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Reactive Sputtering Made Easy

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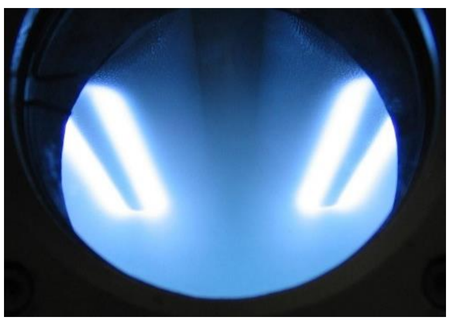
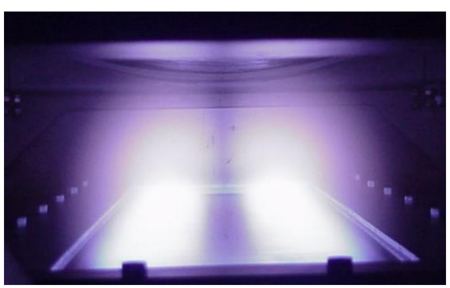
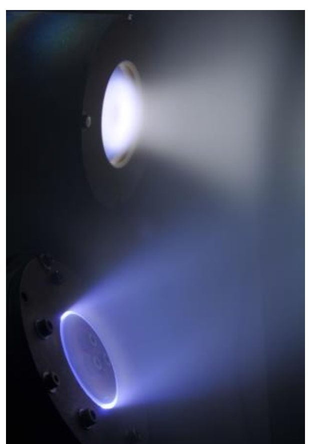
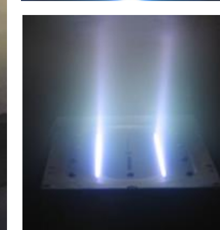
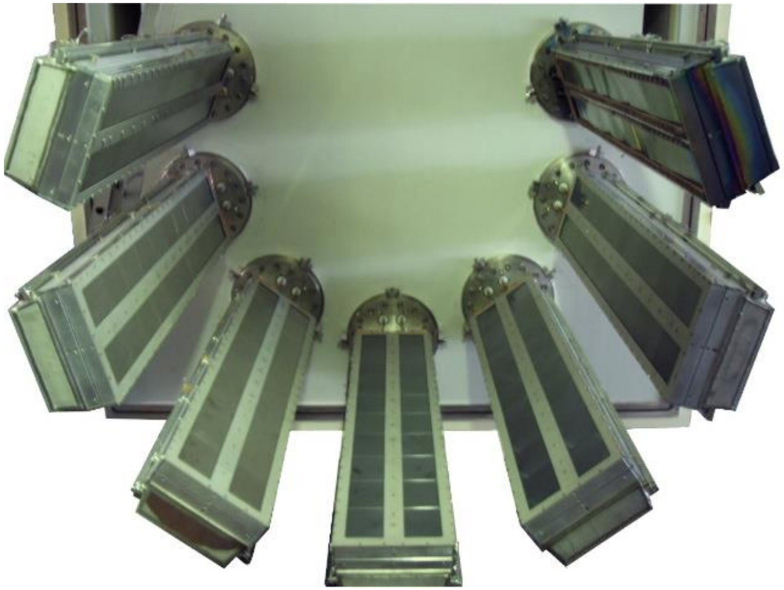






