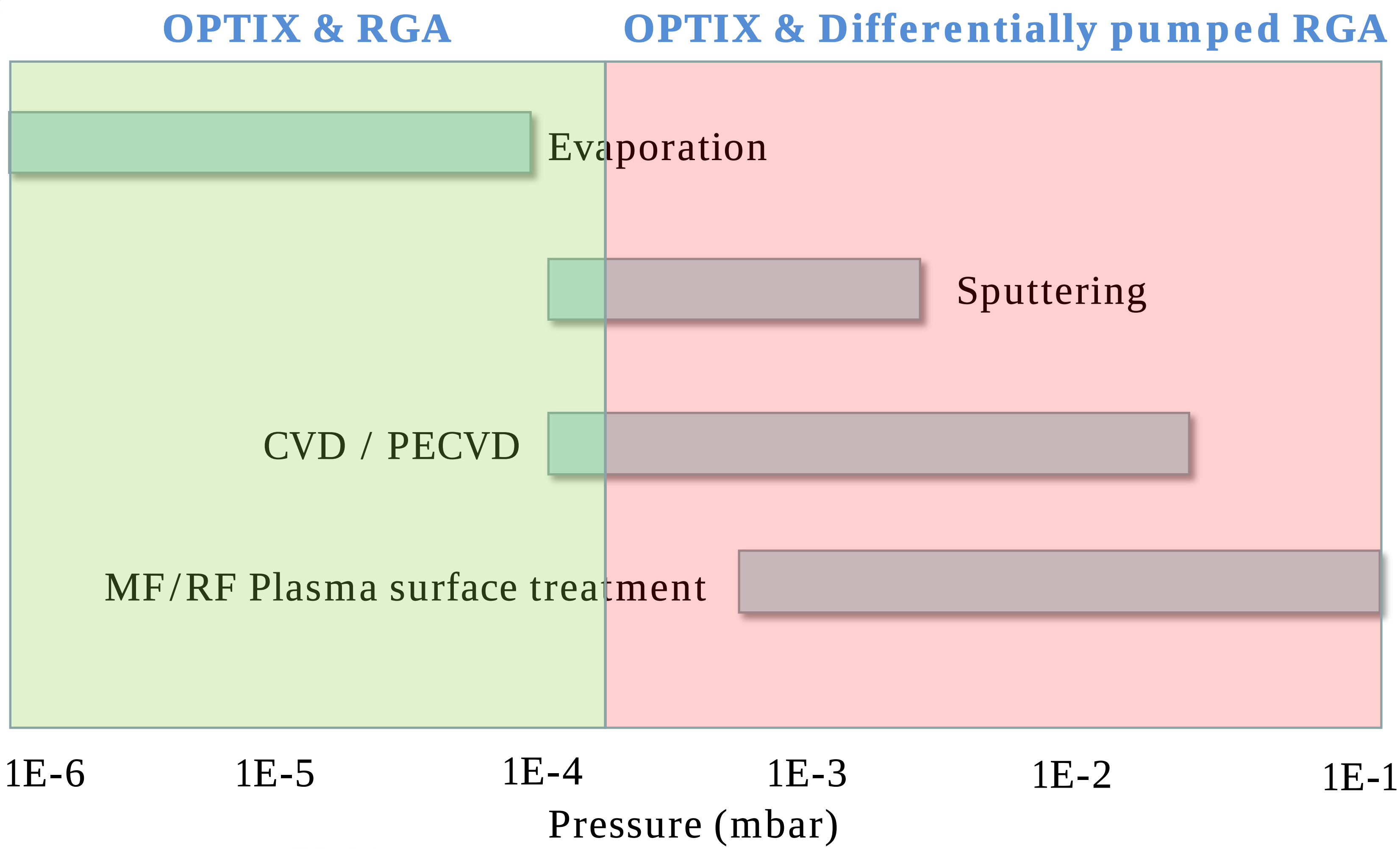
Wide range spectrometer 200-850nm

OPTIX operates in the typical plasma processing pressure range

Easy to use and wide operating range



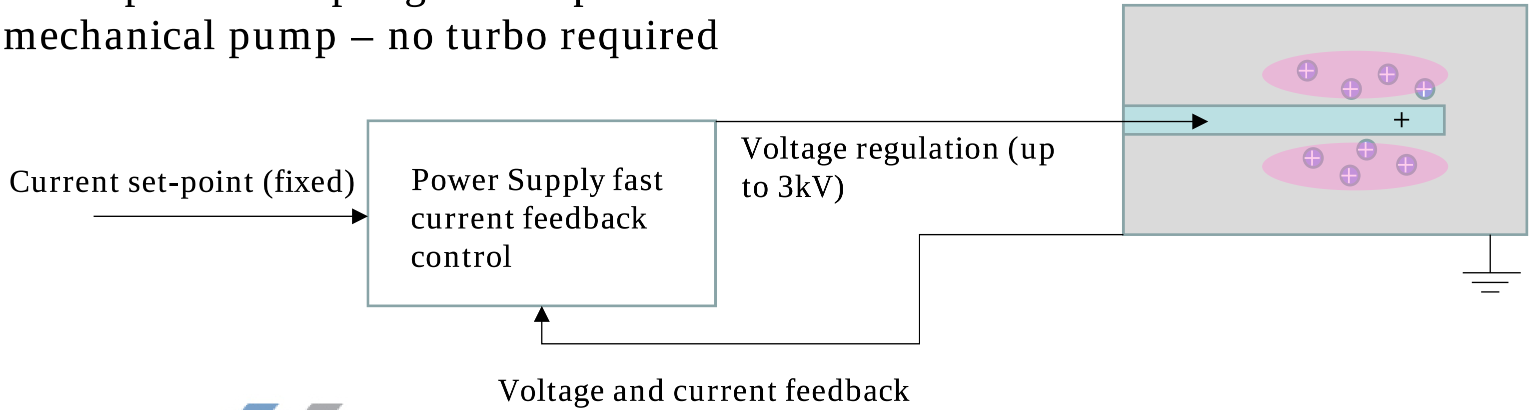
OPTIX vacuum based applications



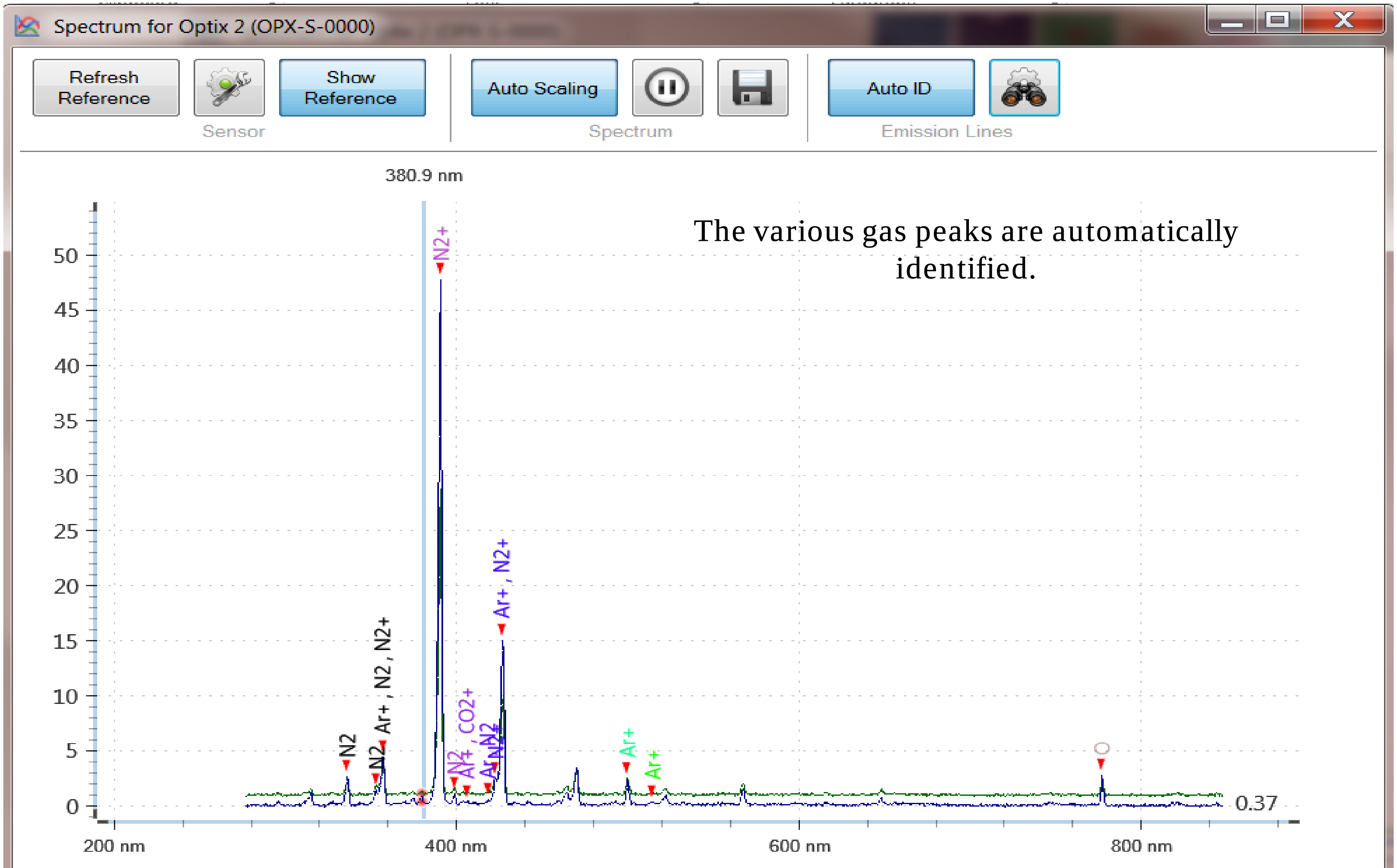
OPTIX Plasma Generation

Unlike RGA's OPTIX detector is separated from the chemicals by an optical window – more rugged – detector cannot contaminate

- Purpose designed and patented plasma generation source
- Very wide range of operation - Plasma present from 0.5 to 10^{-6} mbar
- Fast current feedback control
- Constant current = constant excitation source
- DC mode as standard for 95% of applications, Pulsed DC for highly contaminating atmospheres
- Atmospheric sampling via simple mechanical pump – no turbo required

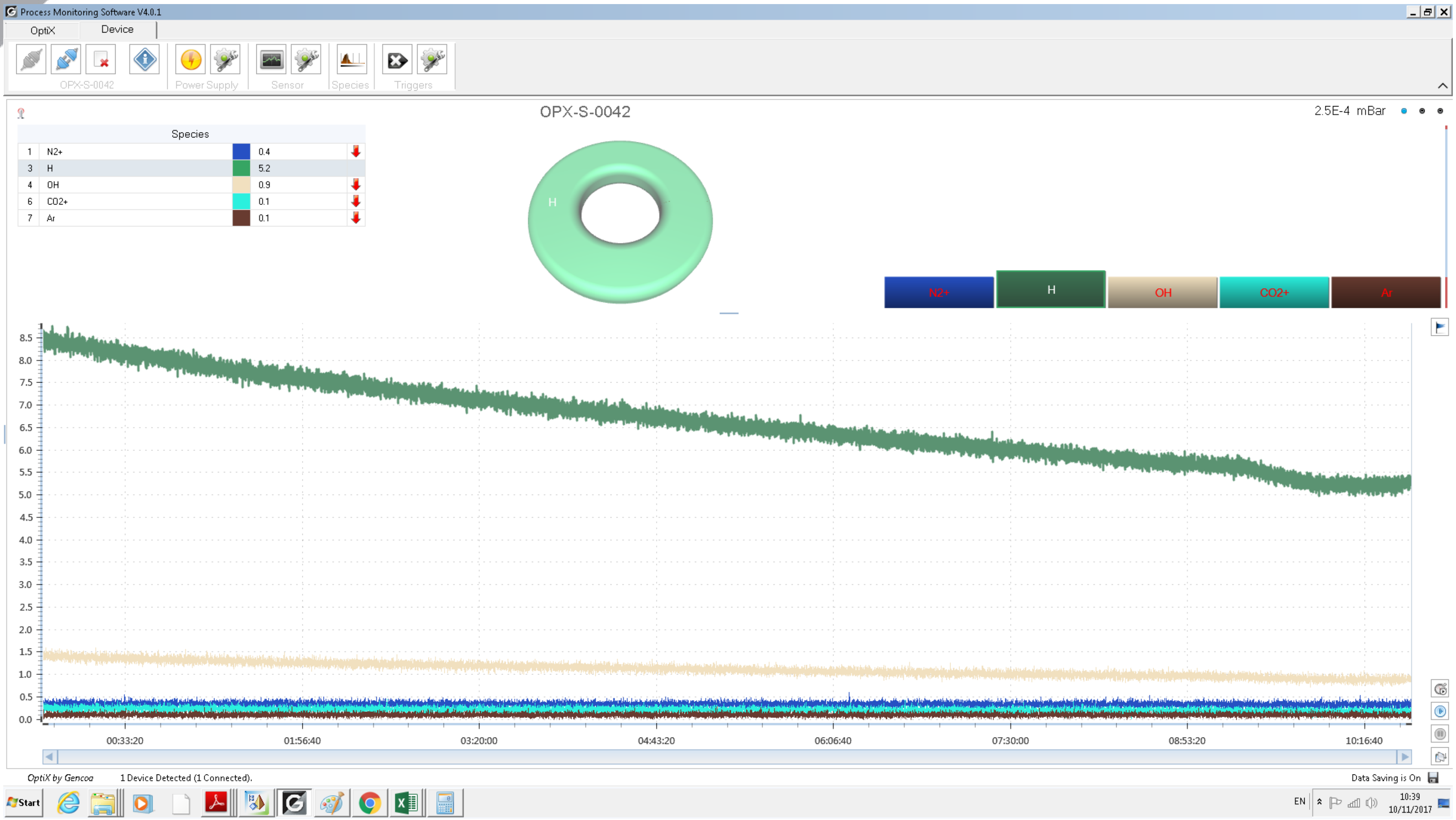


Software Spectrum View - spectrum displays the constituent species of the plasma



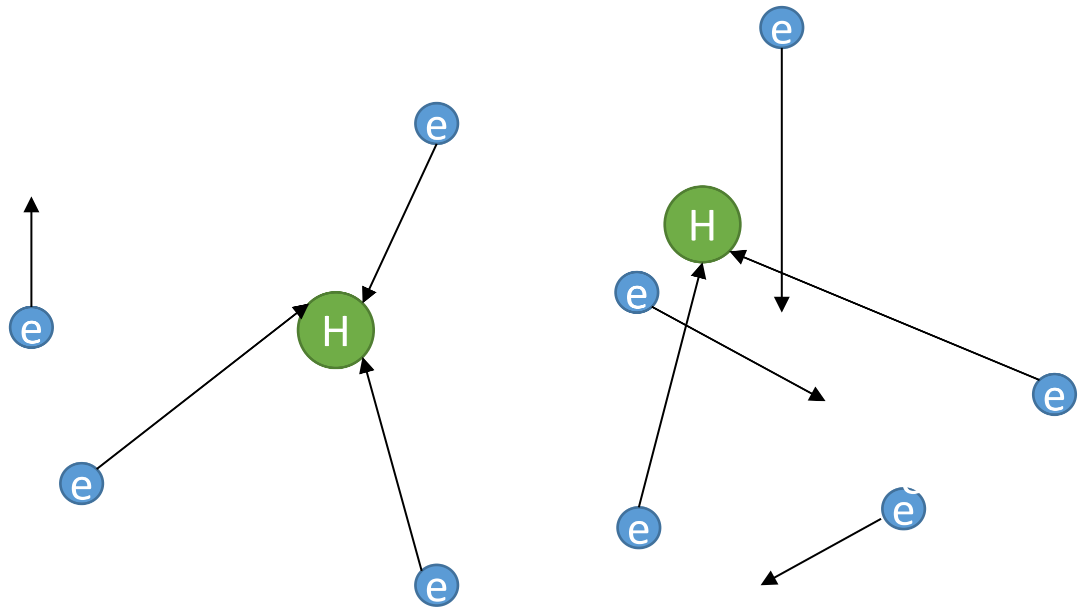
The various gas peaks are automatically identified.

