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SVC Society of Vacuum Coaters TechCon 2025 Nashville

Reactive Magnetron Sputtering Feedback Control, ‘Flexibility for Success’

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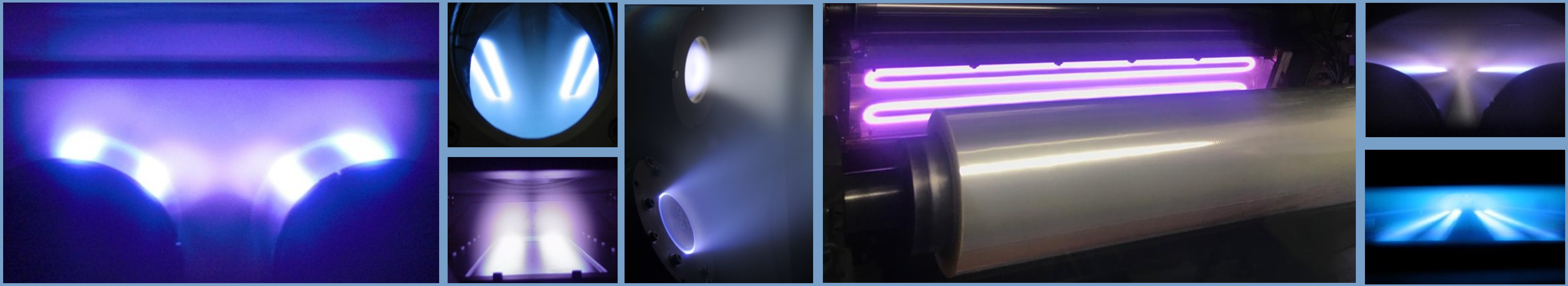
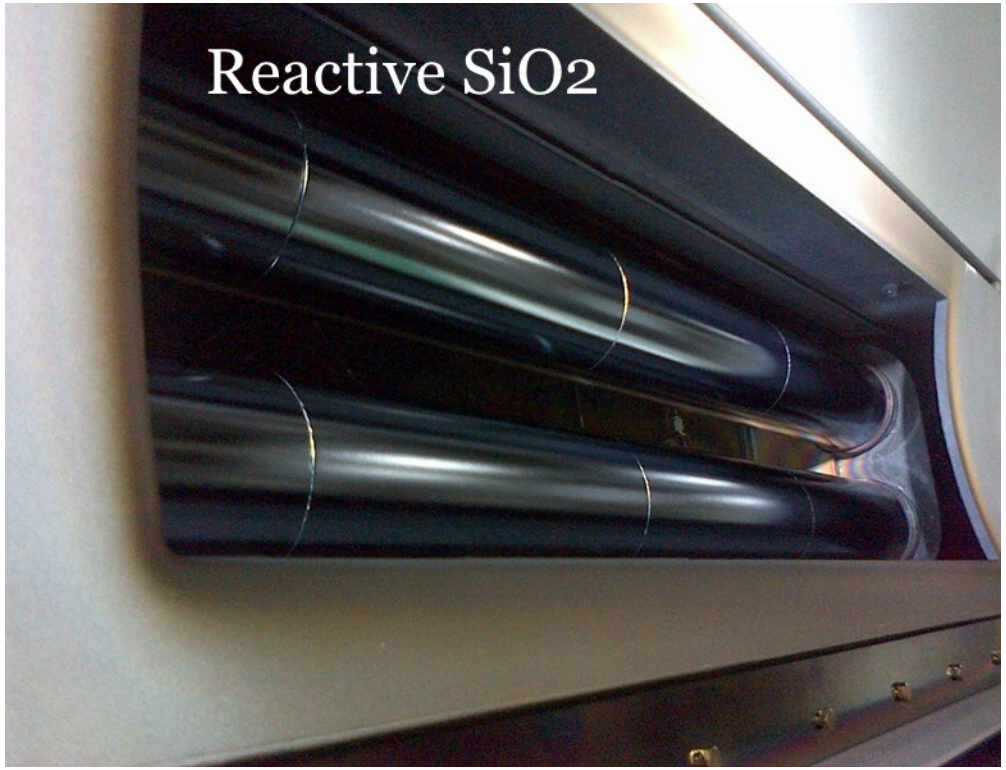


Reactive Magnetron Sputtering Feedback Control, ‘Flexibility for Success’

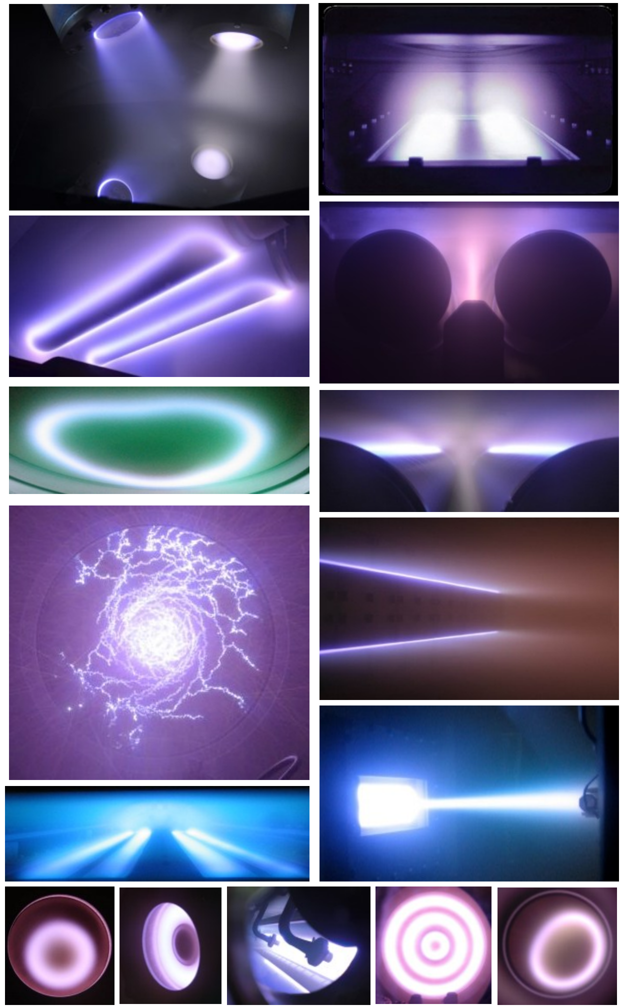


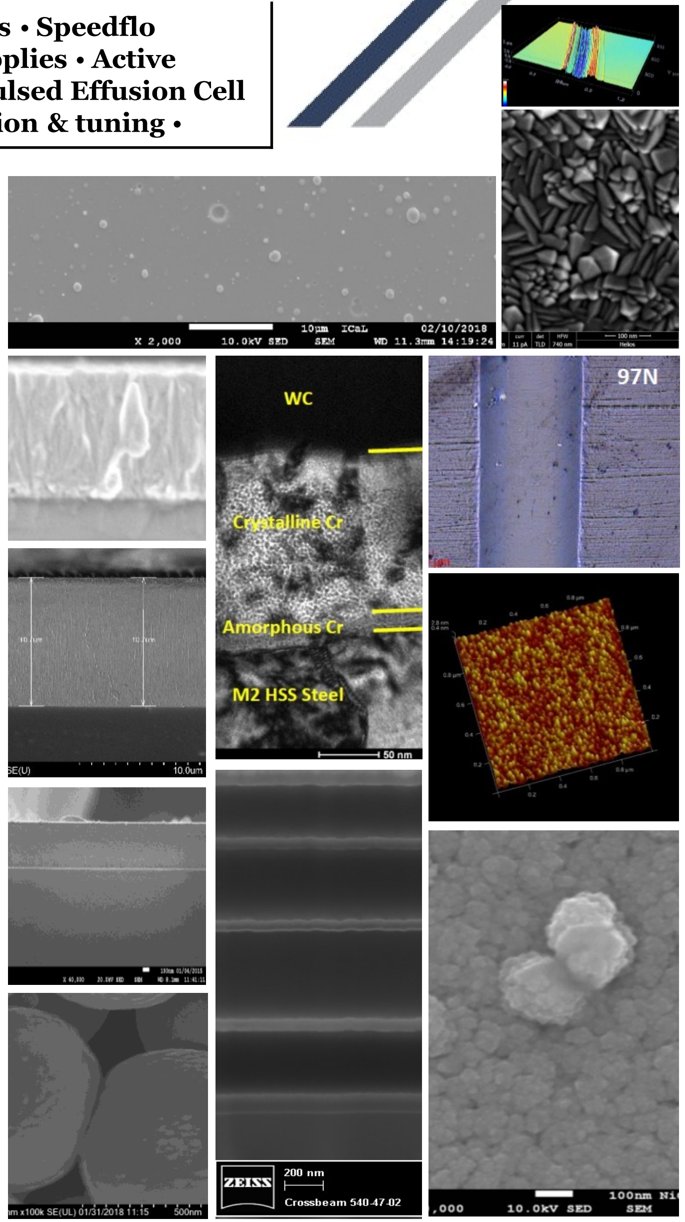
Structure of talk:

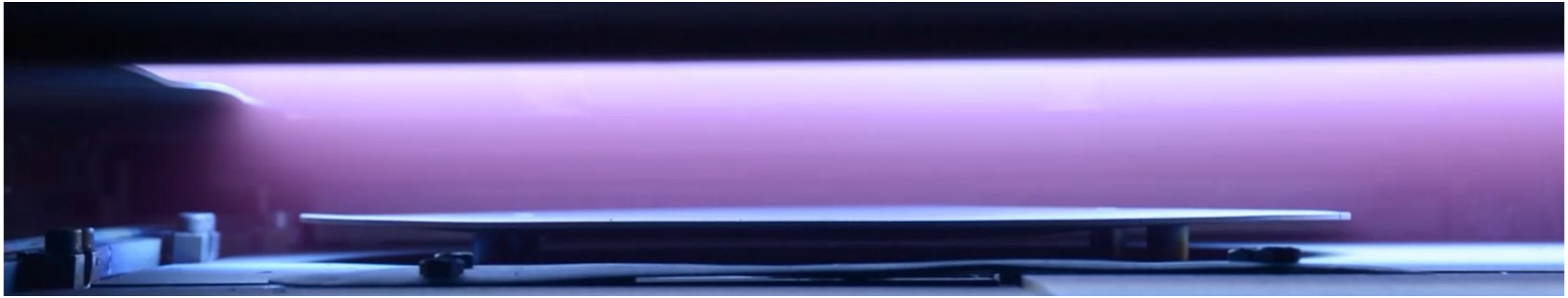
- Hysteresis behaviour
- Why choose feedback control
- What sensors to use
- What controller choice
- Conclusions