Reactive Sputtering is well established to make a wide range of products



Speedflo history

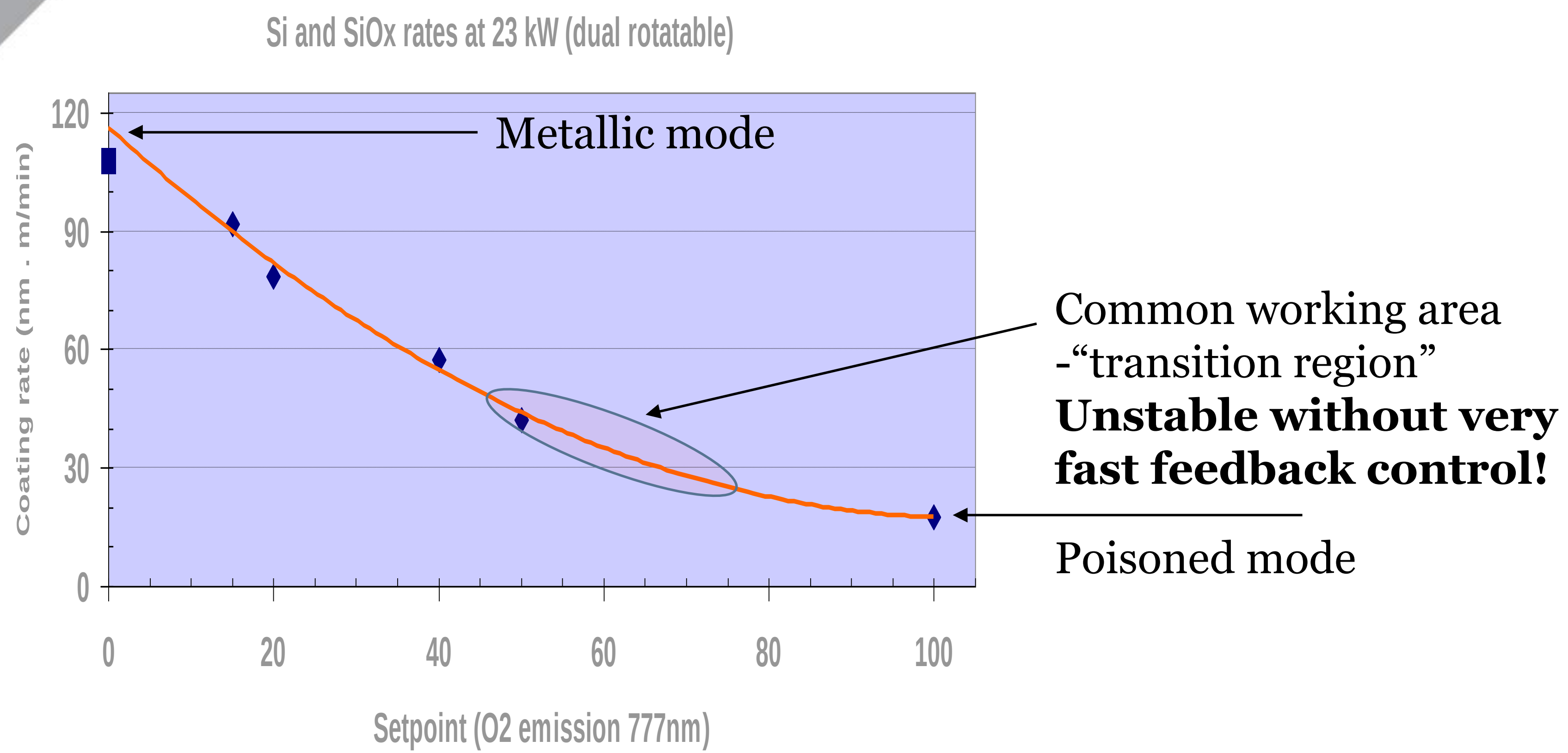
In 2003 Gencoa began the development of a control system "Speedflo" for precision control of sputtering processes.

Within 10 years it has become the global leader and today over 5000 deployed and working in the field maintaining production lines around the world at full capacity.

It is a key component in the manufacture of the iPhone, iPad, Samsung Galaxy and Sony phones.