Software Gas Tracking View



Quantification of gas levels using RPGA

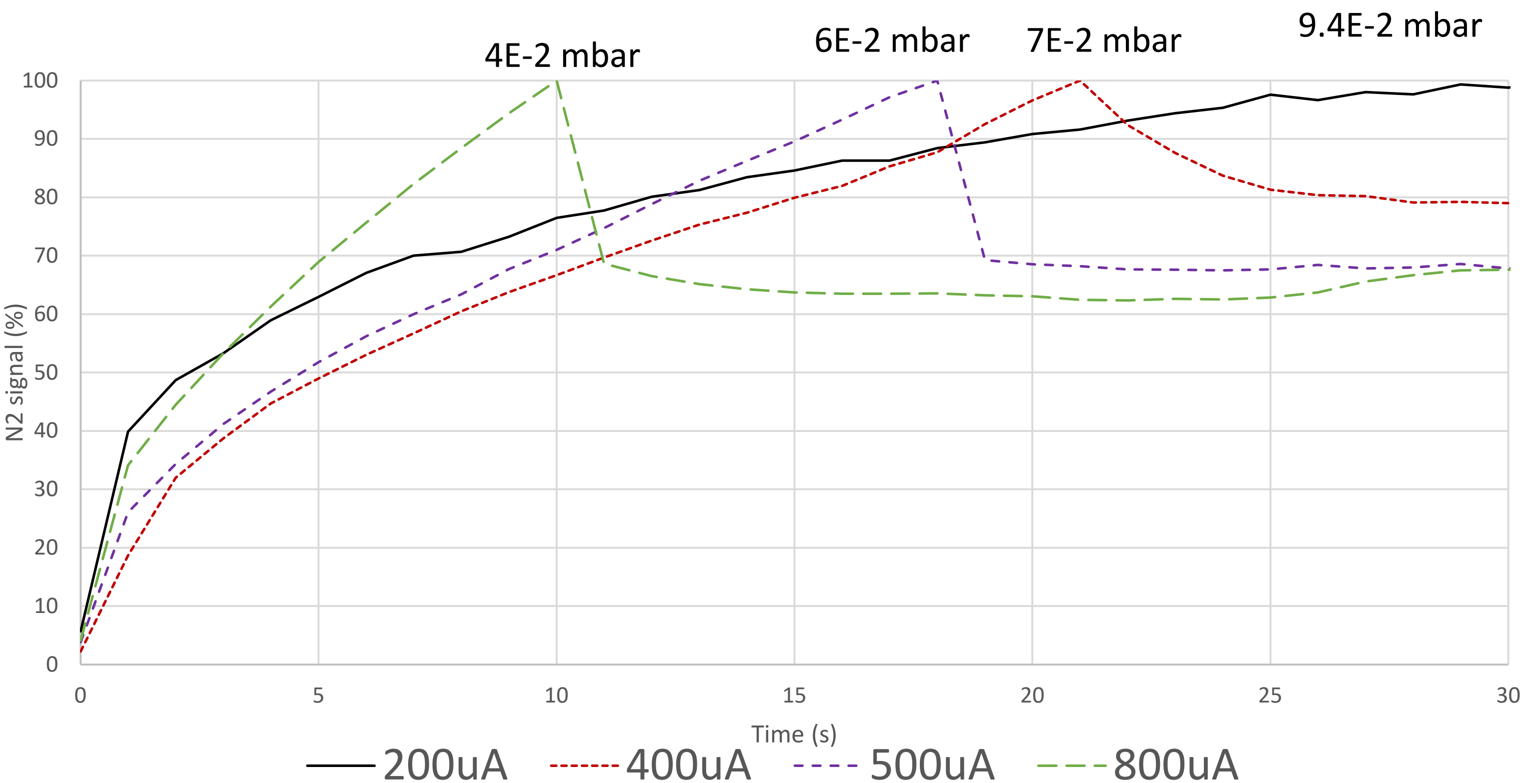
- The sensor results as displayed in the raw spectrum are **qualitative** due to the interaction of different gases within the vacuum
- Even quantities of a gas are equally likely to be collide with free electrons
- Gencoa have developed a mathematical treatment to accurately calculate gas partial pressure



Quantification - Pressure limitations

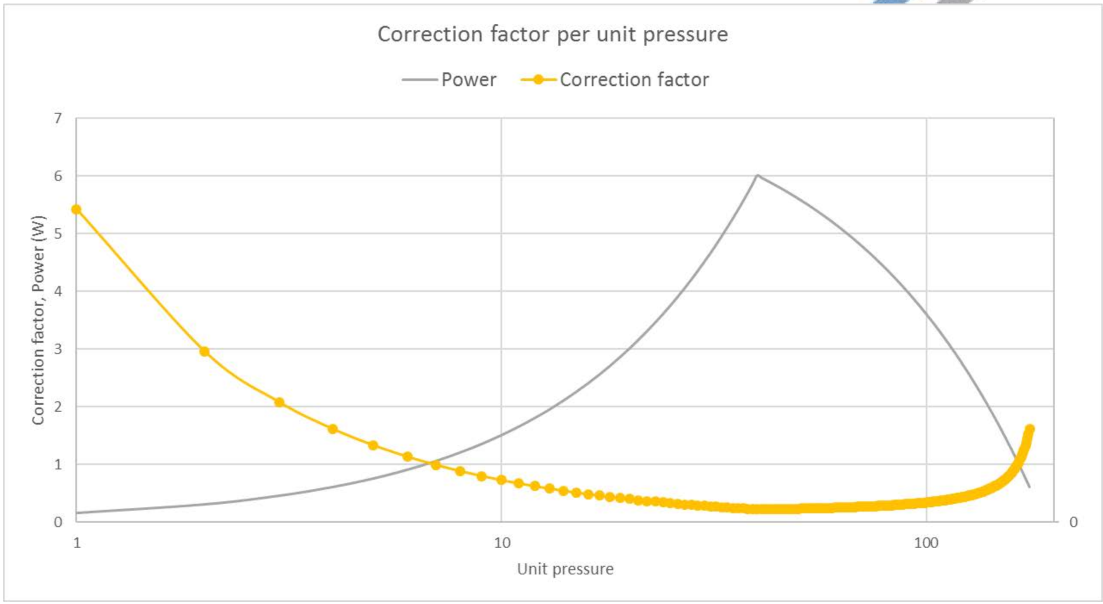
- Higher currents give a superior signal to noise ratio but at the expense of upper operating pressure limit.

- Maximum linear operating range can be achieved with a lower current setpoint – OPTIX can select the current via the user interface.

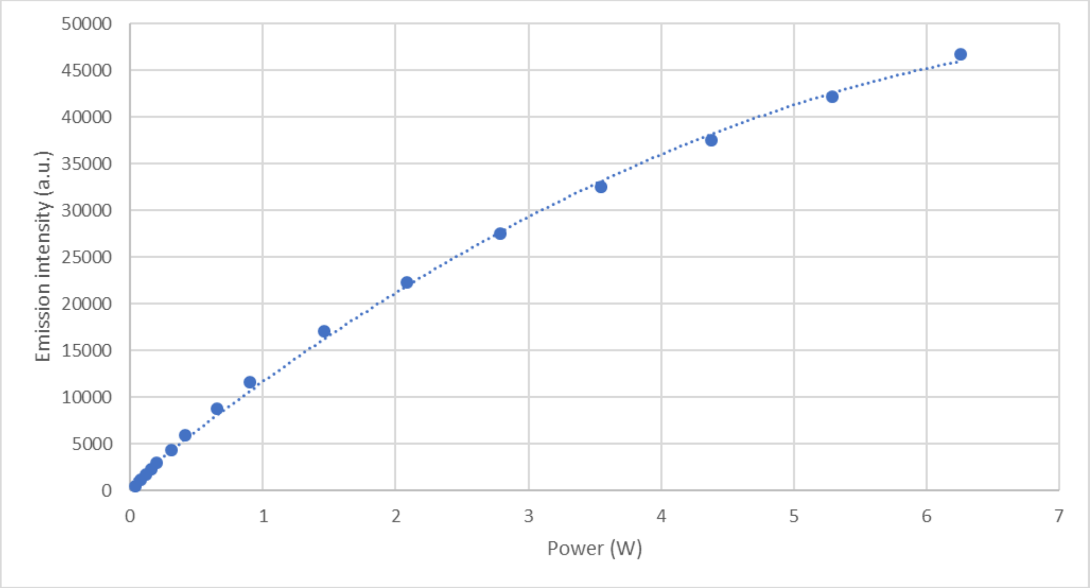


Quantification of gas partial pressures – Plasma Power correction

- The power delivered to the plasma generator will modify the emission intensities and hence distort the gas partial pressure measurement

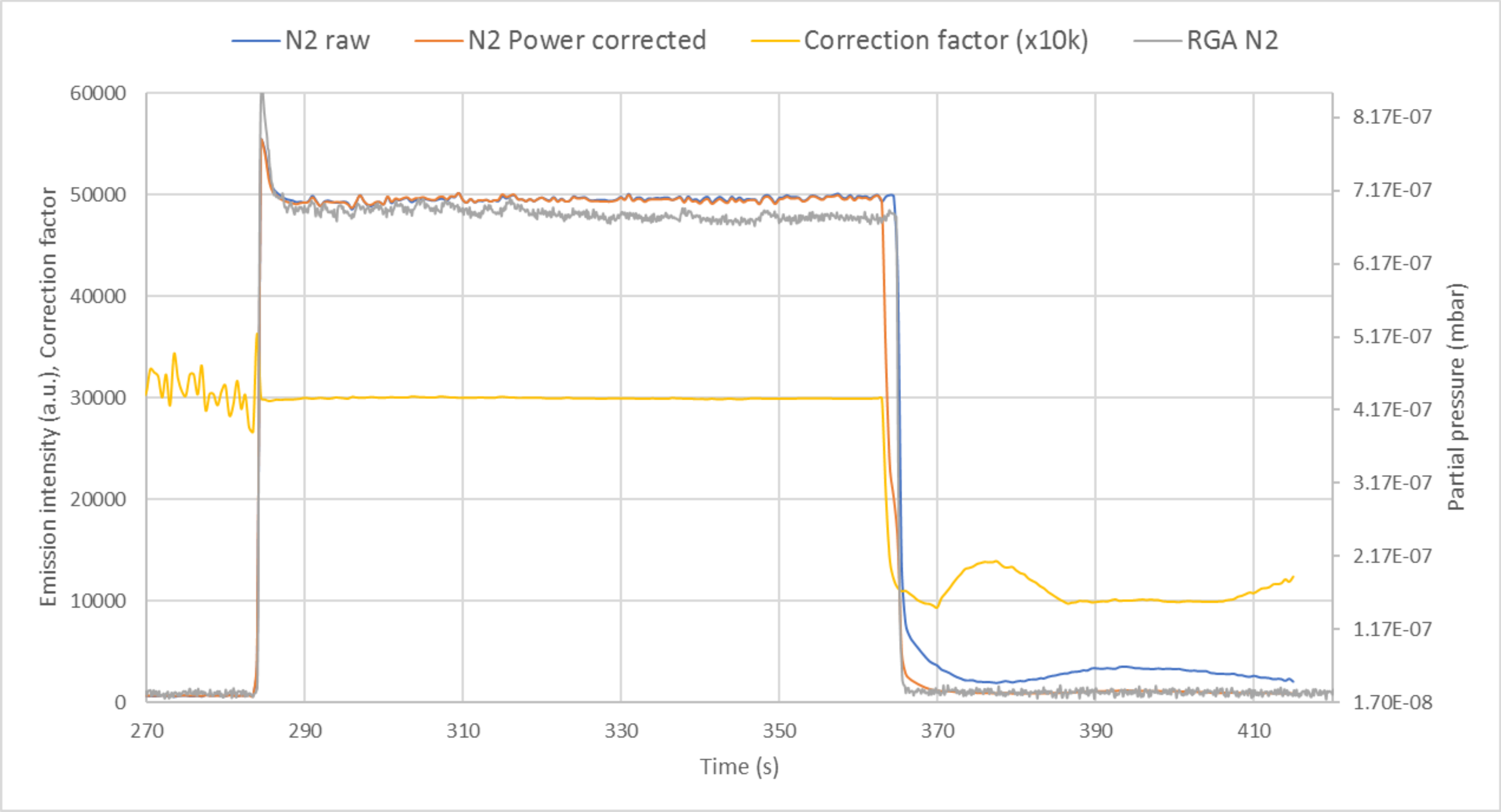


- A correction factor based on the measured power can be applied to the emission to remove this effect