Gencoa 30 years experience creating products to create thin films in vacuum

Rotatable & Planar Magnetron Sputter Cathodes • Retrofit magnetic packs • Plasma Treaters • Speedflo Reactive Gas Controllers • IM Ion Sources & power supplies • Arc MAX sources & power supplies • Active Anodes and Gas Delivery Bars • OPTIX Gas and Chemical Sensing • S and Se Sensor • PEC Pulsed Effusion Cell • V⁺DLC - Transparent DLC • IC Nano antimicrobial layer technology • Process implementation & tuning •

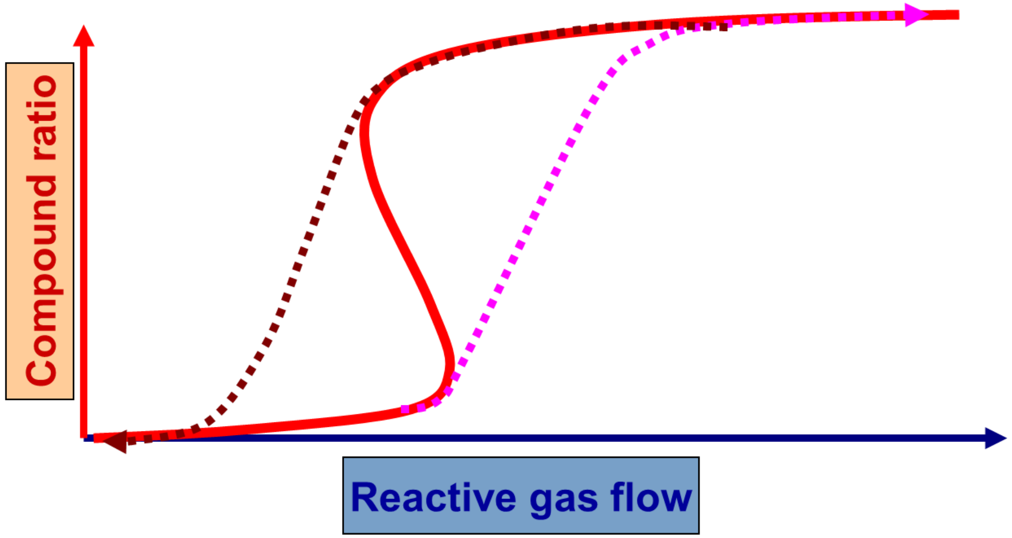


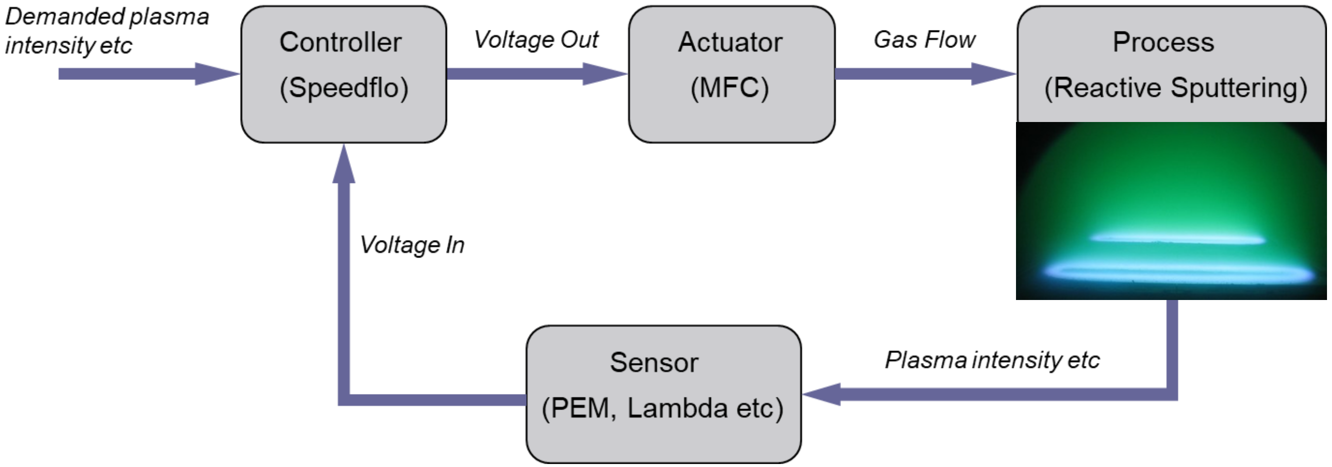




Control of reactive sputtering processes – Hysteresis problem

Traditional view of S-curve / Hysteresis response.

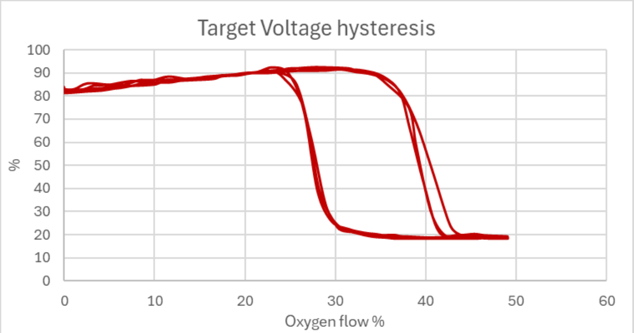


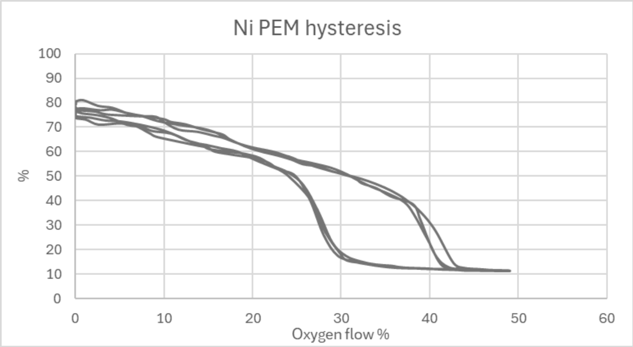


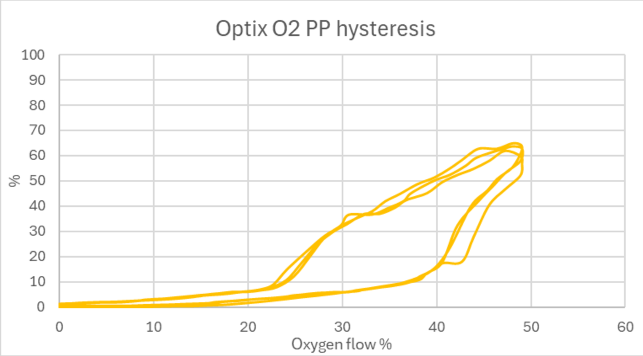
A closed-loop fast feedback control system can eliminate the ‘hysteresis’ problem

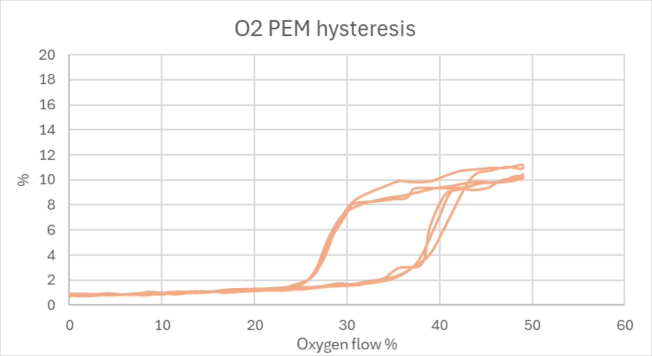
- First start by selecting the most appropriate type of process sensor
- The sensor has to provide a relevant signal from to process to the controller
- Various sensors exist, but the most suitable choice depends upon; budget, the target and gas species present as well as in-process disturbances and system ‘scale’

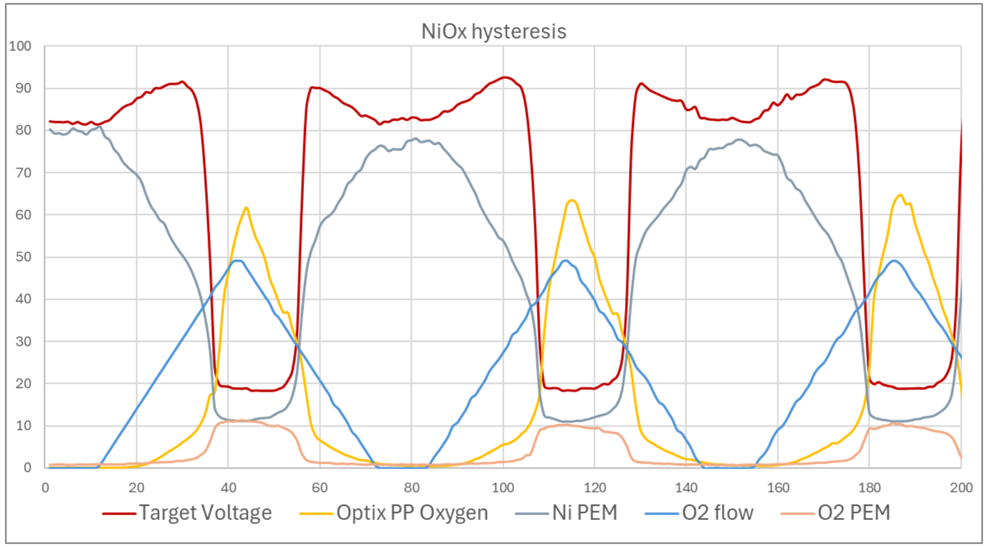
By performing a gas ramp up and down, the response of the process can be seen