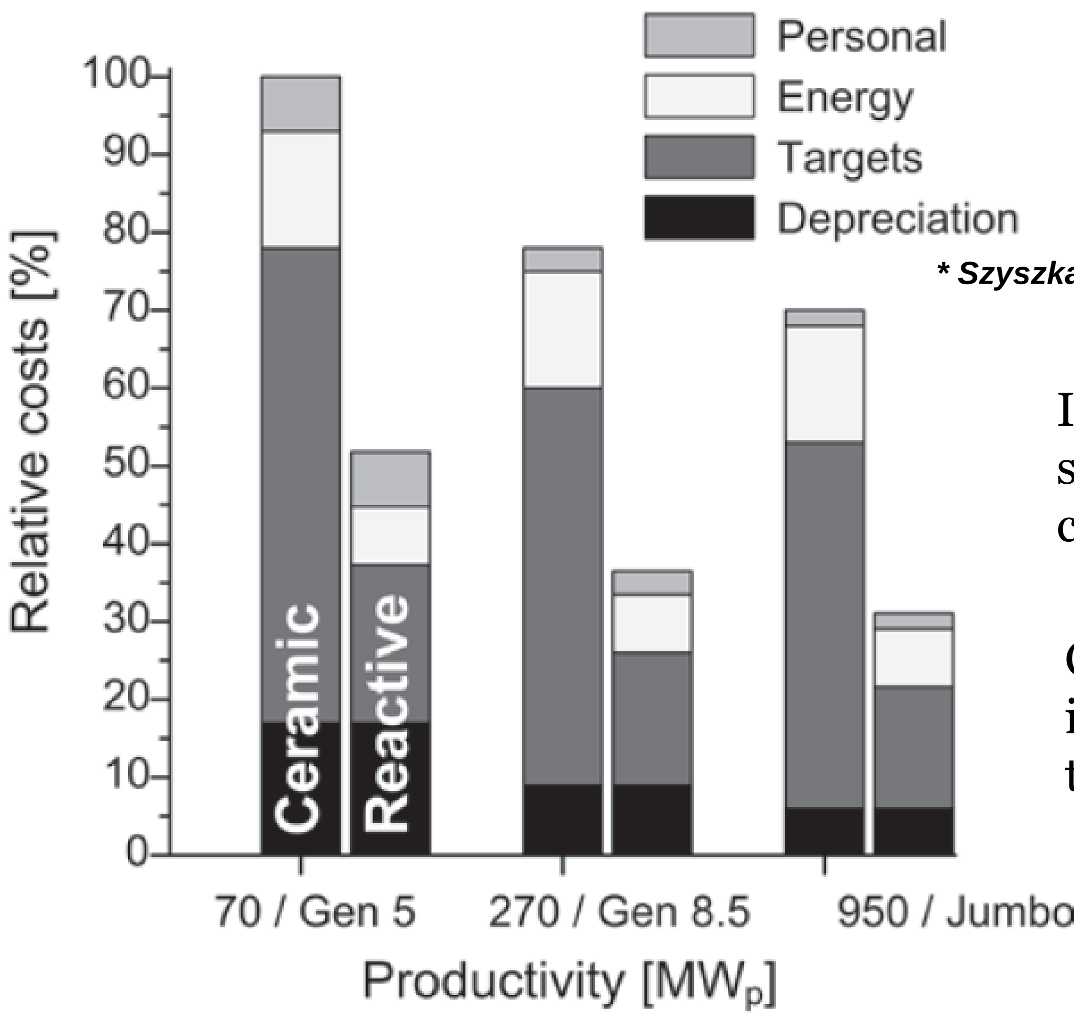
Our control technology has improved production rates 3x in these cases.

Speedflo for reactive sputtering enables processes to run 3 times faster hence reducing costs and driving productivity



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

Reactive sputtering reduces energy by >65% and hence is an important cost driver today