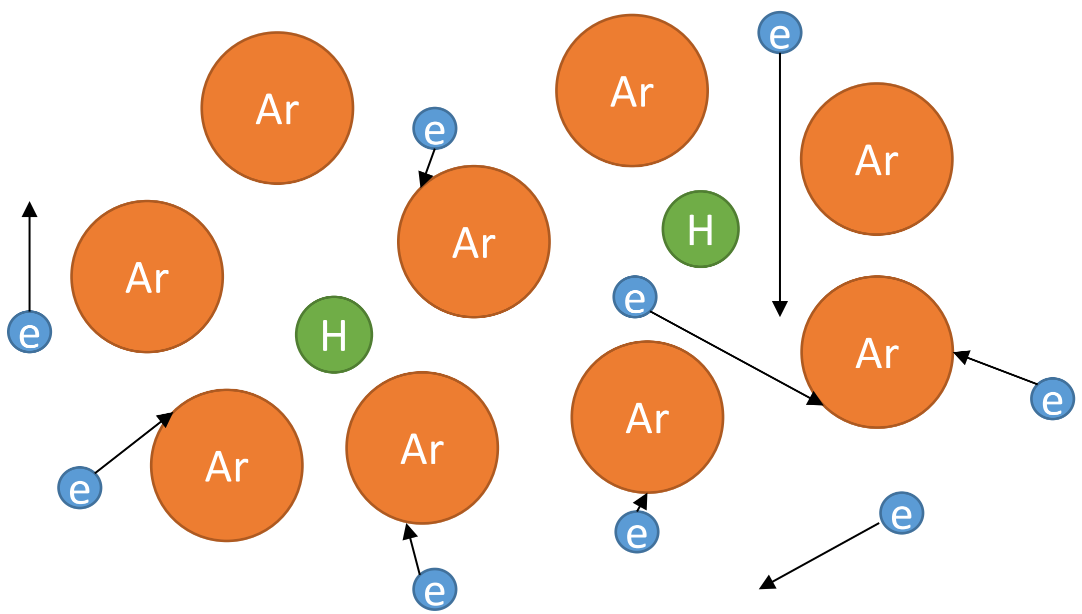
Quantification - Power correction

- The effect of the correction can be clearly seen when compared with a differentially pumped RGA



Quantification of gas levels using RPGA

- Introduction of a >> larger quantity of an additional gas will reduce the likelihood of electron impact on species of a << smaller quantity
- This will have an effect of supressing the emission of these species
- The OPTIX has a correction algorithm for the gas interaction effect to allow accurate quantification of the gas partial pressures



Quantification – Gas interaction

Experimental setup

- The most significant challenge for quantification of the sensor readings is the interactivity of gases
- Without correction the readings are **relative** not absolute
- i.e. increasing partial pressure of one gas will lead to a reduction in the readings of other gases.
- An experimental setup was constructed to investigate this effect and to demonstrate the correction method

Gas input – Ar, N_2, O_2

OPTIX

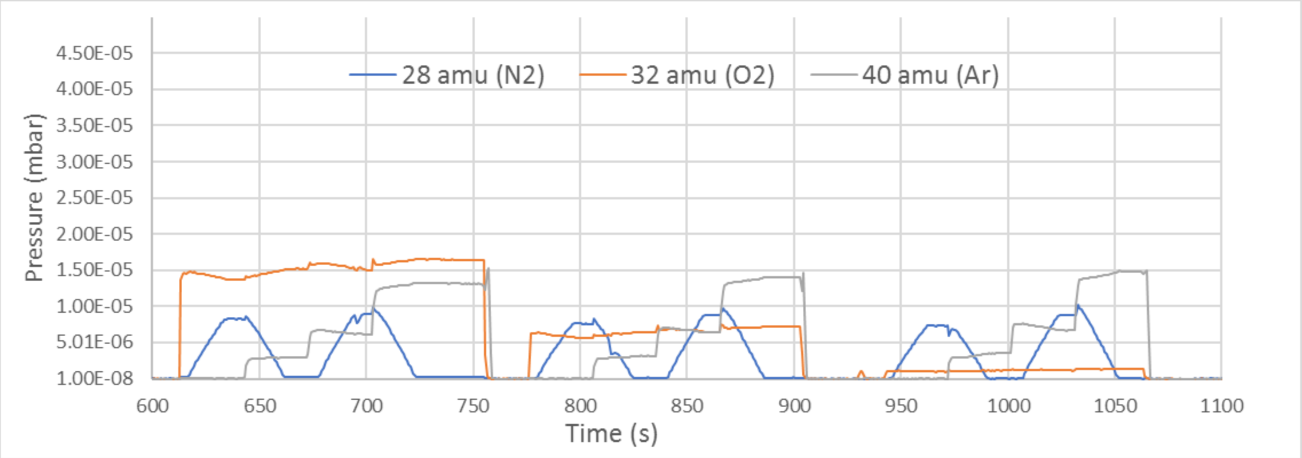
Diff. pumped side

High pressure side

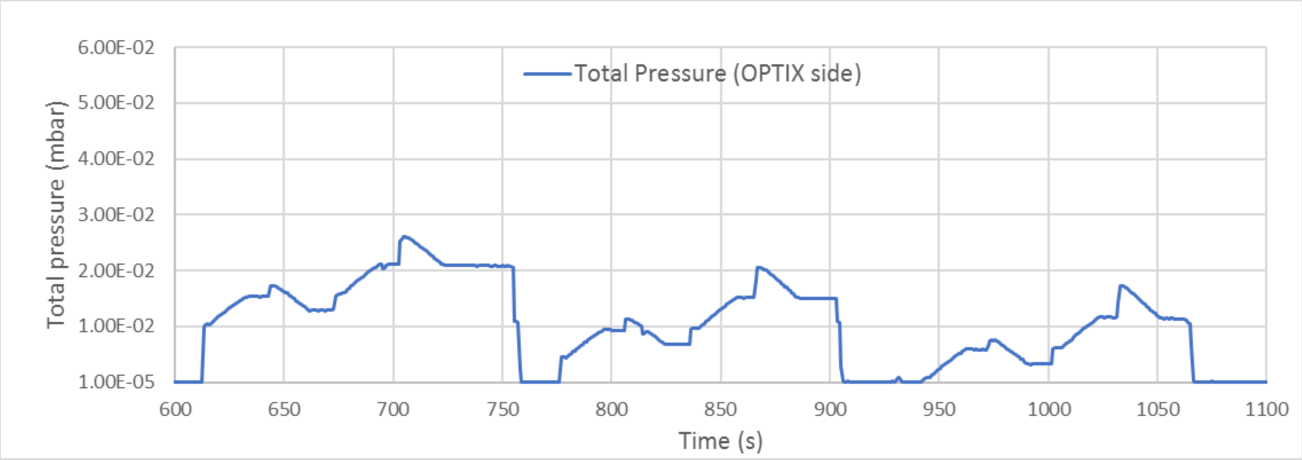
Quantification – Gas interaction

- Ar, N_2, and O_2 were mixed in varying quantities
- Total pressure variation was from 1E-5 to 2E-2 mbar on the high pressure side
- Differentially pumped side was kept below 1E-4 mbar

Diff. pumped RGA



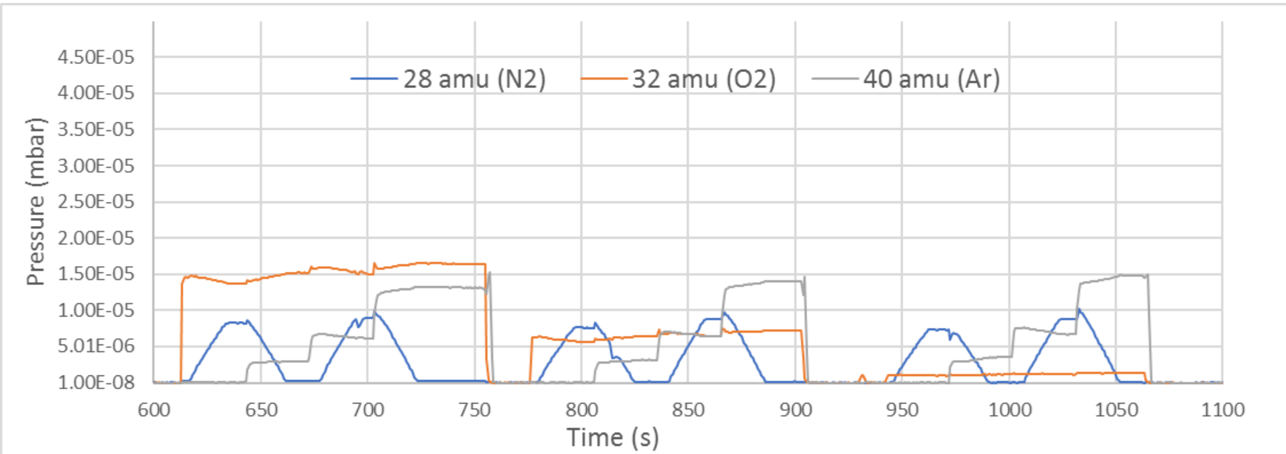
Total pressure



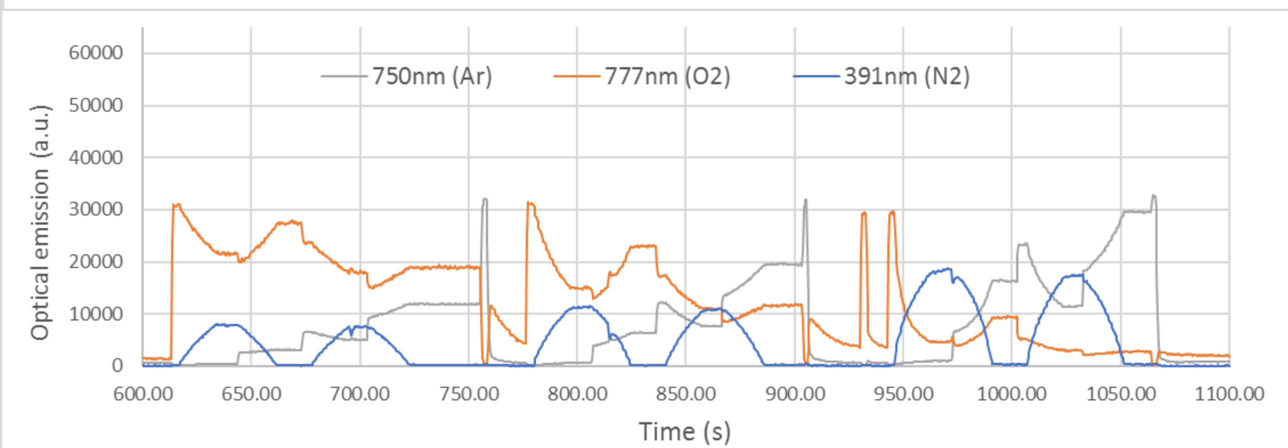
Quantification – Gas interaction

- Gas interaction effects can be clearly seen on the OPTIX readings resulting in different partial pressure measurements compared to the RGA

Diff. pumped RGA



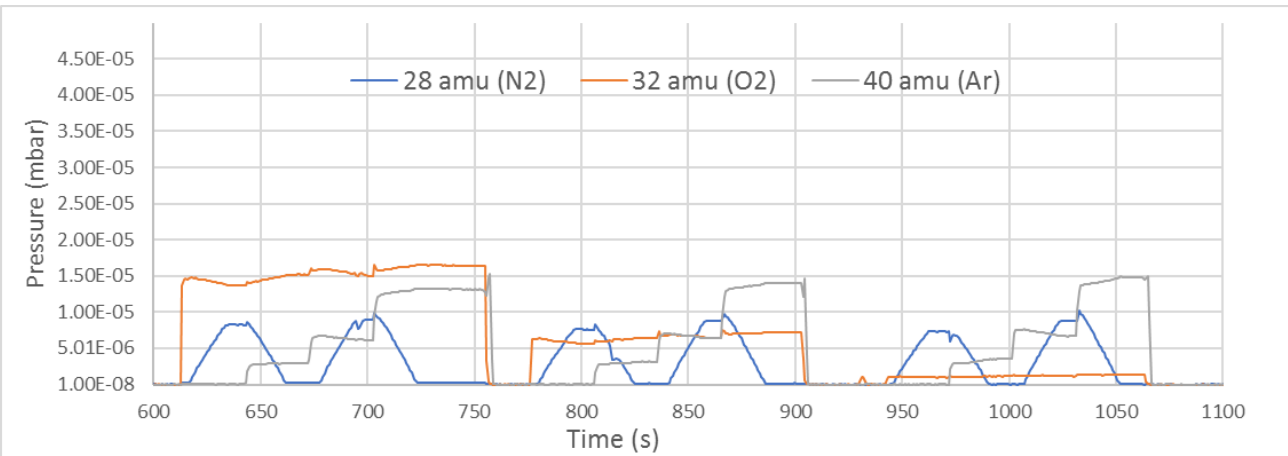
OPTIX readings



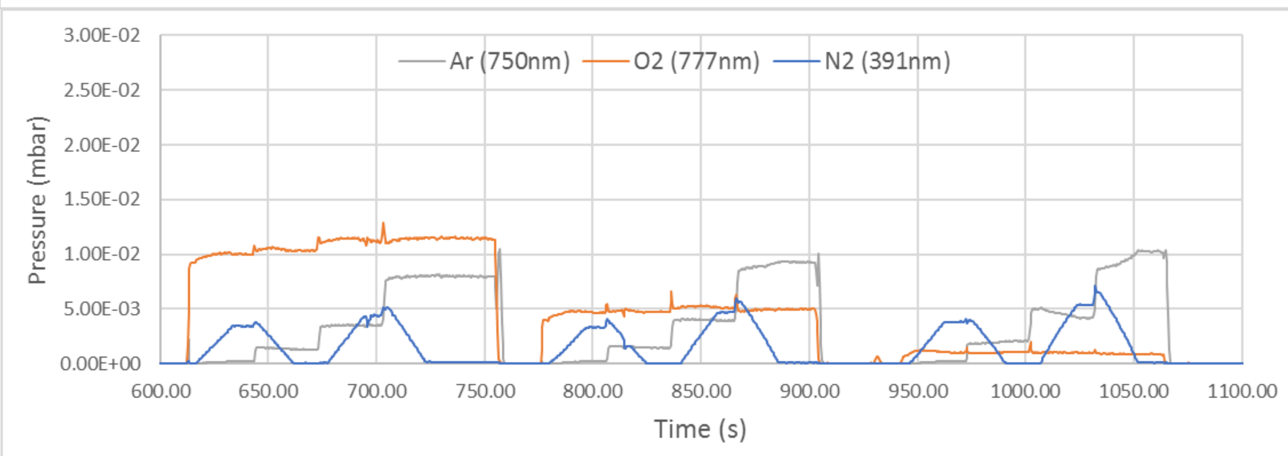
Quantification – Accurate gas partial pressure measurements after the gas effect correction algorithm is used