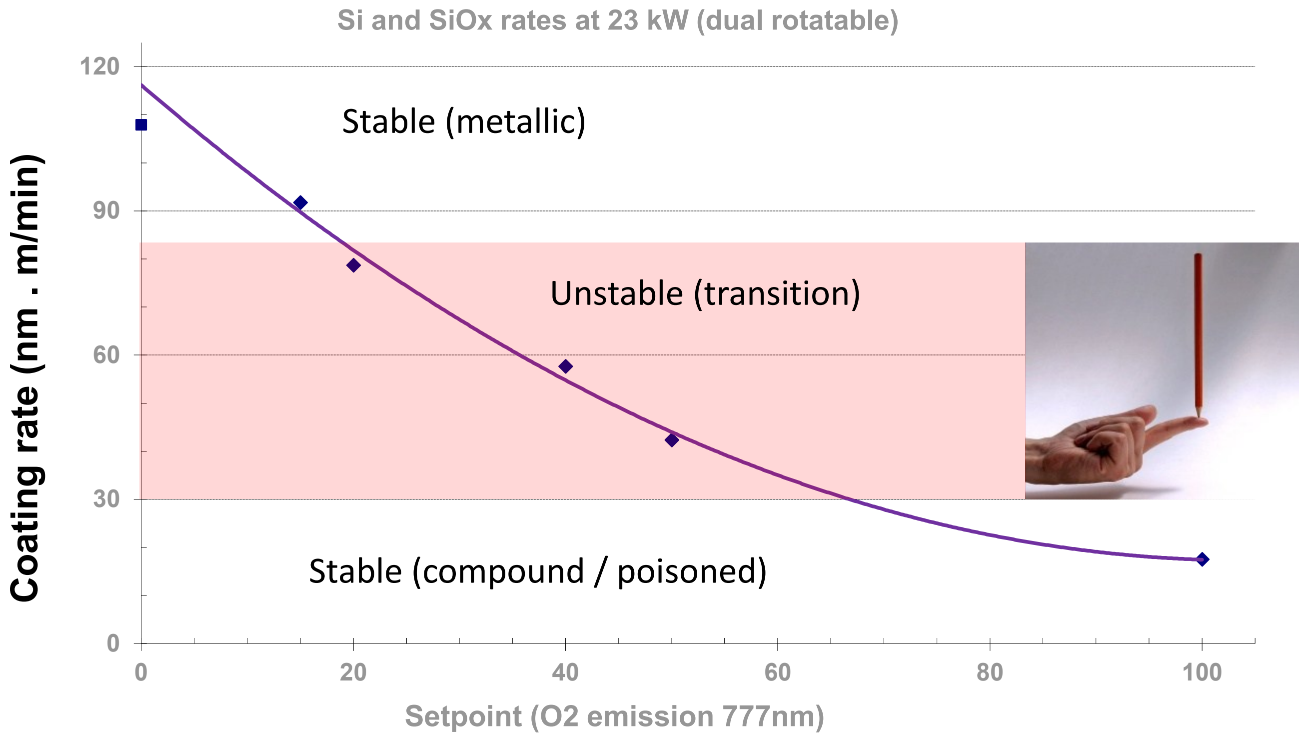




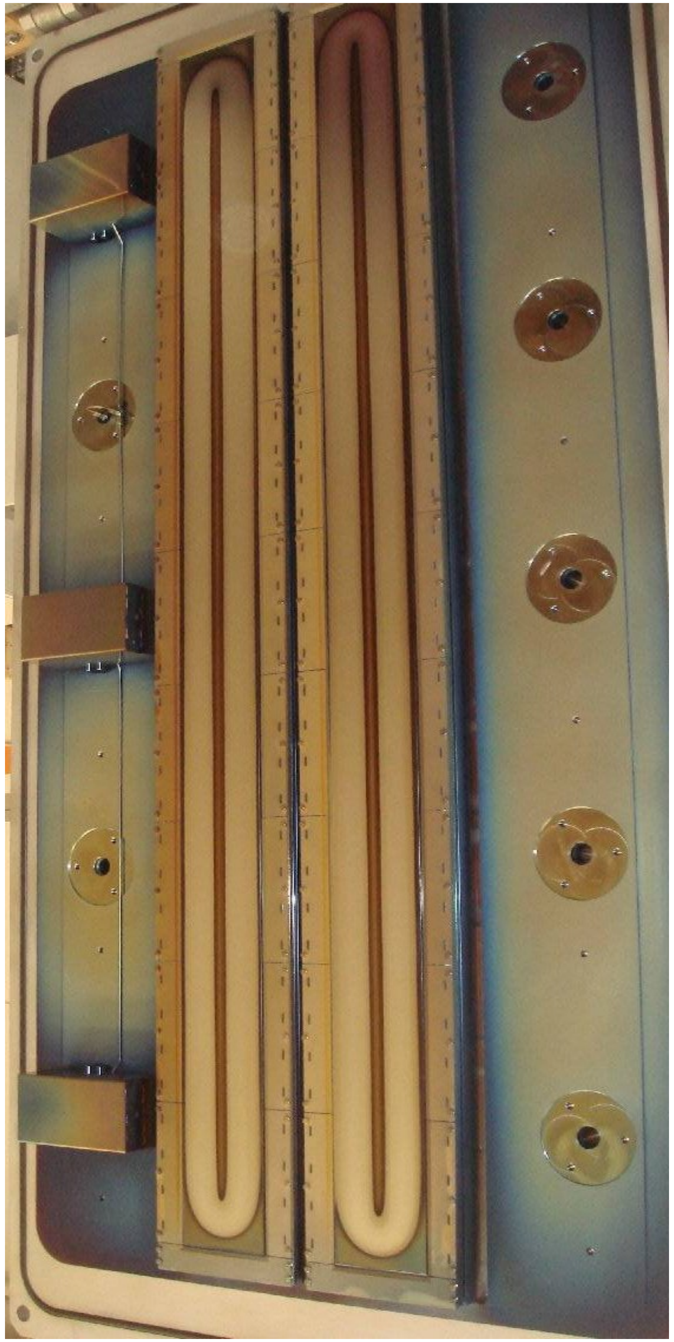


Why adopt closed loop feedback control for reactive sputtering?

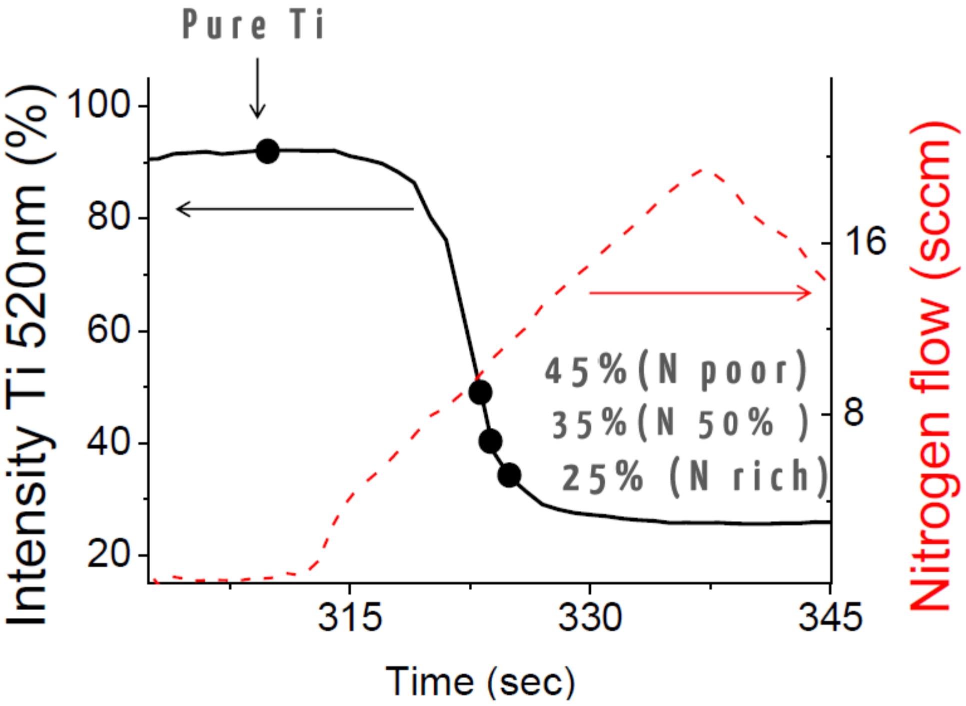
Enables processes to run 2-3 times faster hence reducing costs and improving productivity



Running in poisoned mode yields low deposition rates
However, the transition region is unstable – will tend to poison.



Also closed loop control will deliver more repeatable results eg colour or layer properties