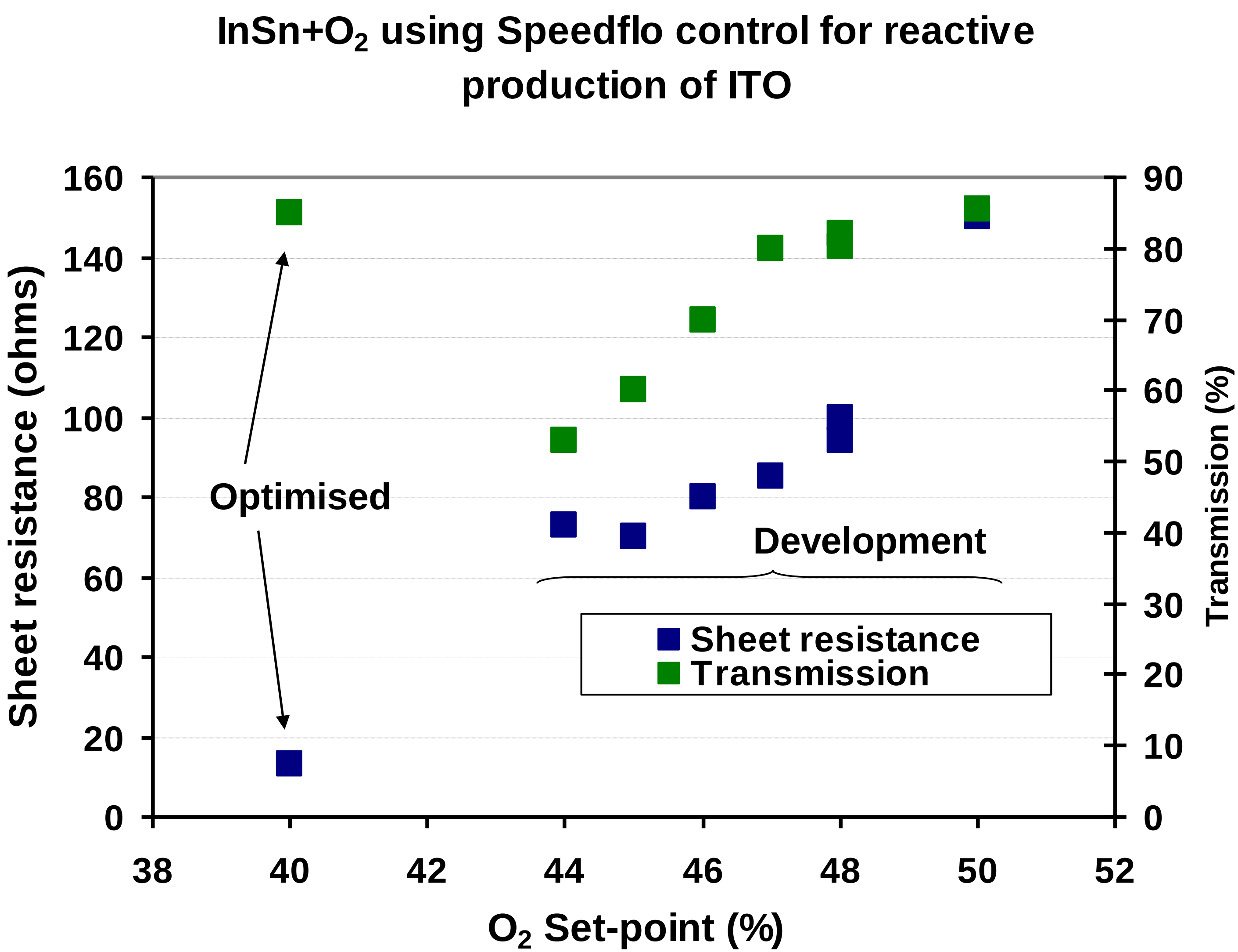


*** Szyszka et al**

In the case of AZO, the reactive sputtering process will be < 50% current ceramic based costs