- An algorithm can be used to correct for the interaction effects
- Partial pressures can then be derived

Diff. pumped RGA



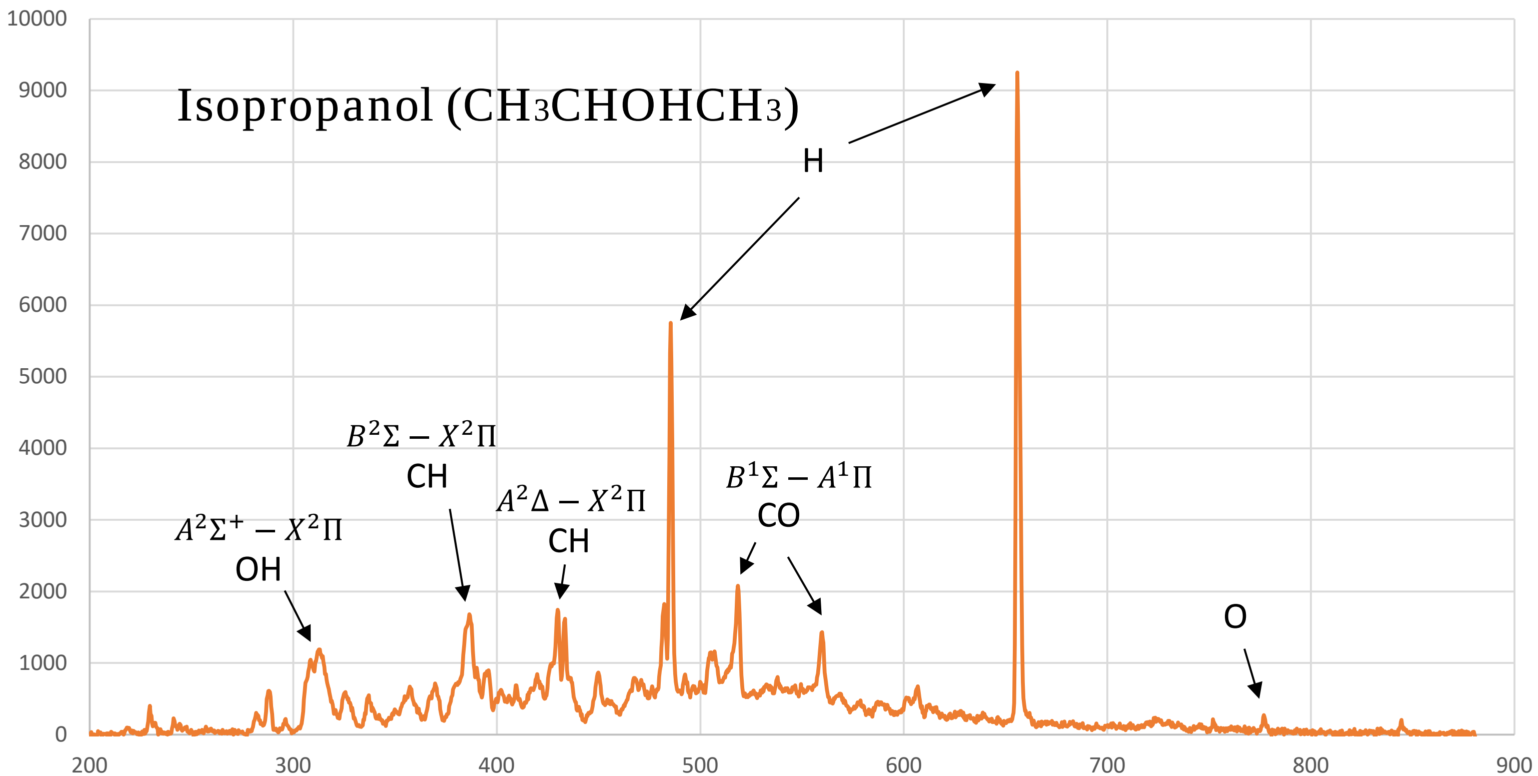
OPTIX readings



Remote Plasma Gas Analysis
Highly Sensitive Optical Method

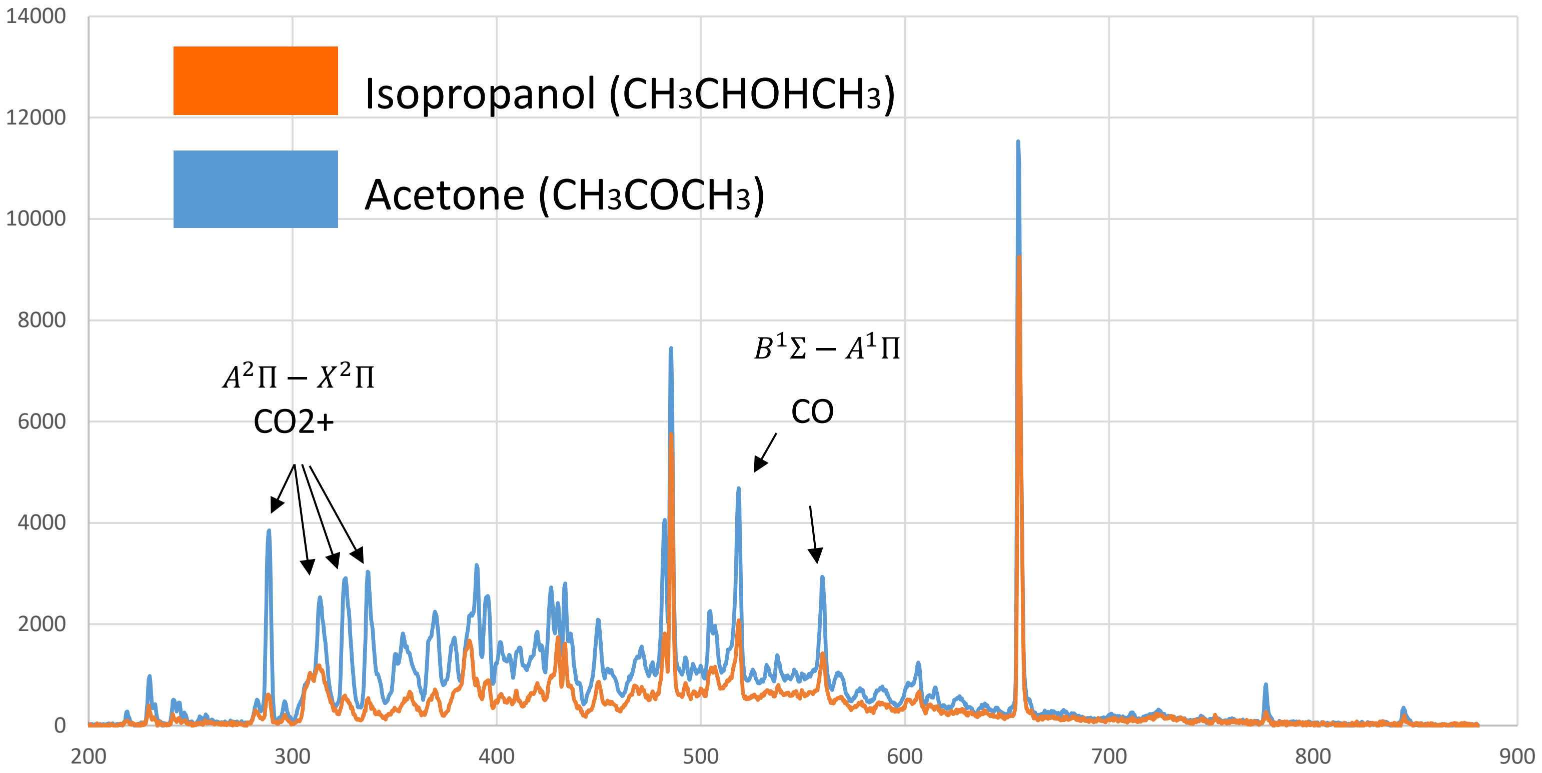
Which species can be observed?

- Atomic emissions and molecular emissions
- Larger molecules are observed as fragments – due to disassociation in the sensor's plasma



Caveats and considerations when using Remote Plasma Gas Analysis - Disassociation

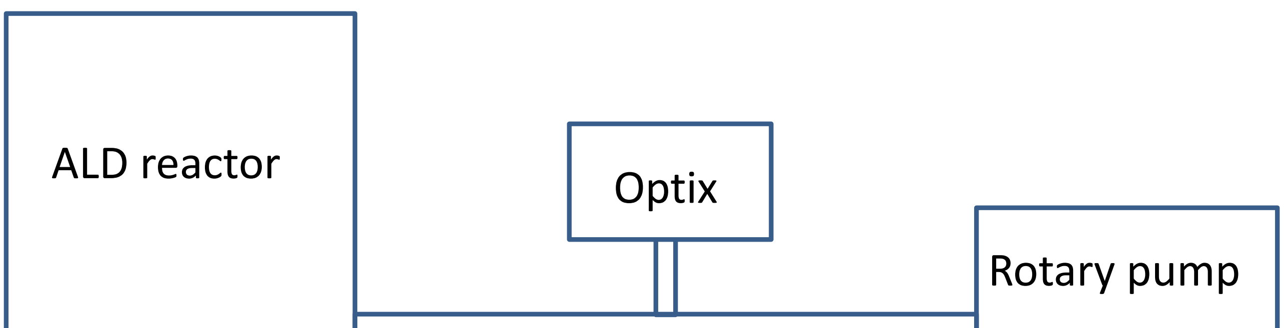
- “Fingerprints” of the original molecule