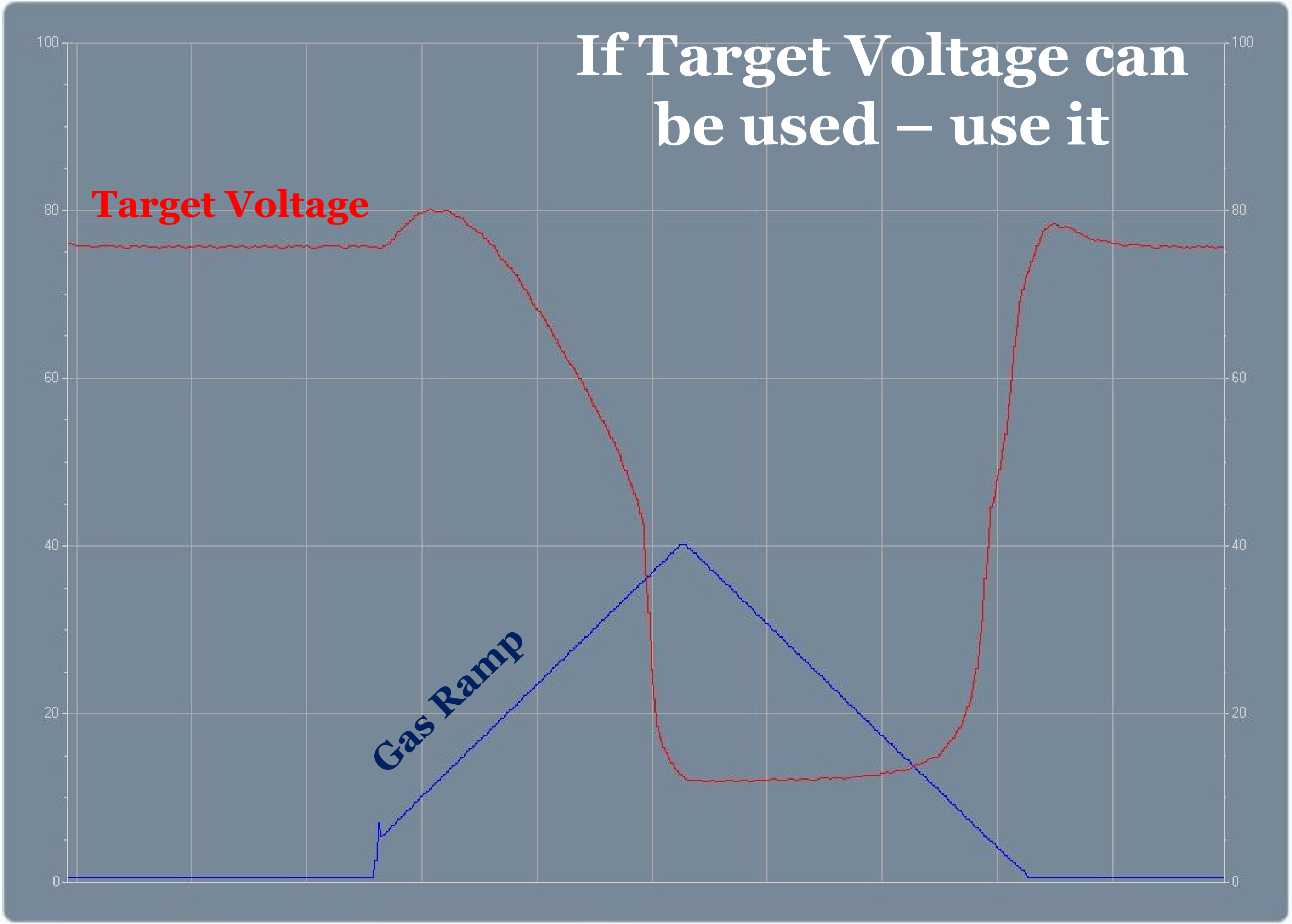
Direct magnetron observation with SpeedFlo CCD

What are the in-situ and ex-situ sensor options

In-situ means sensing the process area directly – receiving a signal from the target or chemistry within the process space	In-situ sensors are; • Target voltage signal • Plasma emission from the sputter target plasma region connected by fibre optic cable to a Photomultiplier Tube (PMT) and Narrow Bandpass Filter (NBF - filter can be configured for either the target species or the gas species). • Plasma emission from the sputter target plasma region connected by fibre optic cable to a spectrometer (can monitor all gas and target species present)
Ex-situ means sensing the process indirectly – receiving a gas signal remotely via a sensor on the chamber wall	Ex-situ sensors are; • Remote Oxygen Gas Signal from a VACGAS G16 Lambda type of sensor • Remote gas signal from an OPTIX plasma head connected via fibre-optic cable to a PMT and NBF. • Remote plasma emission gas signal via a spectrometer – OPTIX device with electronic connection to Speedflo controller

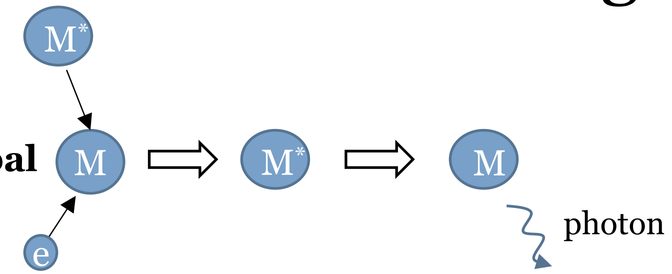
Target Voltage as a Sensor

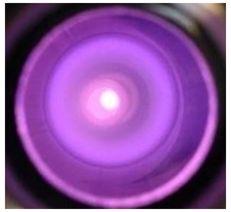
- If the target voltage is transferred from the magnetron power supply via a direct analogue output it is very high speed
- Only cost is a 'cable'
- Ideal signal, but requires a linear change in target voltage with gas flow
- So most successful with silicon and aluminium
- Cannot be used for zone control



Light emission in plasma to sense species present – can be gas or sputtered metals, known as Plasma Emission Monitoring P.E.M

Excitation principal

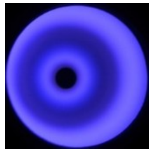




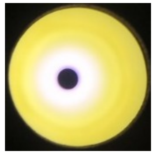
- Quantum mechanics: discrete, allowed excitation states for each molecule / atom
- Energy change between states = wavelength of light emitted = signature for each gas

The same technique is used to analyse the composition of stars

Different gases in plasma emit different "colours"

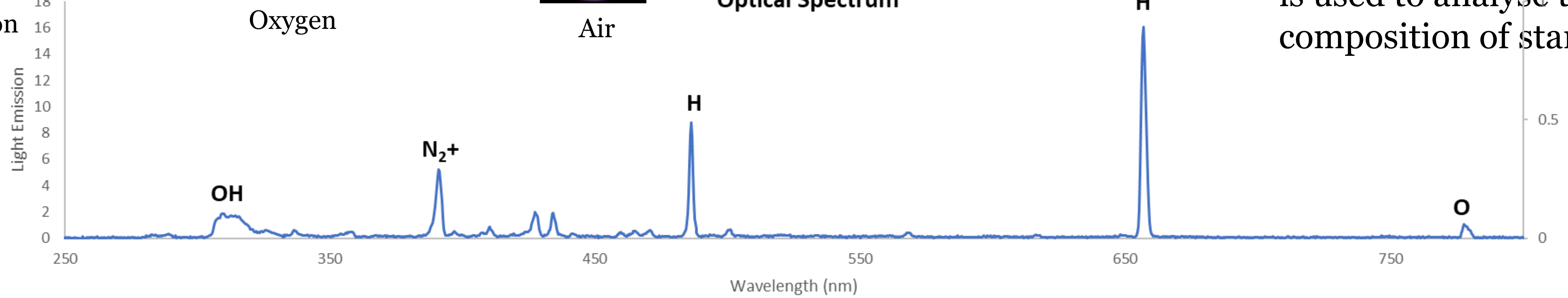


Argon



Oxygen

Air



How to use plasma light as a process sensor

Light from the process or remote plasma is transferred via an optical fibre or lens into a light detector

There are two typical forms of light detector:

- A narrow bandpass filter (NBF) and photomultiplier tube (PMT) – converts a specific wavelength of light intensity into a voltage

- An optical spectrometer which monitors all the visible light emissions present from 250 to 850nm with an intensity output for any species

Pro’s and Con’s of light detectors

Important aspects from a process control point of view is signal speed, signal stability and cost of the device

A narrow bandpass filter (NBF) and photomultiplier tube (PMT):

- Very high speed as signal converted to a voltage output within a millisecond, no drift or temperature effects, moderate cost, but only 1 gas or metal monitored

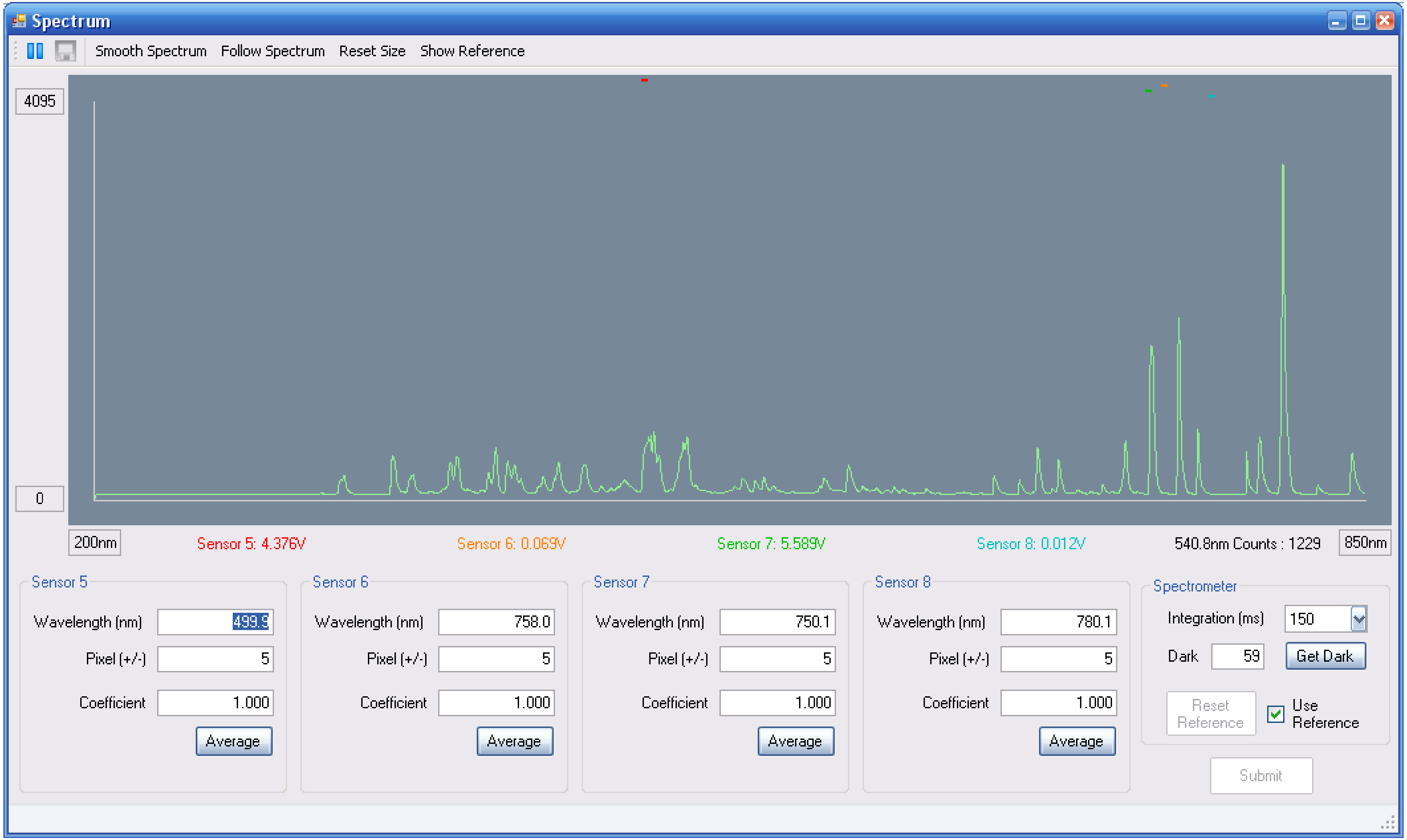
An optical spectrometer

- Lower speed as typically integration time is in the 100’s of milliseconds to ensure a good signal to noise ratio, subject to ‘drift’ as based upon CCD arrays (auto recalibration required), higher cost depending upon the resolution and sensitivity, can combine multiple species and ratios