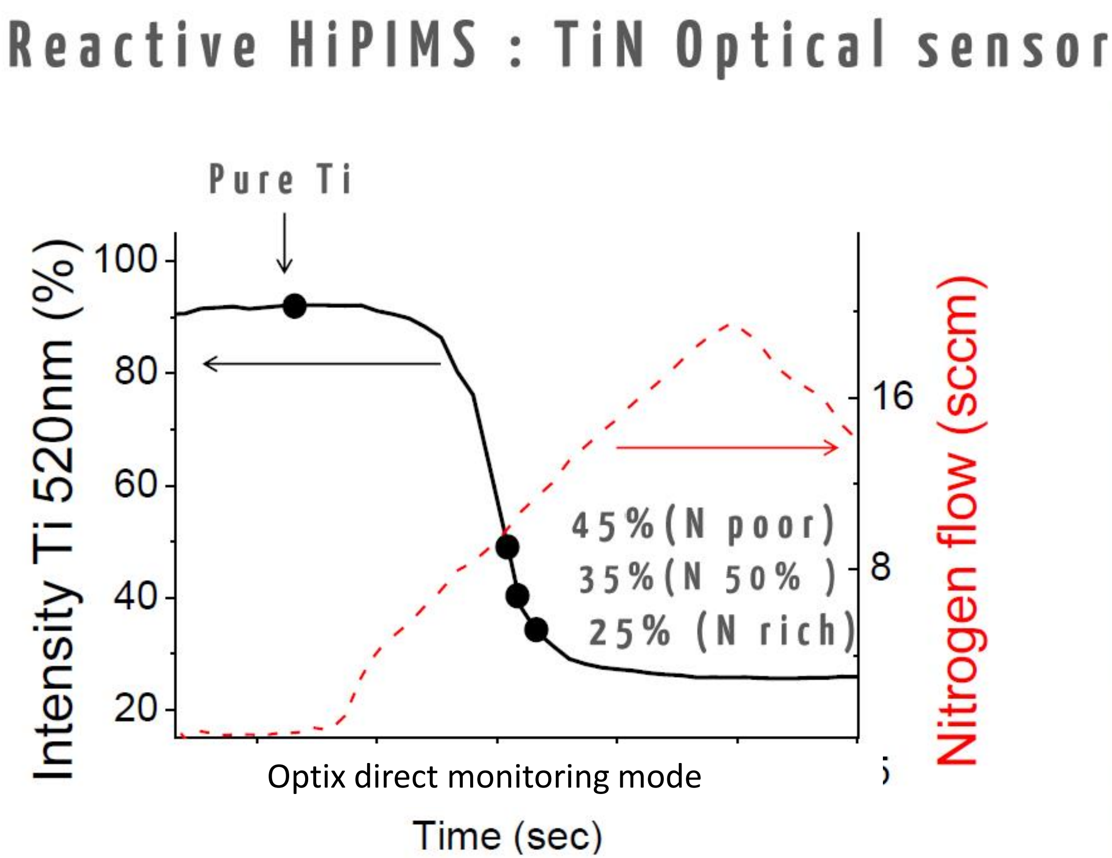
Controlled reactive sputtering is x 3 the rate in production than ceramic AZO

‘Speedflo’ reactive sputtering controller with a dual rotatable magnetron for ITO production – easy layer property tuning