ALD monitoring experimental setup

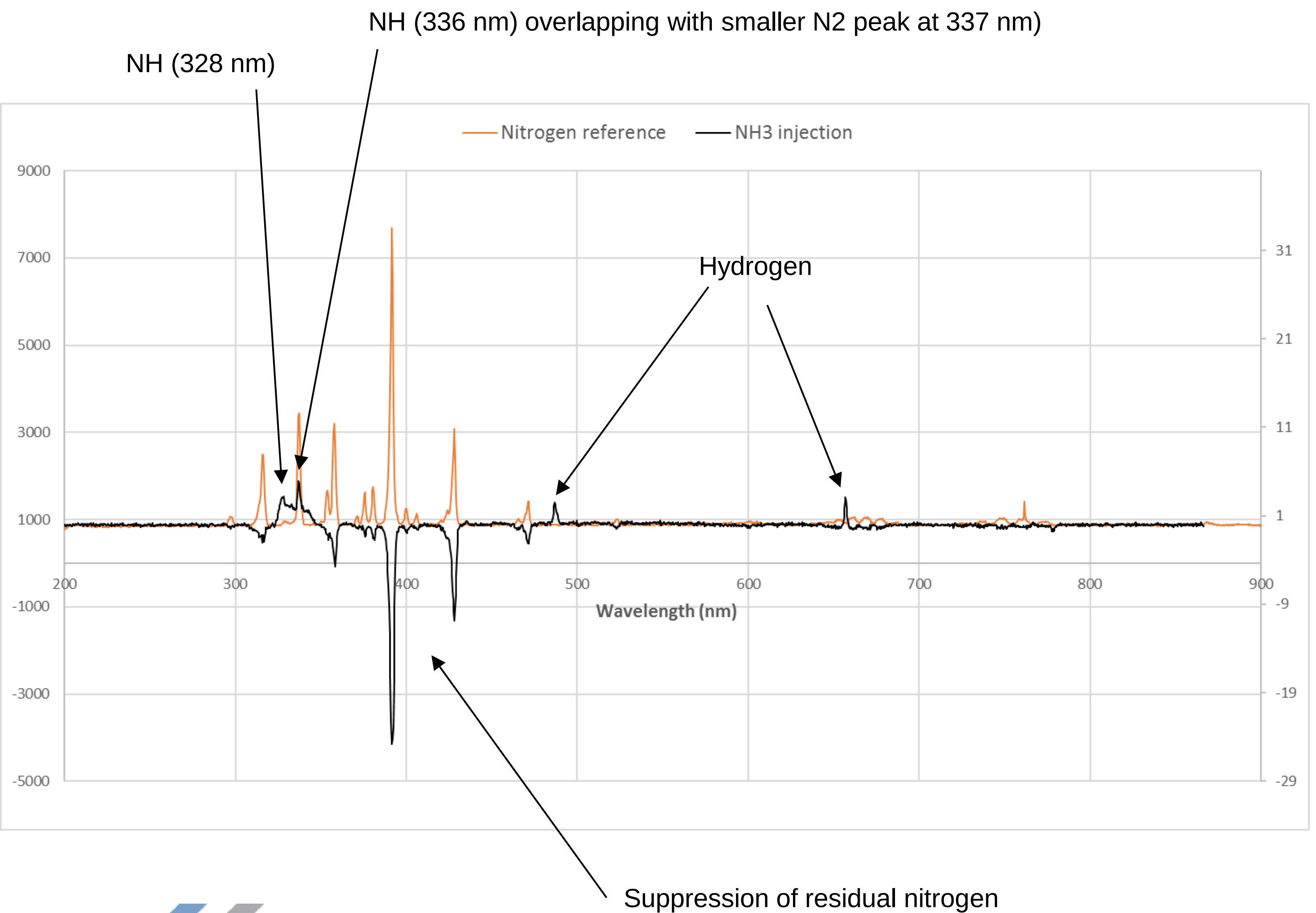
University of Liverpool

Dr. Richard Potter and Ben Peek



Precursor detection

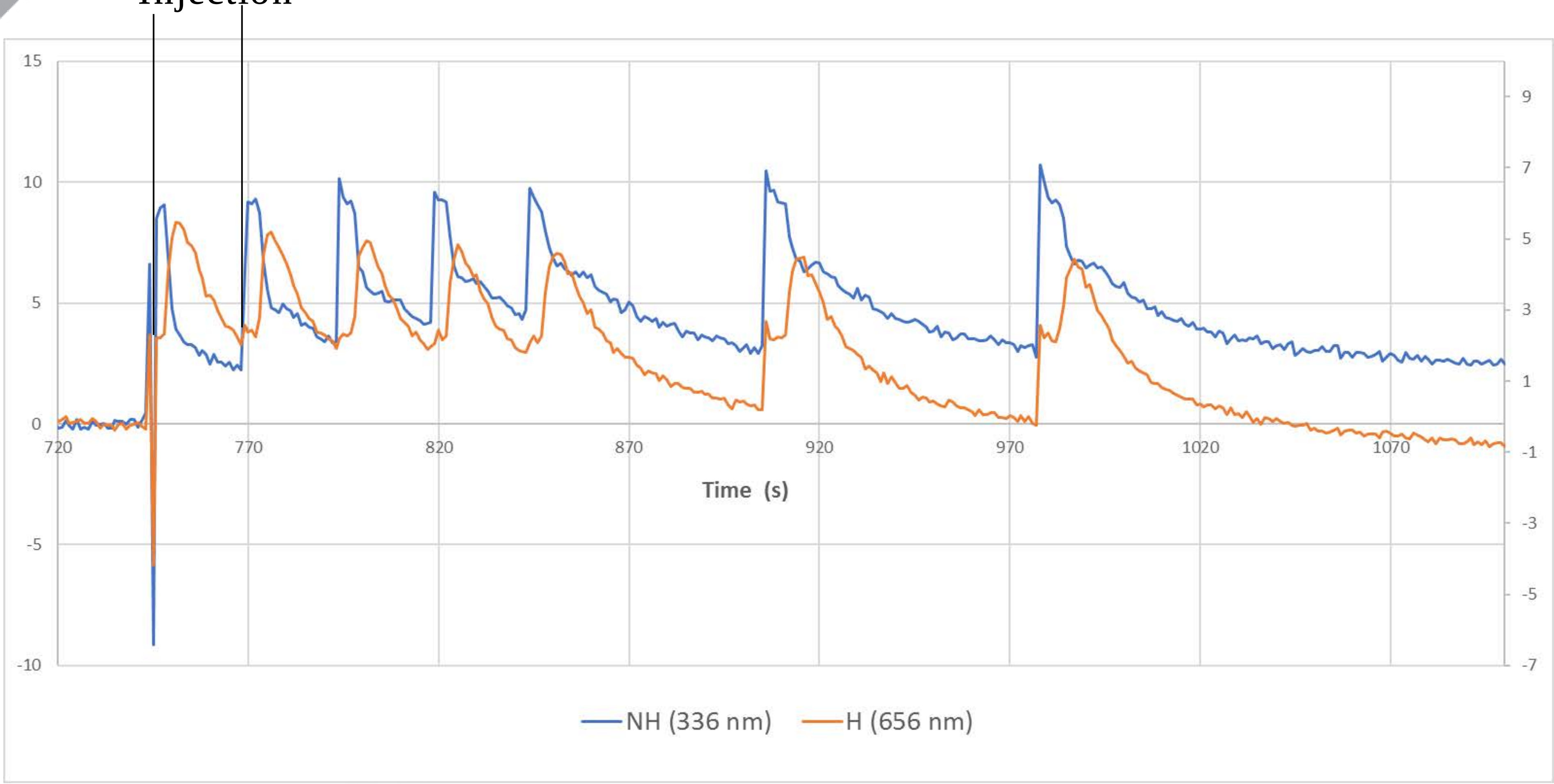
NH_3



Atomic layer deposition precursor monitoring

NH3

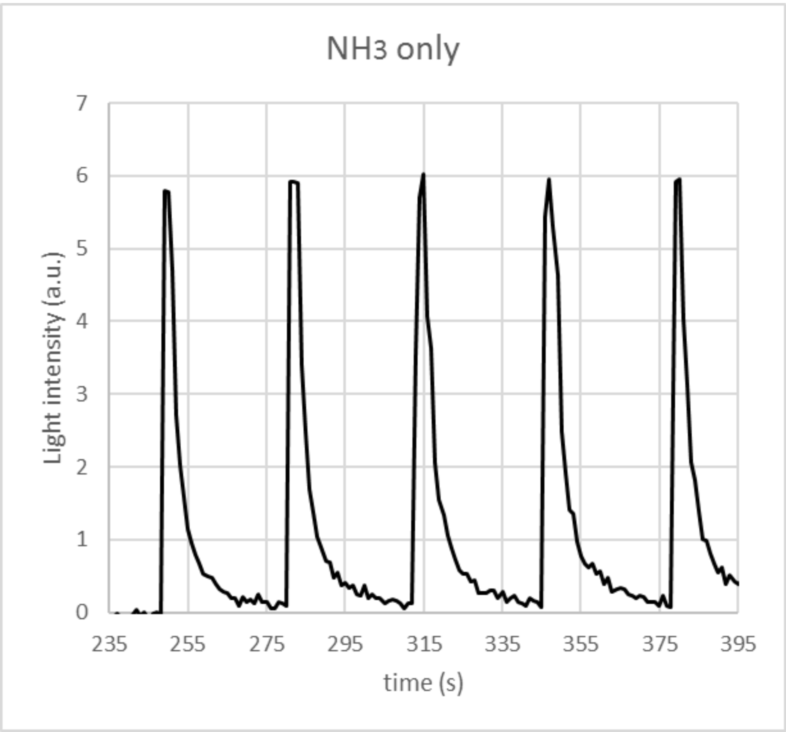
Injection

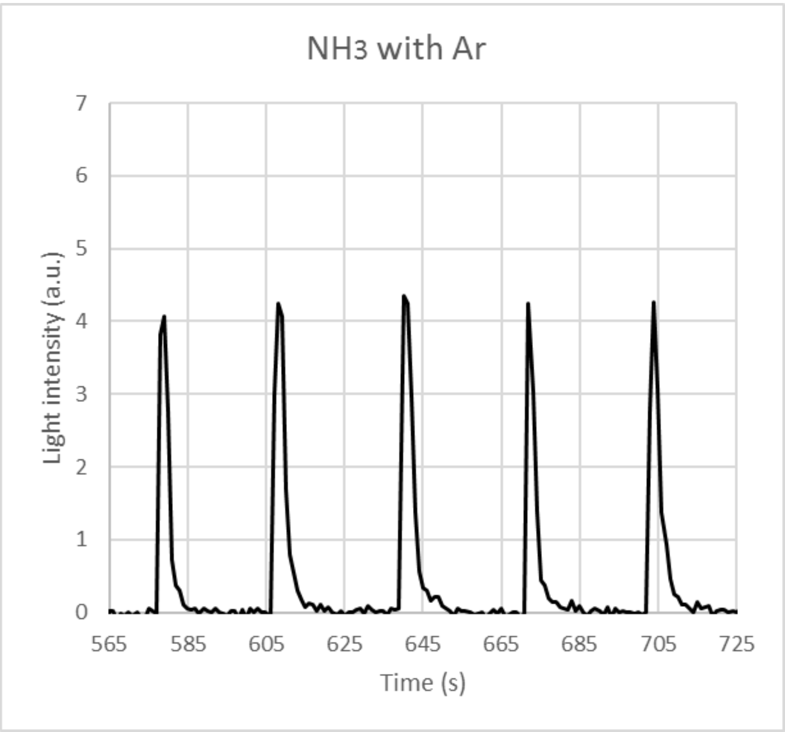


Precursor detection

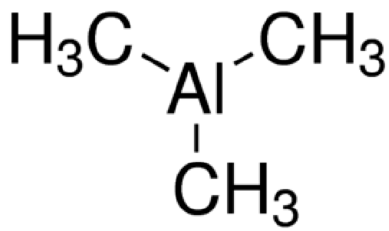
NH_3

NH (328 nm)