Spectrometers freedom to choose any wavelength

Different wavelength channels can be combined to control around gas ratio's

Useful for R&D as more flexibility especially if In and Ex P.E.M Situ combined



‘Remote’ light emission based sensors

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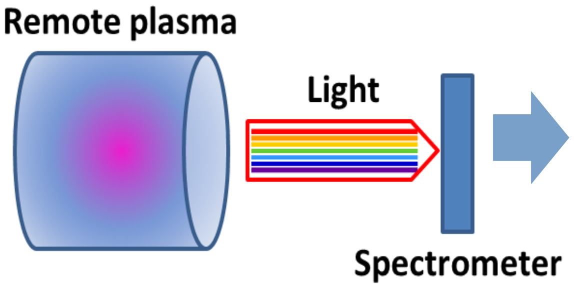
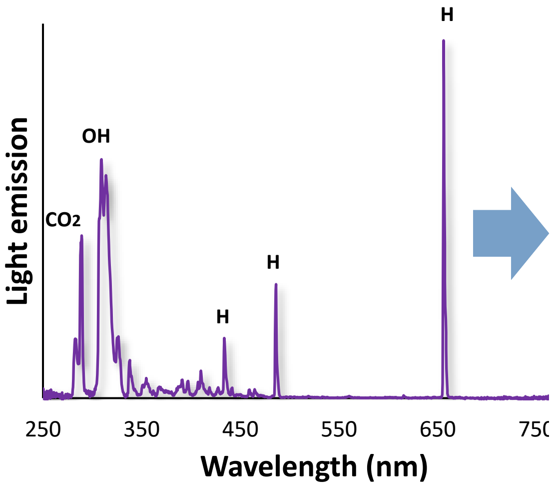
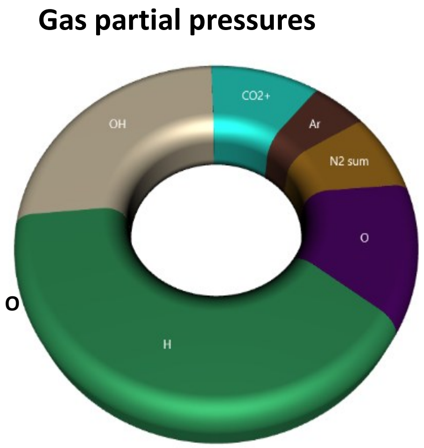
Remote sensing of gas species provides a more stable signal – <u>light fluctuations from the process plasma due to substrate movement or arcs not seen in the remote signal – unbeatable signal stability</u>

- Only the excess gaseous species monitored and can be combined with either a PMT or Spectrometer (OPTIX)

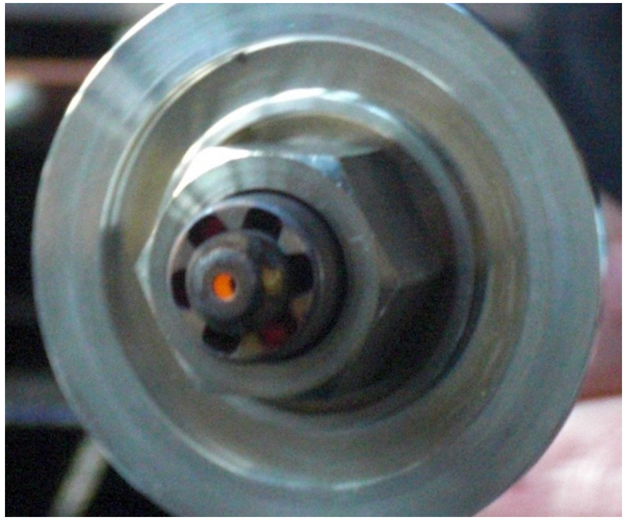


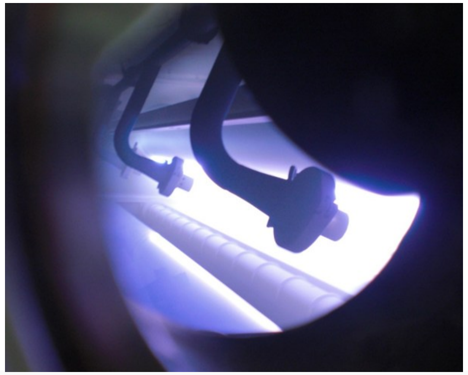




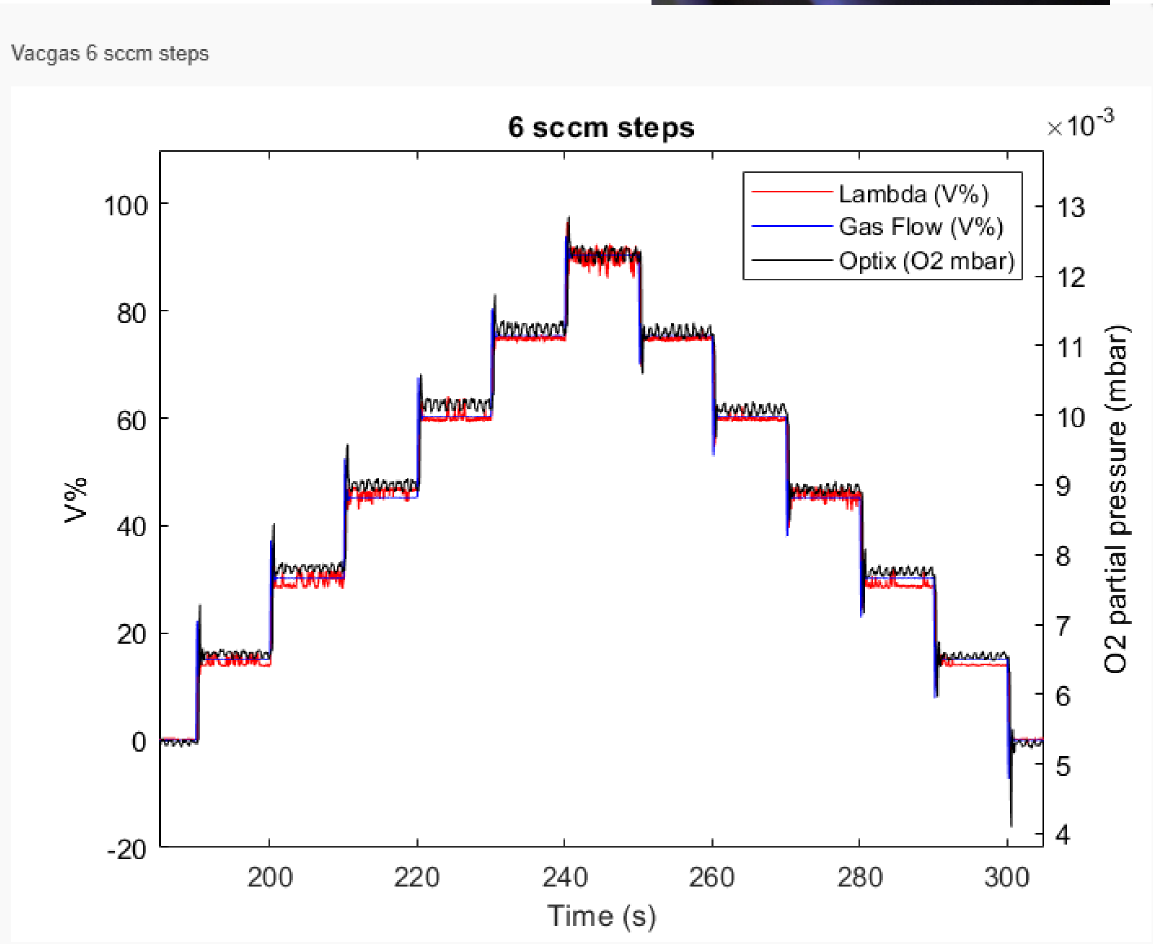
Remote or in-situ Oxygen Sensor

Lambda based sensor provides an O_2 partial pressure





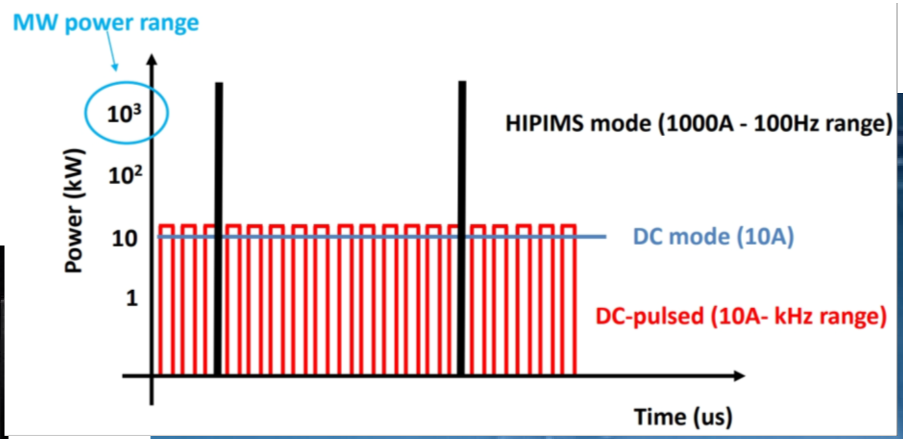
- High stability as VacGasG16 controls the sensor head temperature precisely and not subject to plasma fluctuations
- Similar cost to PMT
  - Similar response as spectrometer