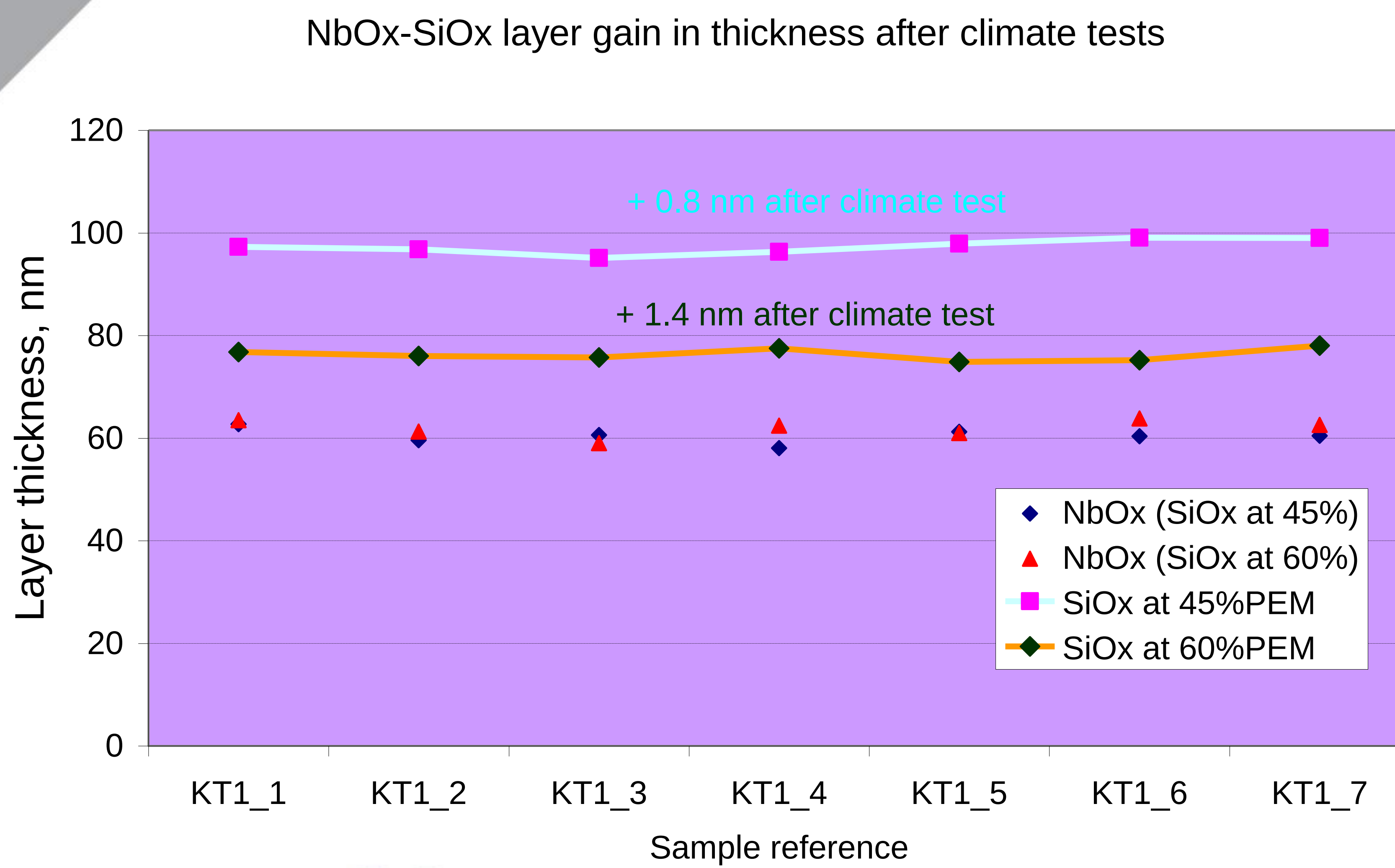
Speedflo and reactive sputtering for the production of 'Gold'

Titanium and nitrogen system give a visual indication of the different material properties at different control setpoints