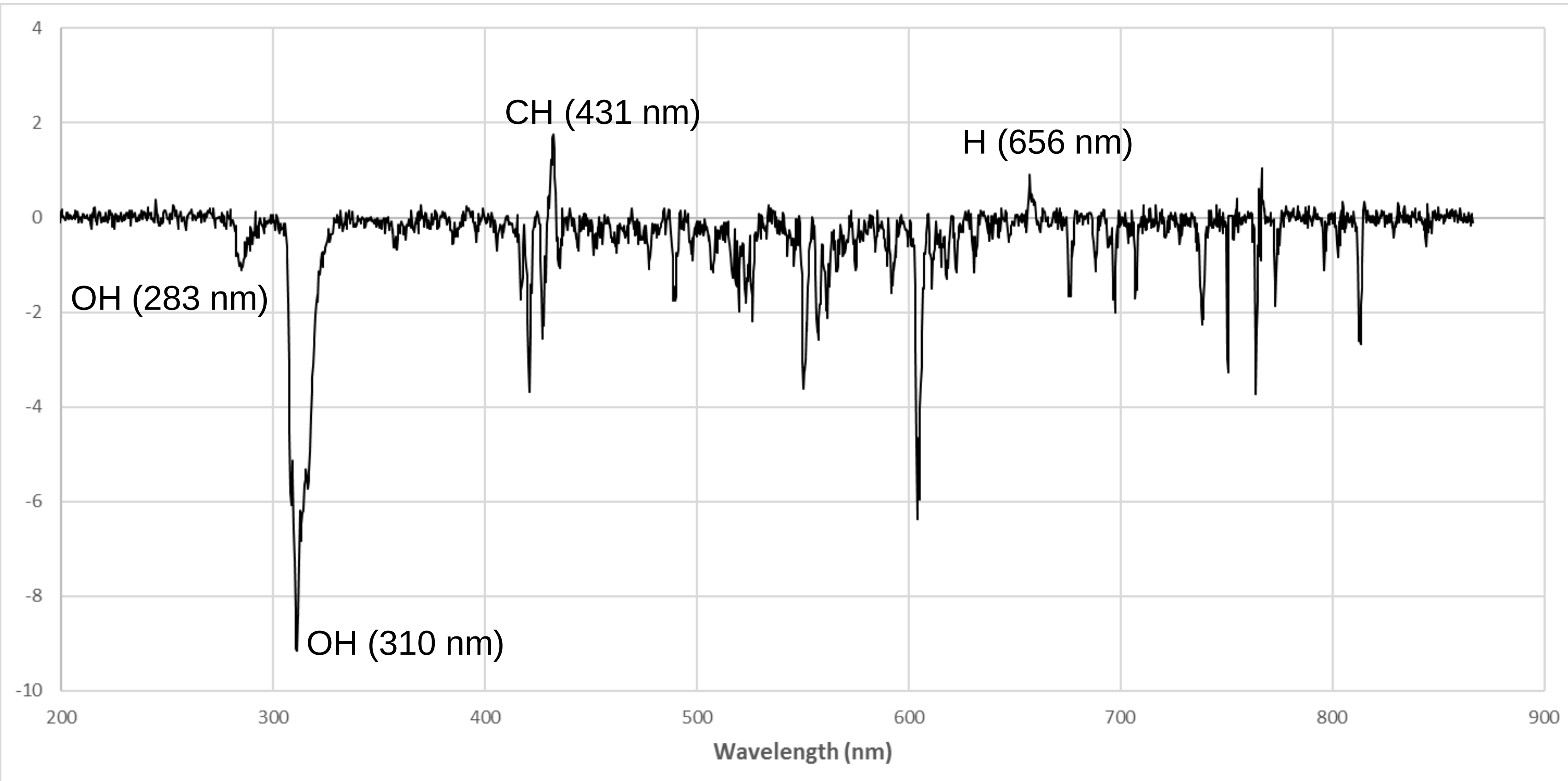




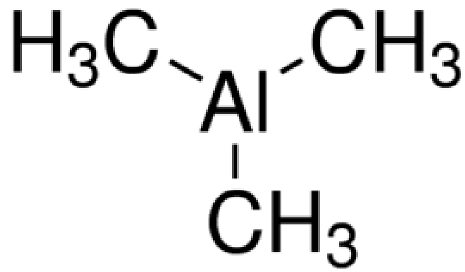
Precursor detection



TMA

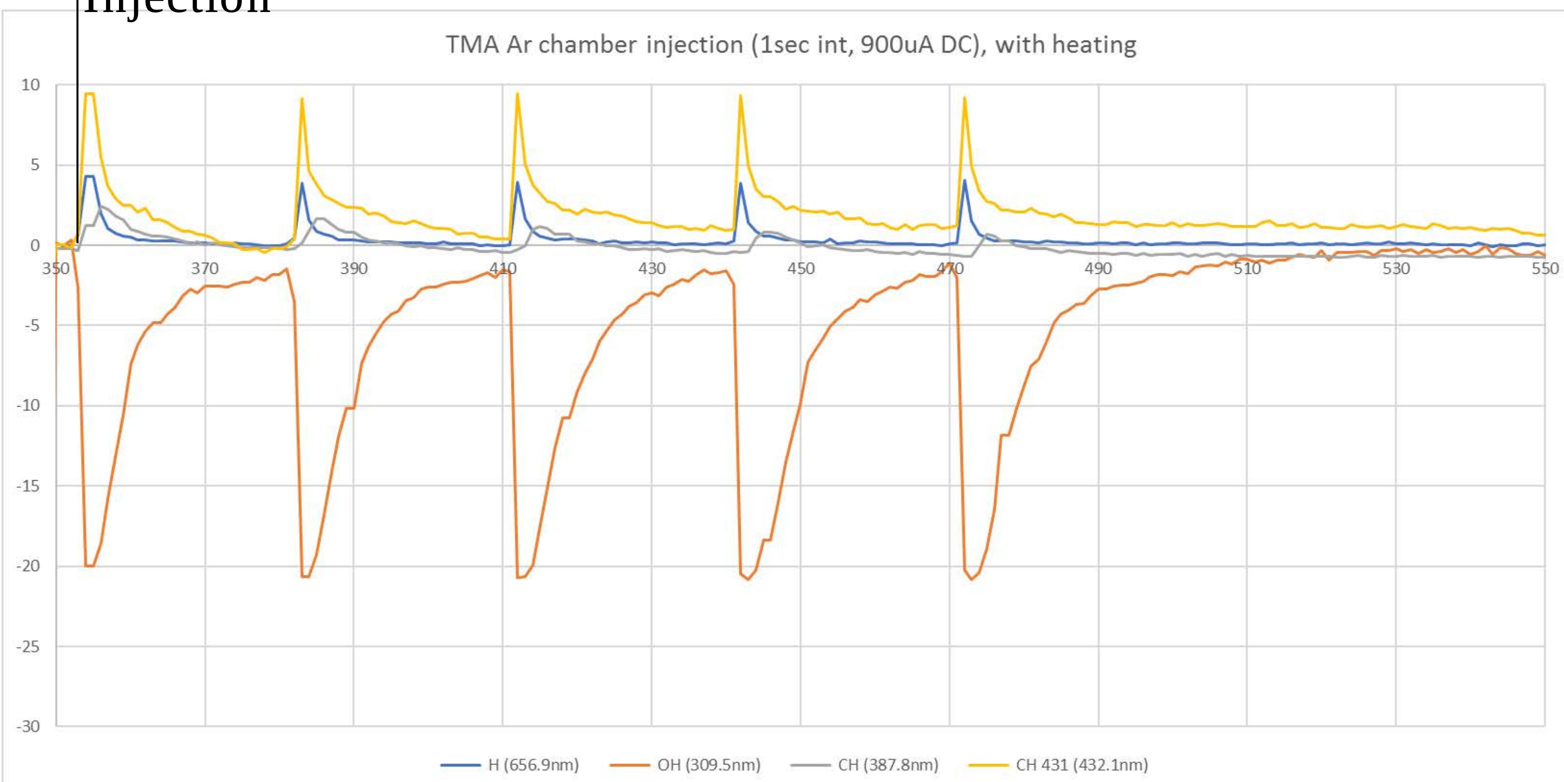


Atomic layer deposition precursor monitoring



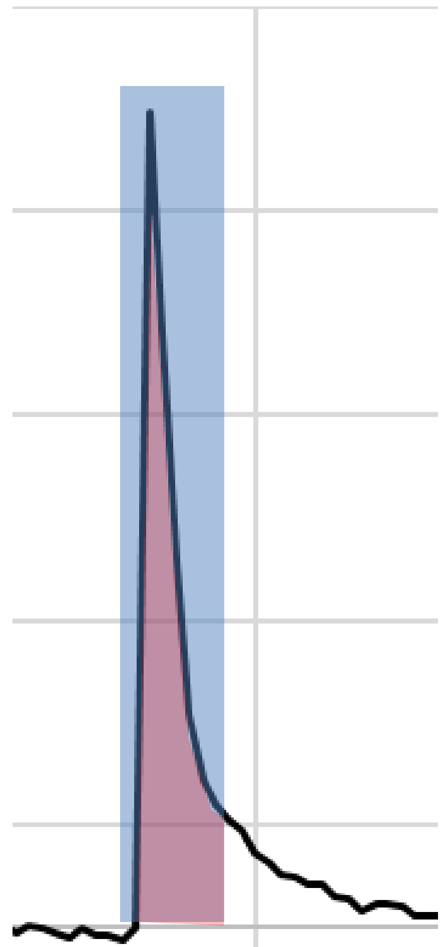
TMA

Injection



Deposition cycle monitoring

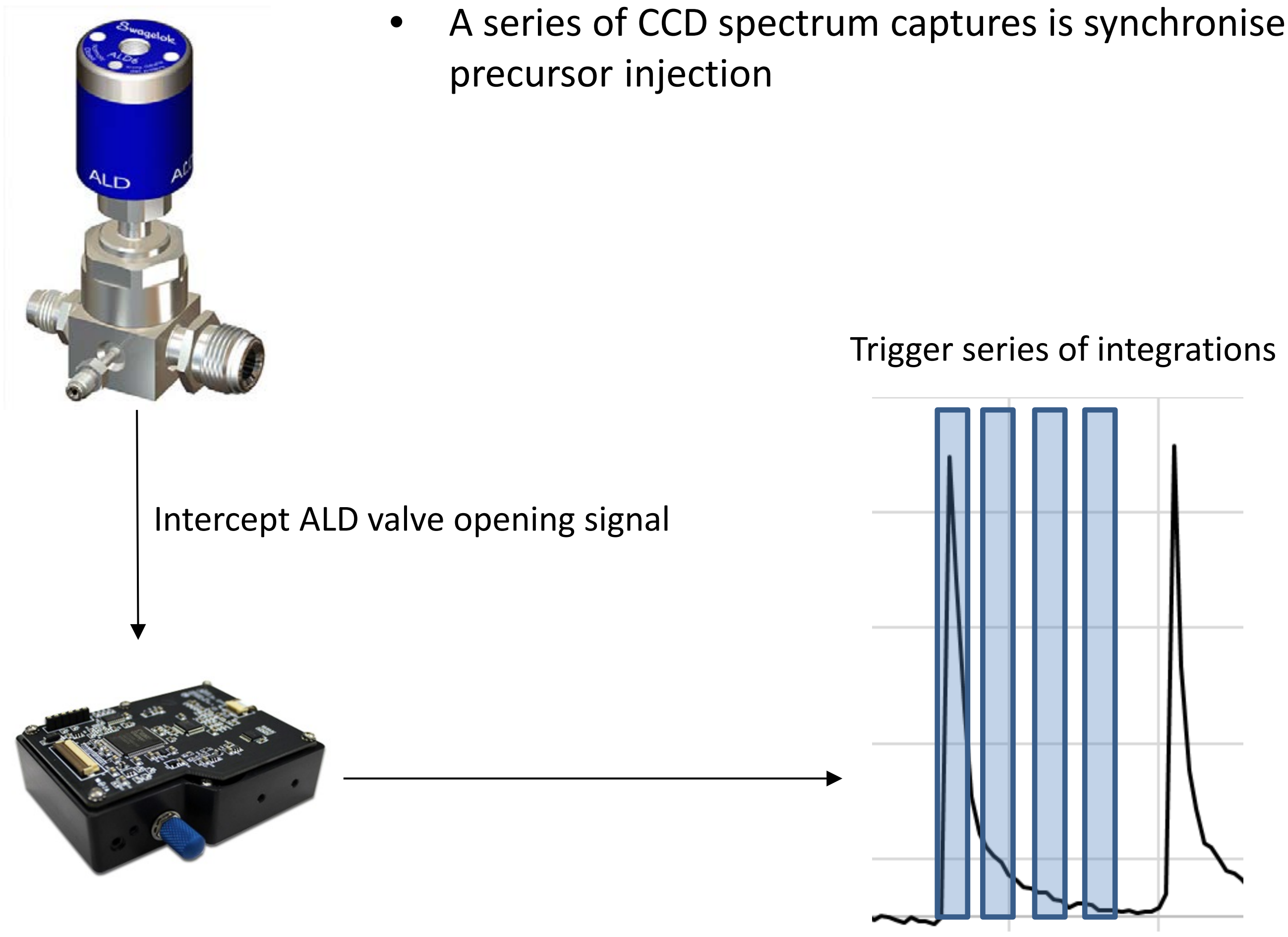
Synchronisation of the CCD capture with the ALD pulse



Deposition cycle monitoring

Synchronisation of the CCD capture with the ALD pulse

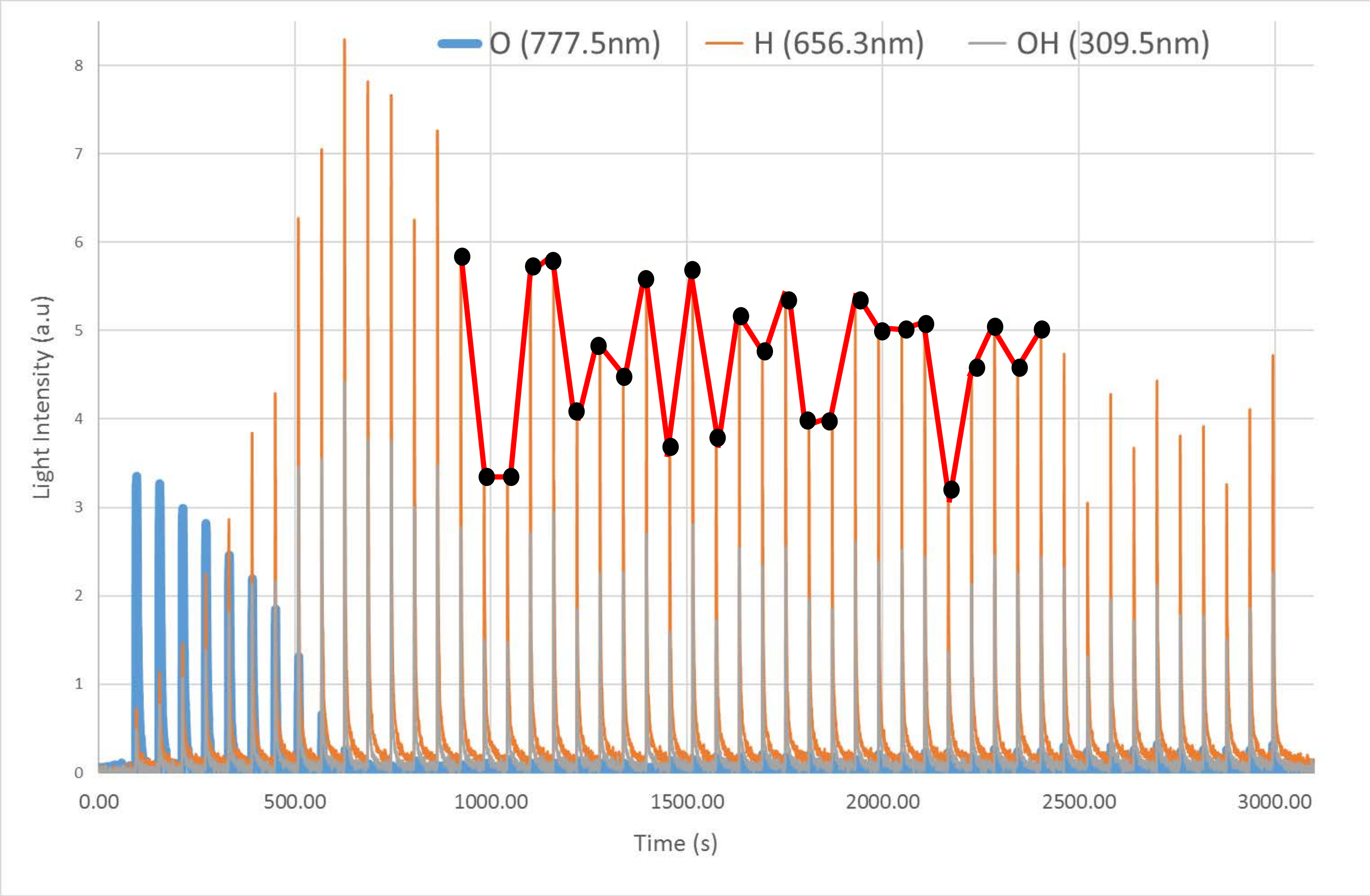
- A series of CCD spectrum captures is synchronised with each precursor injection



Deposition cycle monitoring

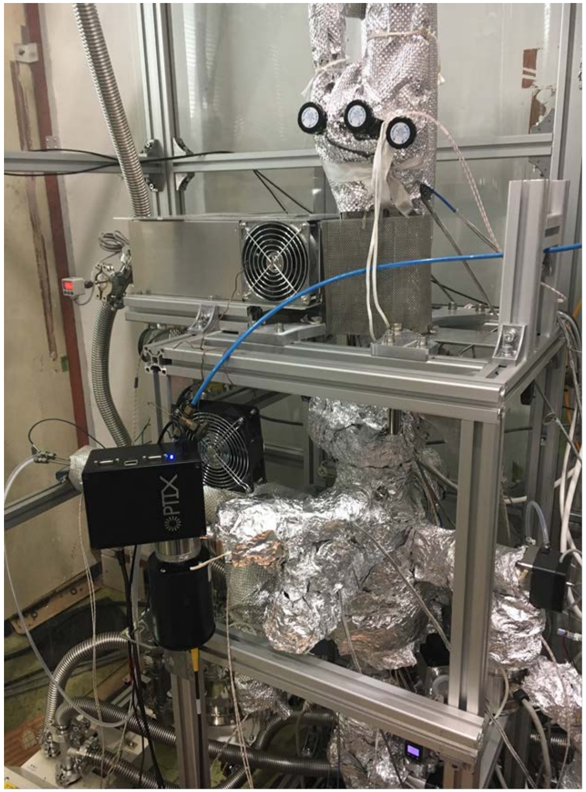
Synchronisation of the CCD capture with the ALD pulse

- The H maxima of each precursor pulse was recorded

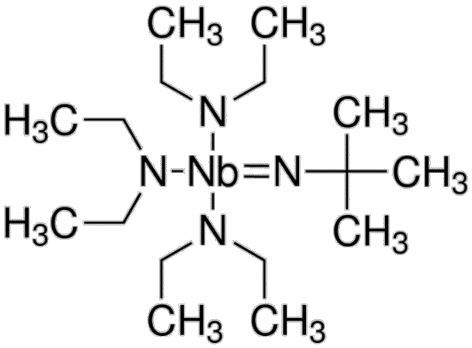


Application Example Atomic layer deposition precursor monitoring Deposition of NbN via PEALD