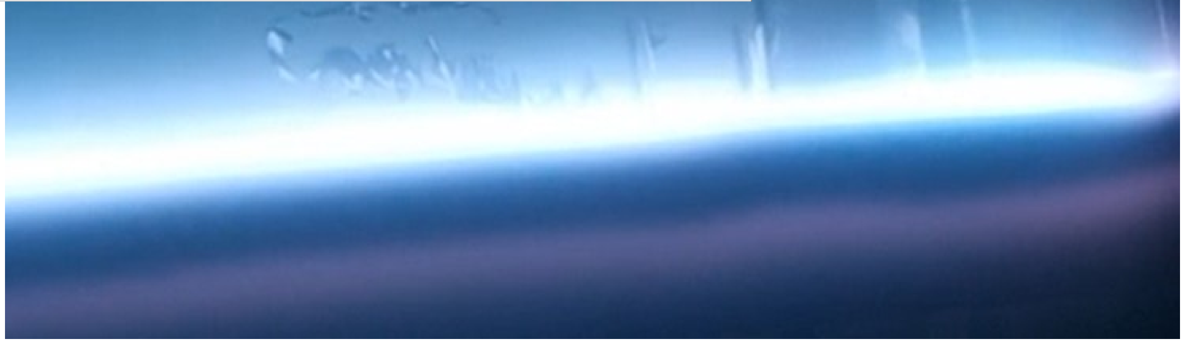


What about Hipims

Hipims – High Power Impulse Magnetron Sputtering Shows Hystersis

- Hipims has a period pulse hence ‘fast’ sensors such as target voltage and PMT require signal capture – Hipims ‘switch’ is extra hardware that provides a constant signal from the pulse
- Slower sensors such as a spectrometer or VacGas G16 (Lambda) work as normal





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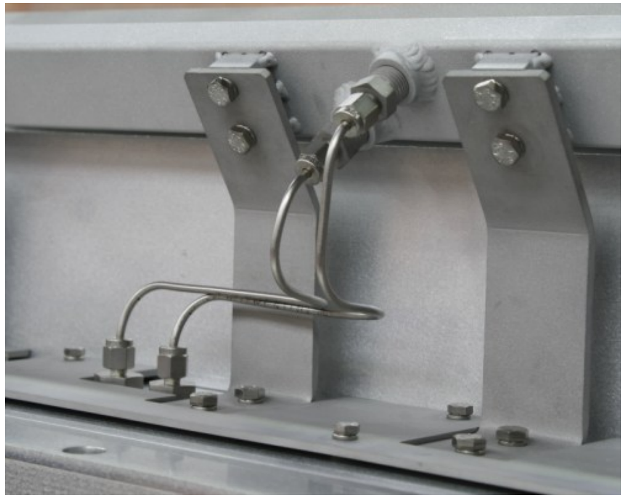
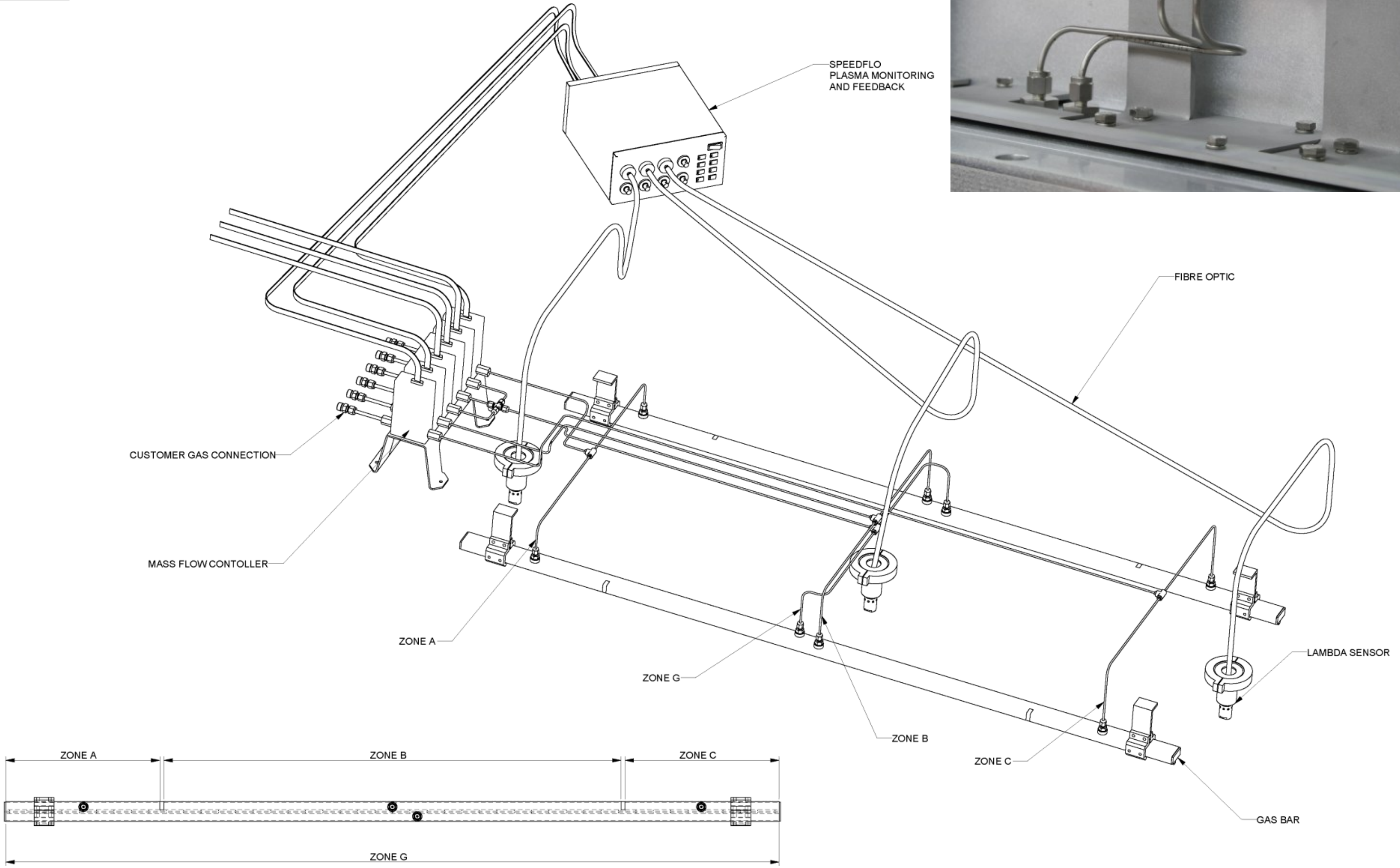
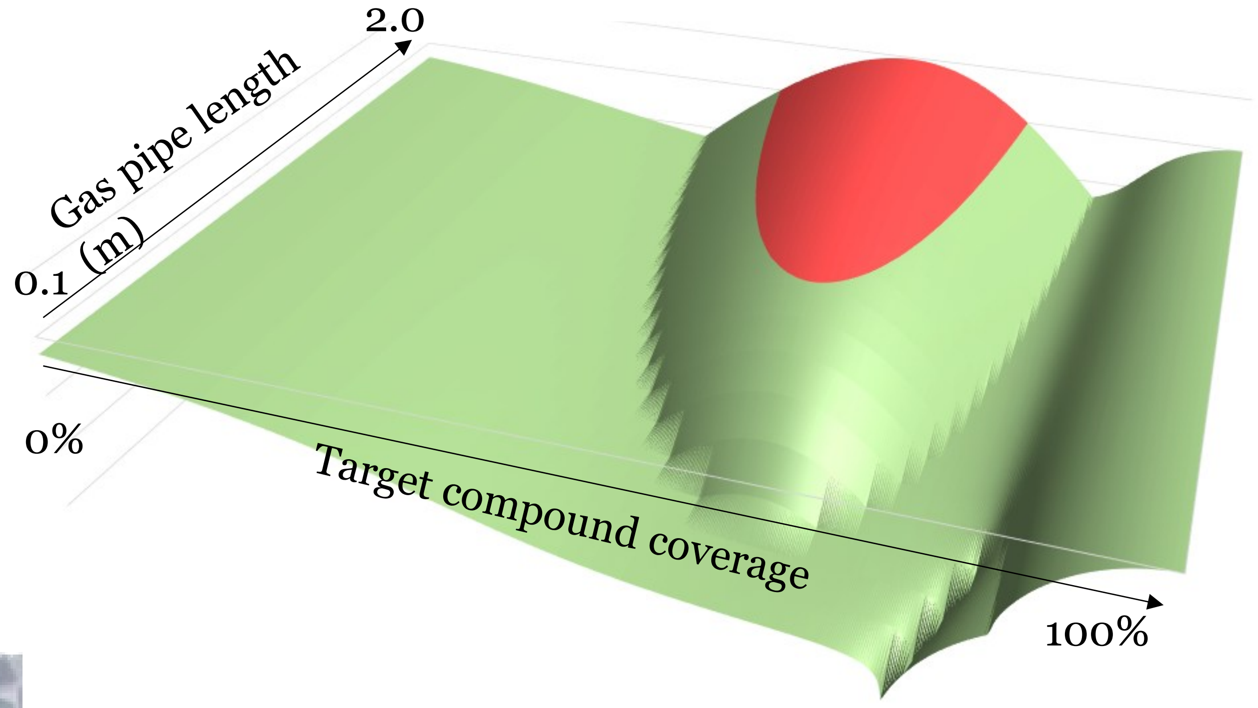
Optimum gas bar designs and sensor locations as well as the length of gas connections and MFC response times all have an influence on the closed loop control