ALD user, Japan



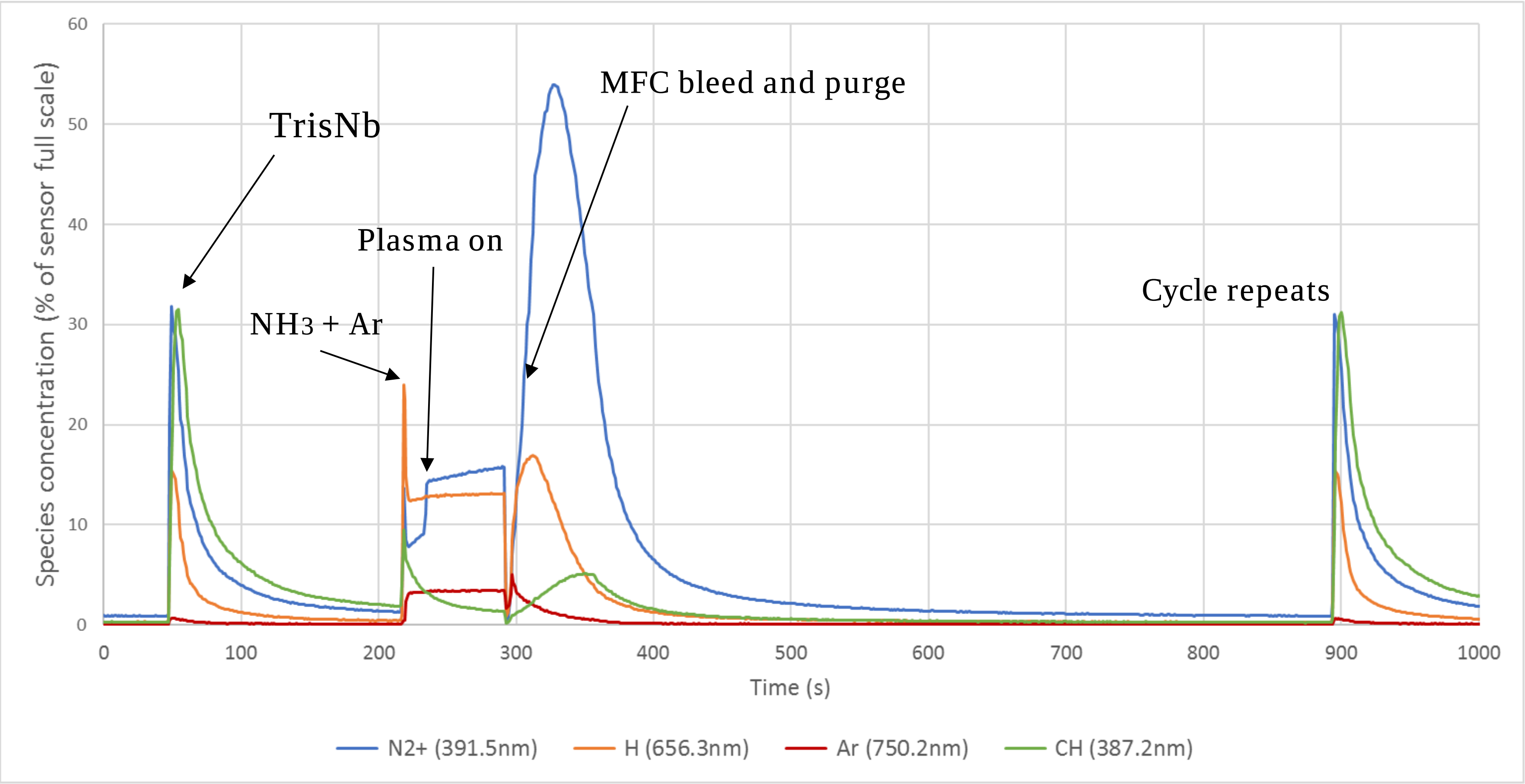
- Detection of TrisNb via CH, N and H



- Detection of NH_3 via N and H

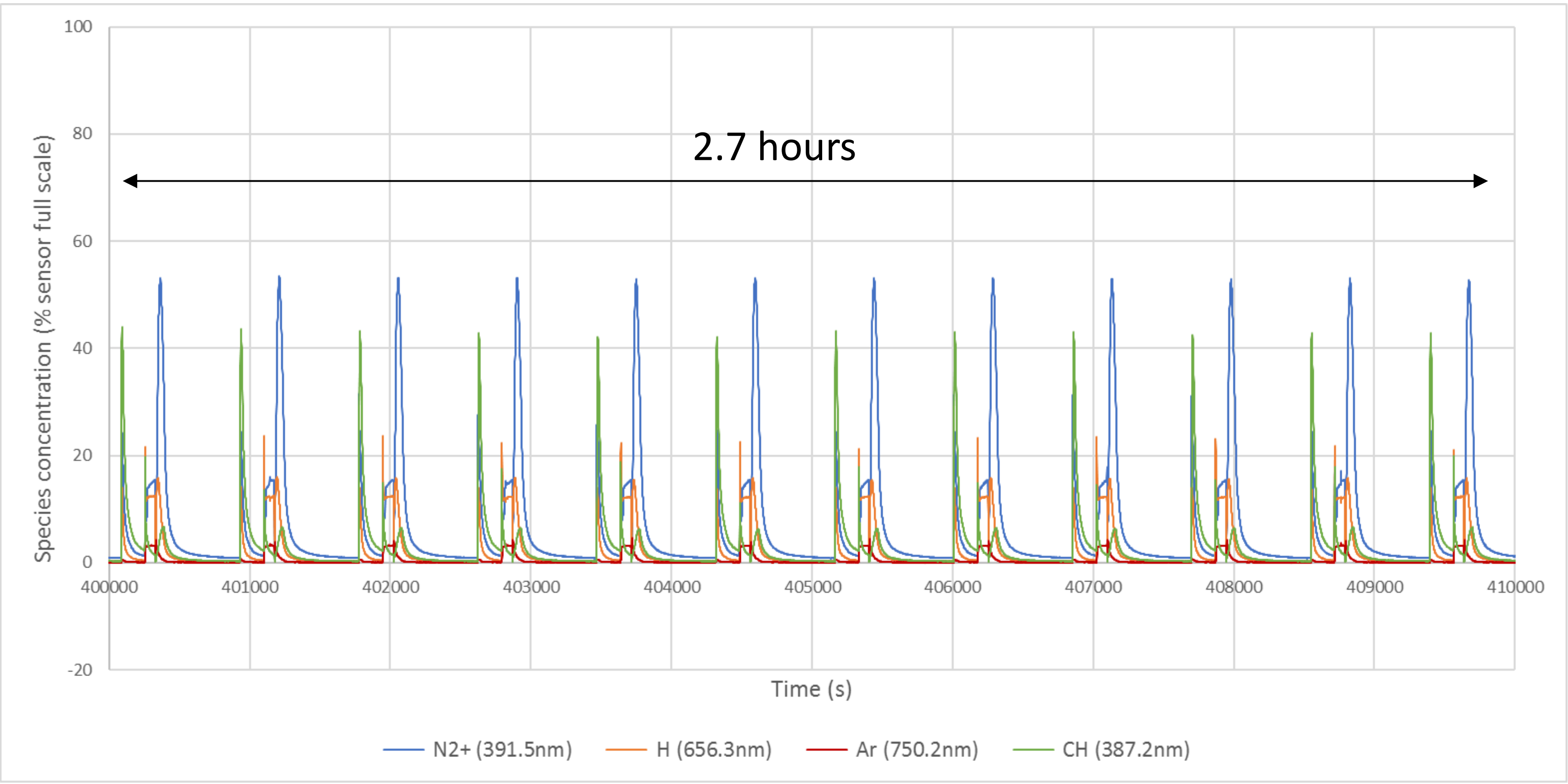
OPTIX Atomic layer deposition precursor monitoring

NbN deposition step



ALD Monitoring – Full process for 2.7 hours

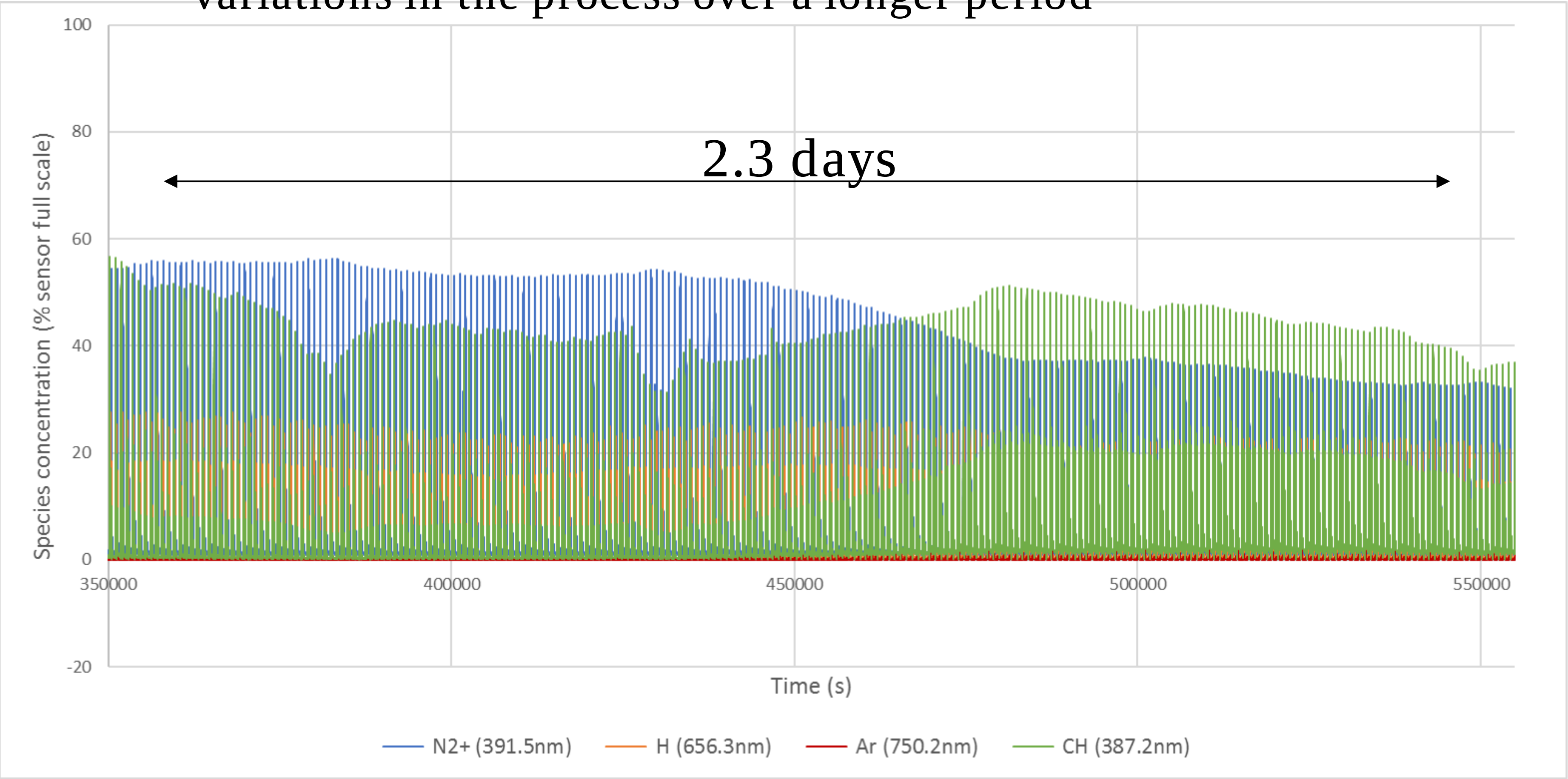
Deposition of NbN via PEALD



Atomic layer deposition precursor monitoring

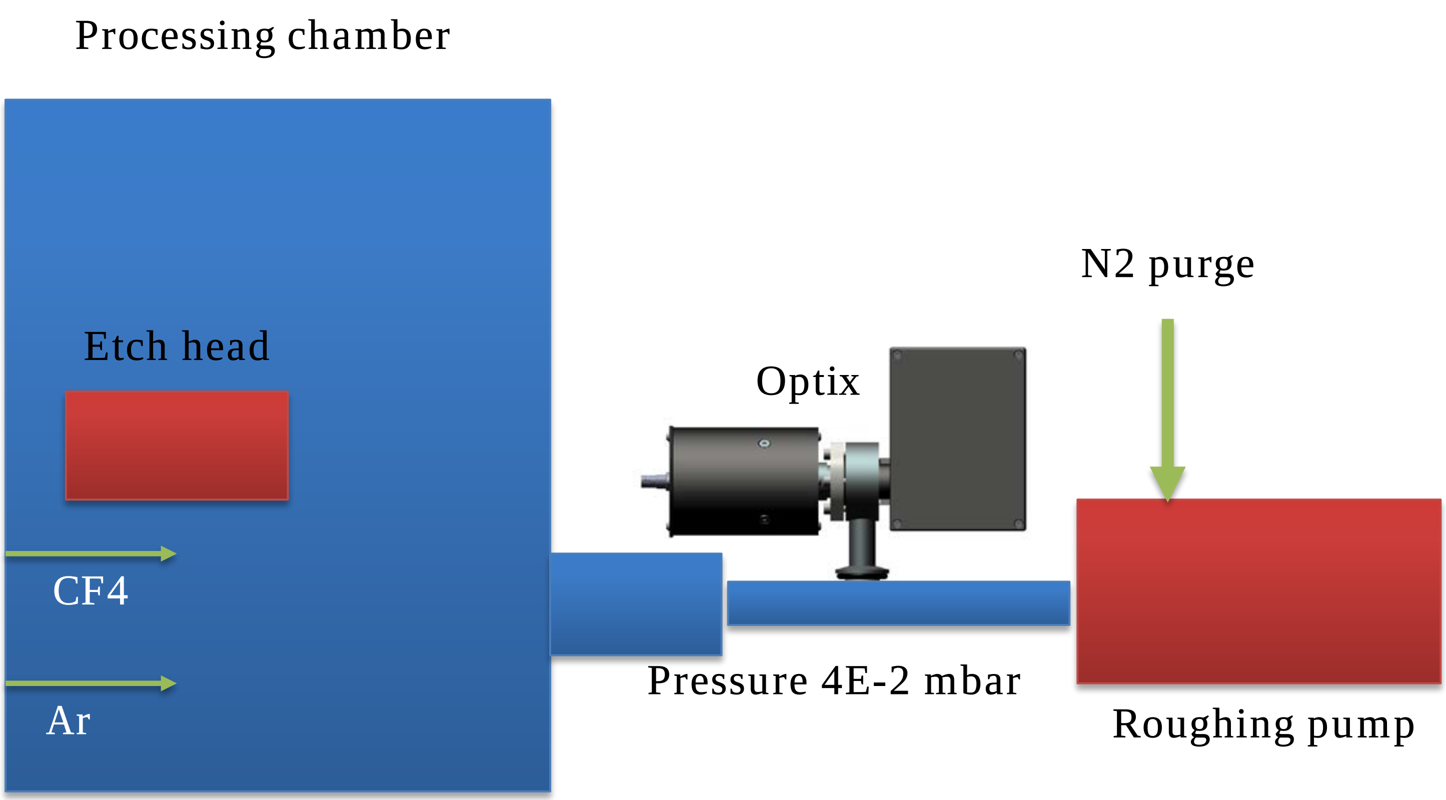
Deposition of NbN via PEALD

- Sensor is robust of the full 2+ day deposition cycle and displays variations in the process over a longer period

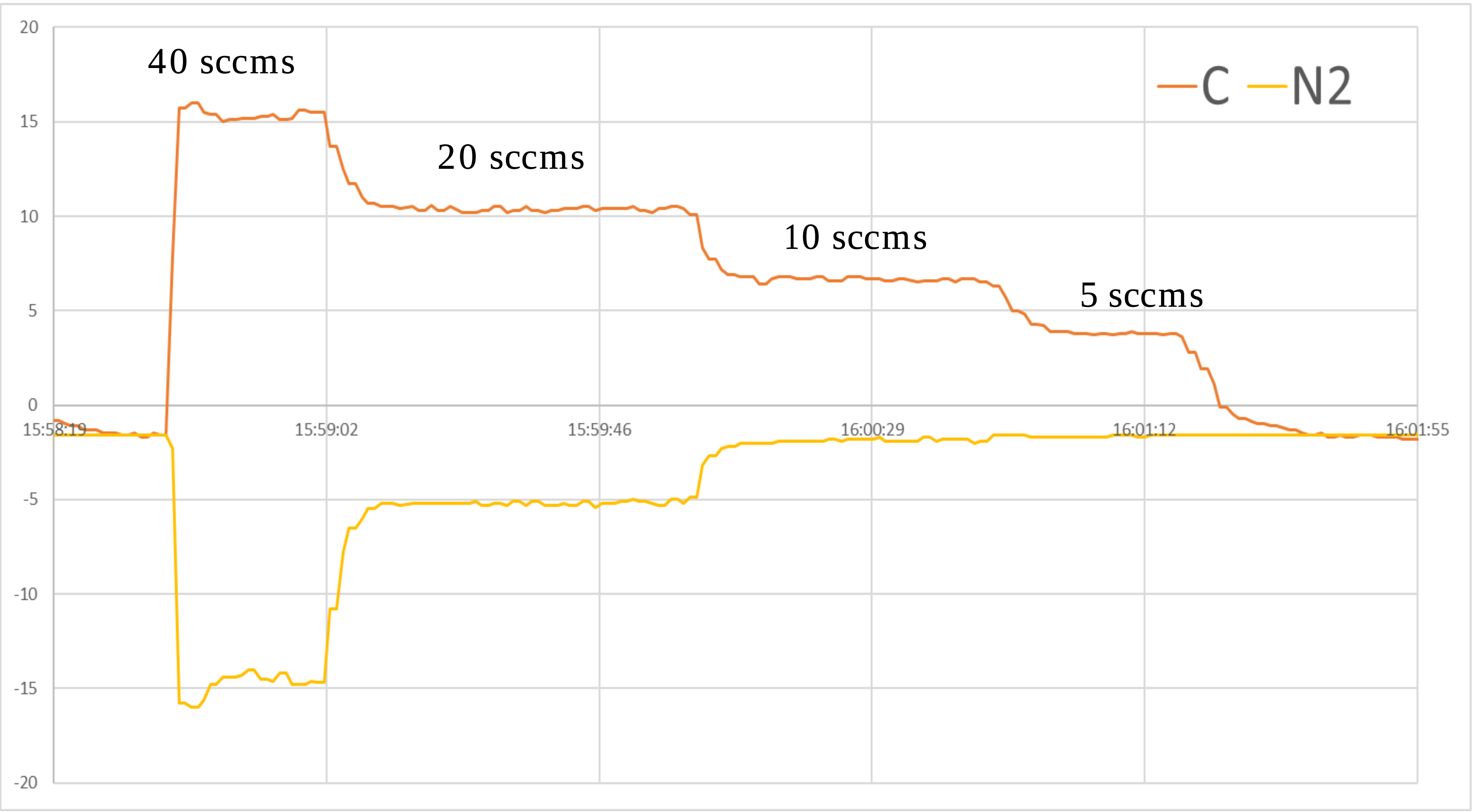


Application Example - Characterising a reactive ion etch process

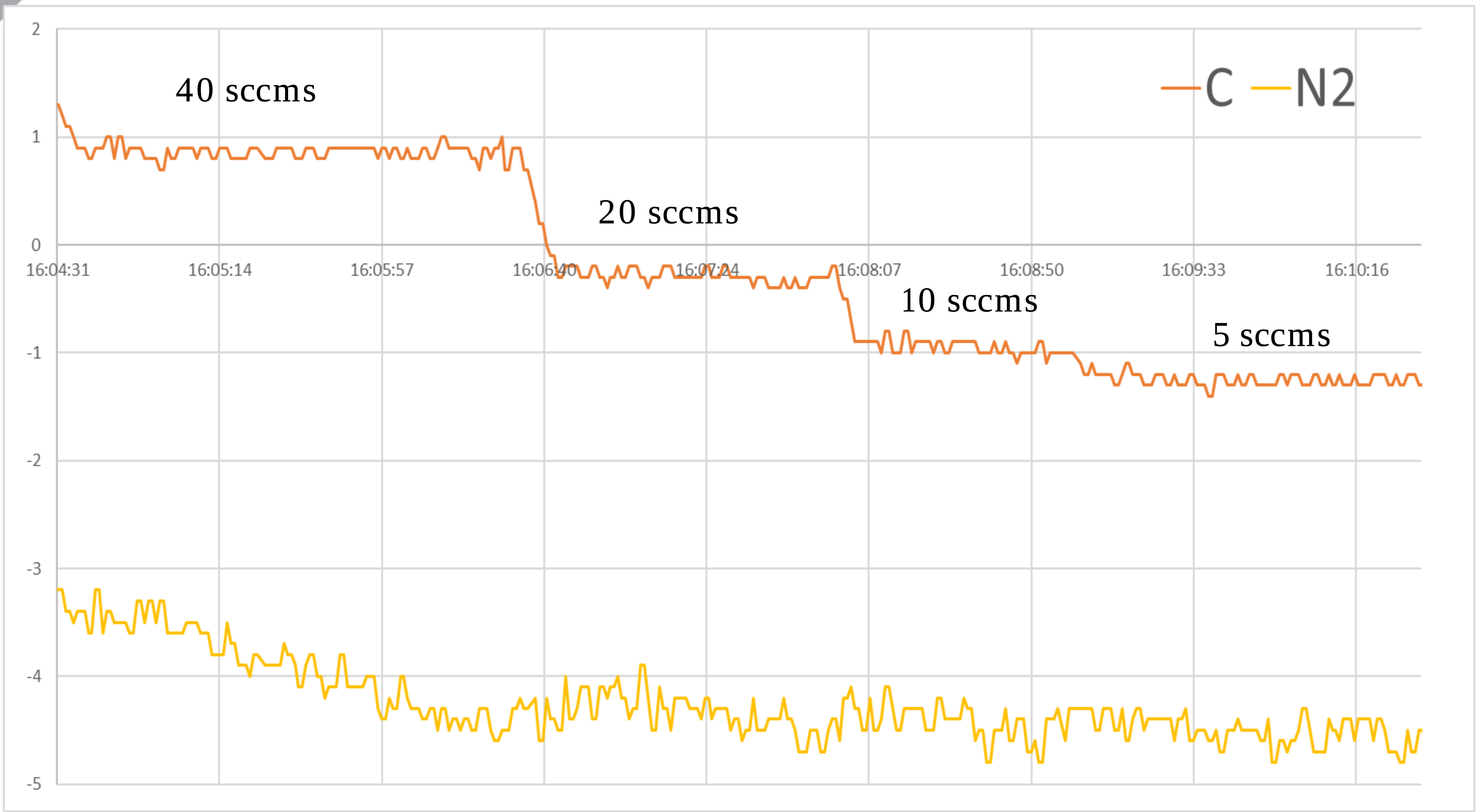
Detection of reactive ion etching effluent in the process backing line



CF4 detection (no Ar background)

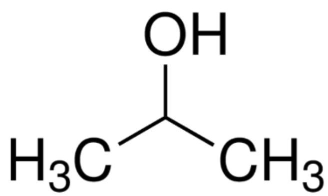


CF4 detection (Ar background)



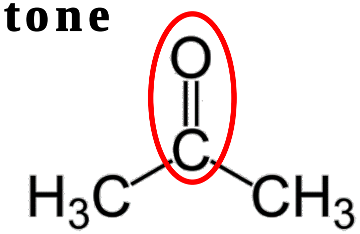
Sensing from atmosphere

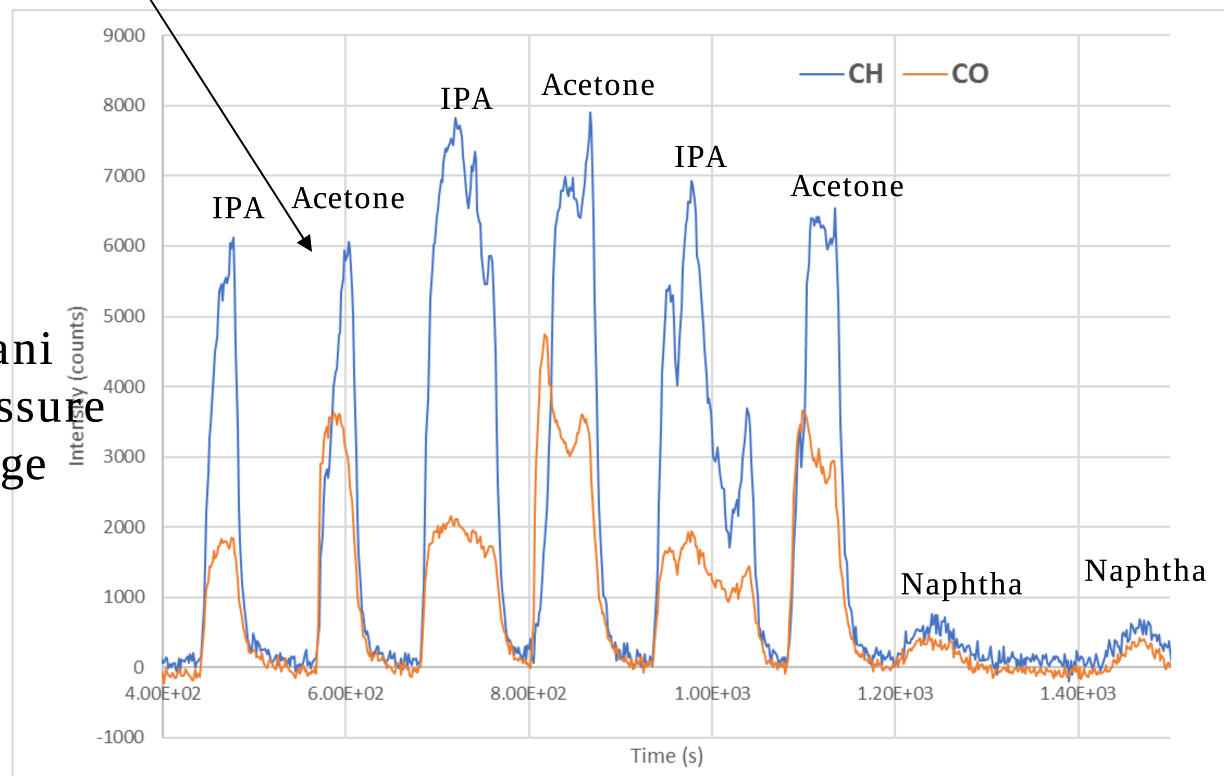
IPA

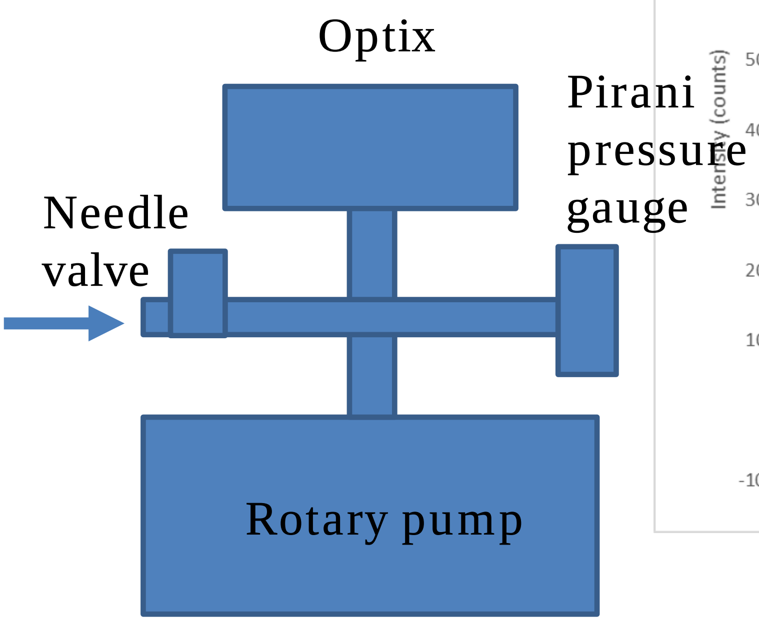


Acetone has a higher CO reading due to the presence of a CO bond

Acetone







Summary

- Remote PEM combined with spectroscopy can perform “RGA-like” functions
- Can use this method directly at higher process pressures – no need to differentially pump unless atmospheric sensing
- The detector is separated from the vacuum environment hence not affected by hostile chemistry present in the vacuum
- OPTIX is hence less sensitive to contamination than RGA’s, can be used for ’dirty’ hydrocarbon environments as well as etch, CVD and ALD type processes.
- This sensing technique is highly robust – plasma generator will not contaminate or stop functioning