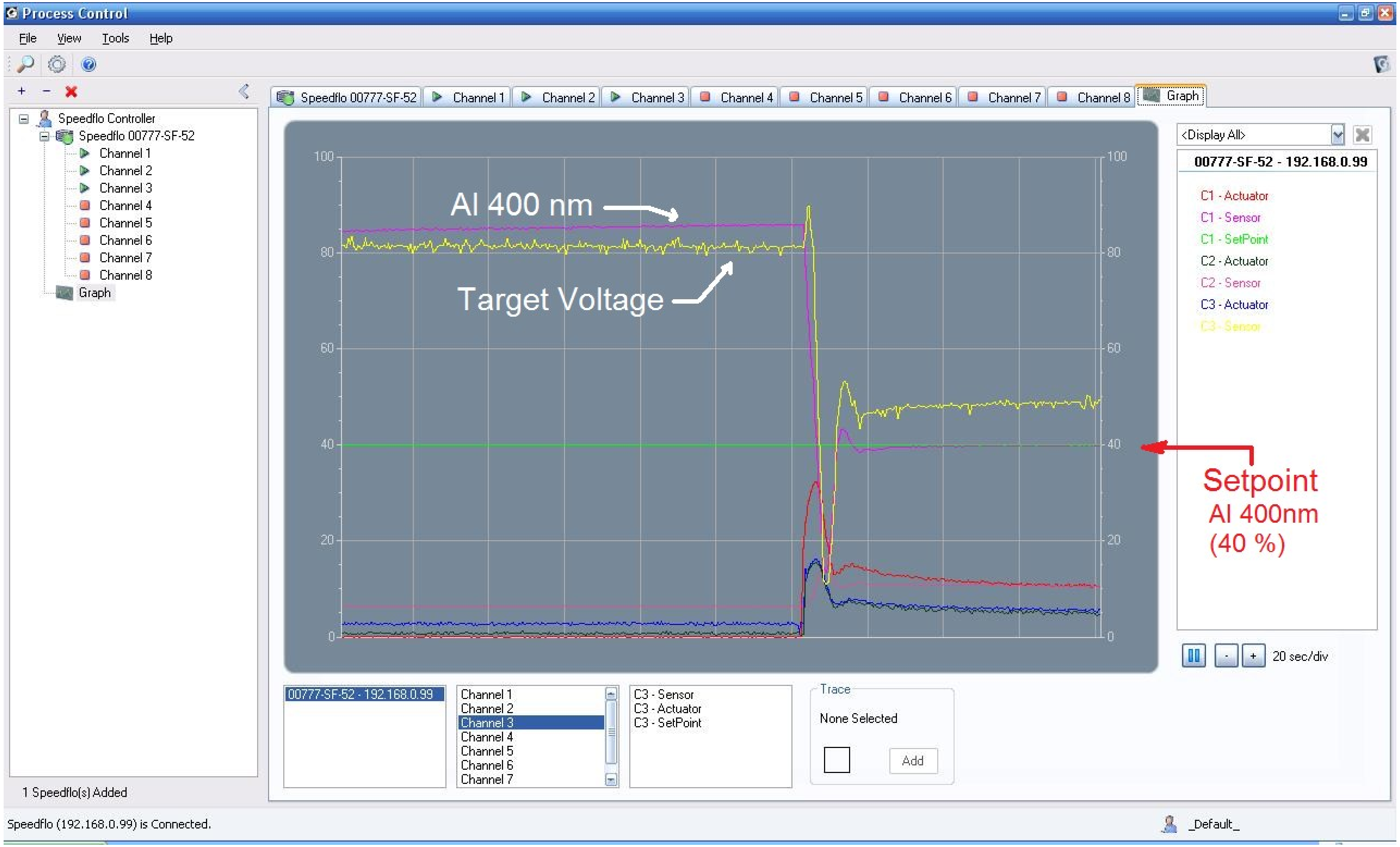




Fast responding target material systems may not allow control across all settings if for instance the gas flow through the delivery tubes has a delay – ie long gas pipe lengths

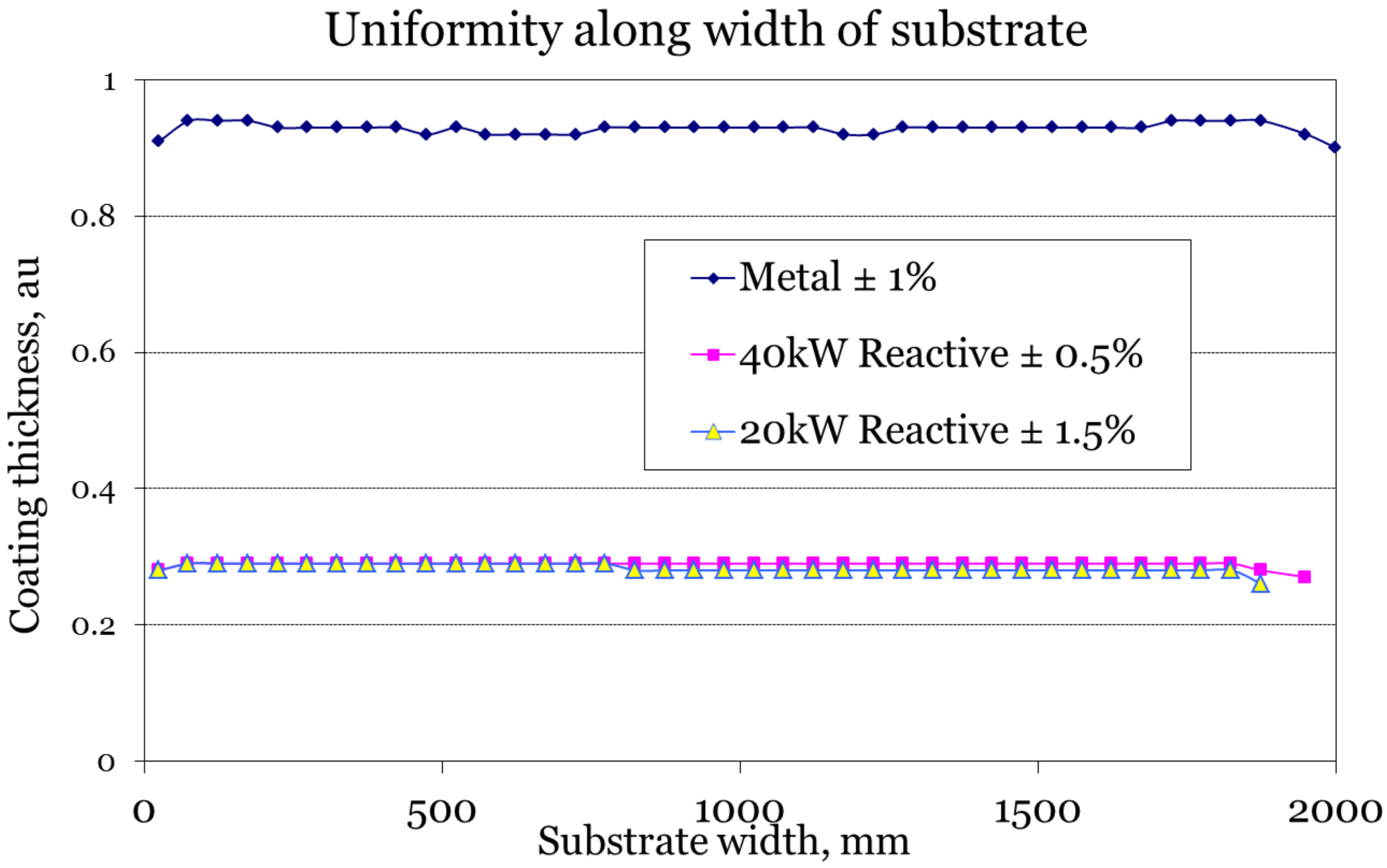


Example of reactive gas control for Al2O3 on web for ultra-barrier applications



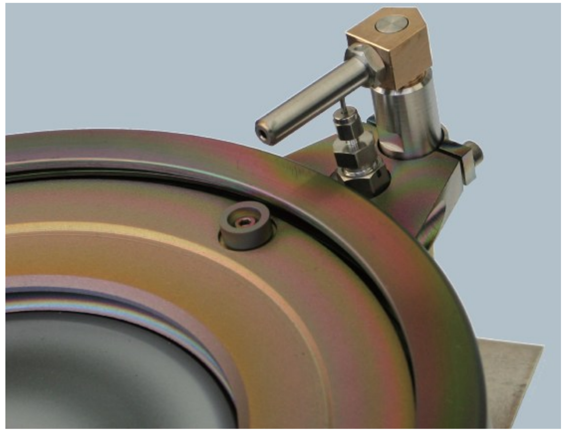
Muilti-zone reactive sputtering has the ability to improve coating uniformity by local feedback control loops

- By having ability to sense and control different gas zones across a large area plasma gives the ability to get tight control of uniformity
- The flexibility of the controller software as well as gas bar design is the key to success



Summary of available sensors

In-situ



In/Ex-situ

Ex-situ

Choosing between Speedflo Controller Types

Three different units are available based upon the number and types of input / outputs required

SPF/M Mini Speedflo	*SPF16 Speedflo*	*SPF Speedflo*
2 input Channels with 3 MFC outputs	Upto 16 Channels with mixed configuration between input or output, 'plug and play'	8 input Channels with 8 MFC outputs
1-2 voltage input (target voltage, VACG16, OPTIX analogue) 1 plasma emission input (in/ex situ, spectrometer or PMT)	1-16 voltage input (target voltage, VACG16, PMT, OPTIX partial pressure) Output number is 16 – minus input number	1-8 voltage input (target voltage, VACG16, OPTIX analogue) 1-4 plasma emission input (in/ex situ, 1 spectrometer max or 1-4PMT)

SPF/M Speedflo Mini

Cost effective fast reactive gas feedback controller for smaller scale systems requiring fewer input / outputs.

- ***All Speedflo models have the patented auto-tuner***

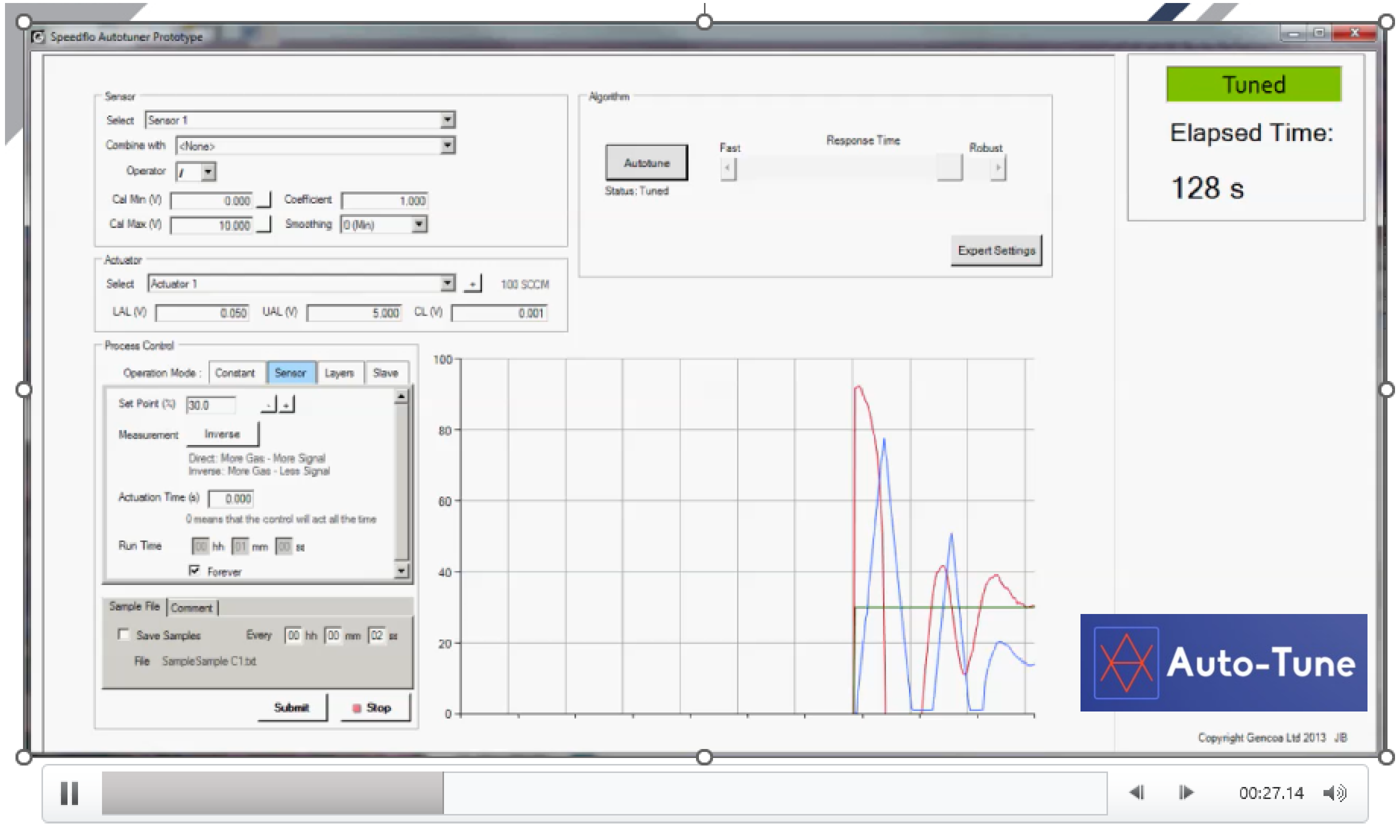
SPF/M Mini Speedflo

2 input Channels with 3 MFC outputs

Input channel can be mixed between 1-2 voltage input (target voltage, VACGas G16, OPTIX analogue)

& 1 plasma emission input (in/ex situ, spectrometer or PMT)

Optional 2 channel Hipims 'switch' input



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SPF Speedflo

Industrial fast & configurable reactive gas feedback controller for large scale systems requiring multiple input / outputs.

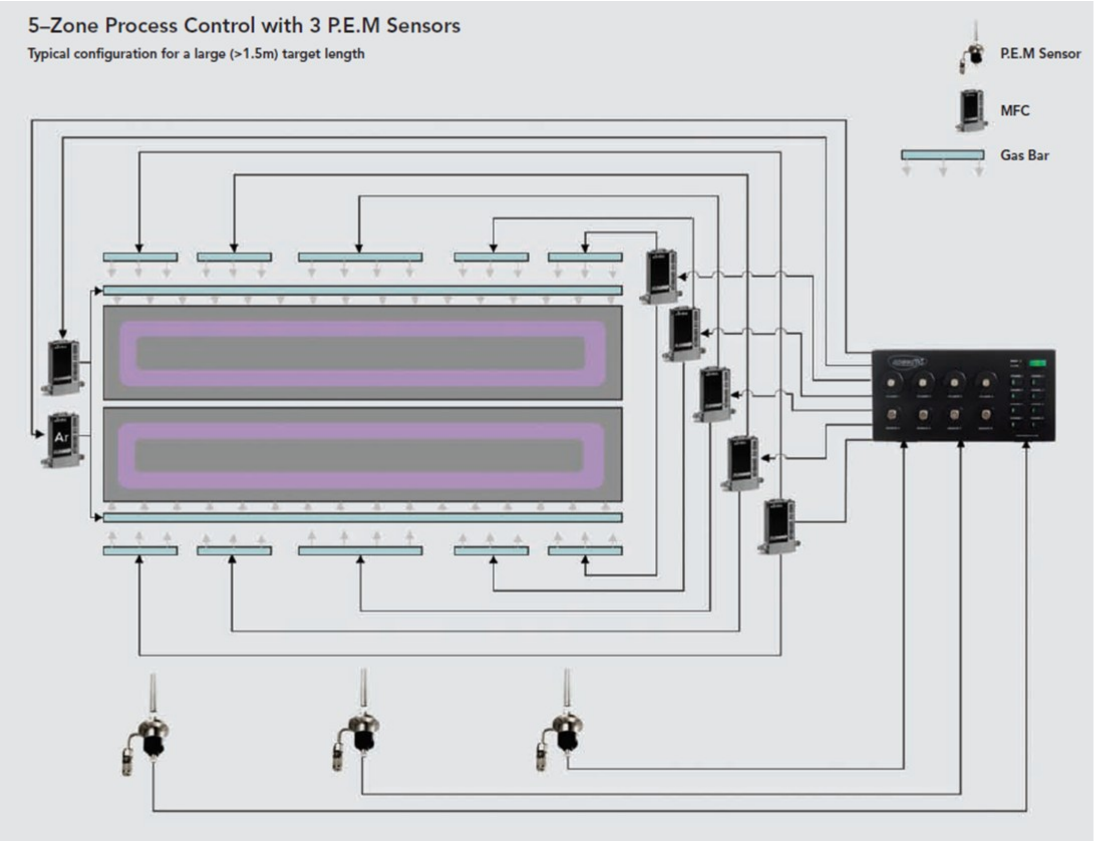
- *Workhorse for large area process control requiring zone control*

SPF Speedflo

8 input Channels with 8 MFC outputs

Input channels can be mixed between 1-8 voltage input (target voltage, VACGas G16, OPTIX analogue)

& 1-4 plasma emission input (in/ex situ, spectrometer (1 only) or PMT (upto 4)



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SPF16 Speedflo

Flexible reactive gas feedback controller any possible control situation which can be easily reconfigured

- *Internal Controller Area Network (CAN bus) system to handle large amounts of data at high speed for millisecond control over upto 16 channels*

SPF16 Speedflo

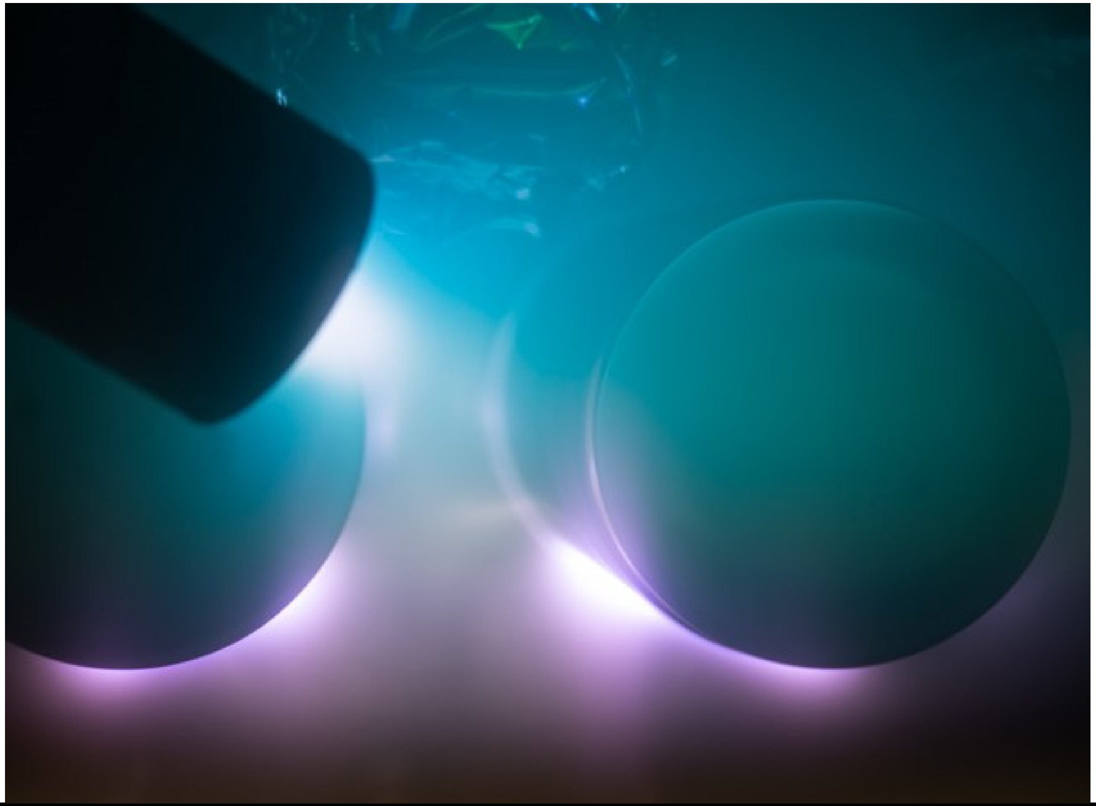
Auto-Tune

16 input / output Channels can be configured in any way

Input channels can be mixed between voltage input (target voltage, VACGas G16, OPTIX analogue), plasma emission input (in/ex situ), spectrometer (upto 16) or PMT, hipims

OPTIX gas sensing input channel upto 16 with transfer of gas partial pressures (multiple gas or ratios)

Add or remove cards to change the configuration – Plug and Play at the process site.



Reactive Magnetron Sputtering Feedback Control, ‘Flexibility for Success’

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Conclusions

- A wide range of sensors are available that ensures a suitable match for any reactive sputtering situation
- Depending upon the process scale, one of 3 controllers will ensure a good cost to complexity ratio
- Reactive sputtering feedback control can even the most complex problems
- Advantages of control are higher rates, better quality and improved energy efficiency