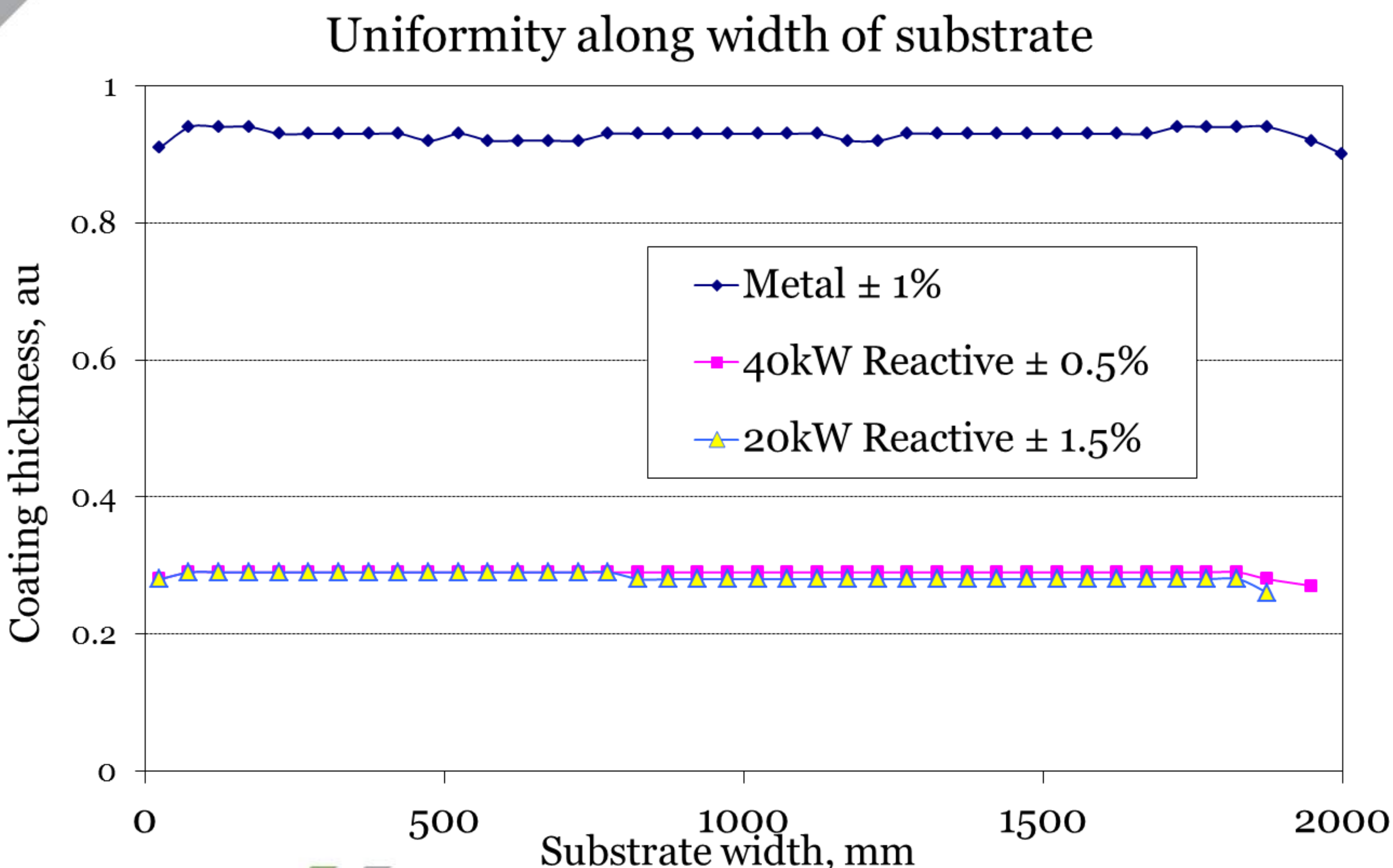


Direct magnetron observation with SpeedFlo CCD

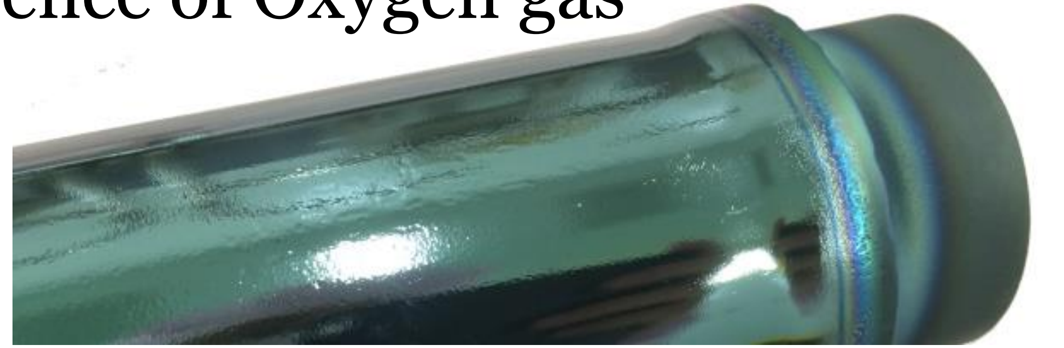
Speedflo and reactive sputtering for the production of more corrosion resistance

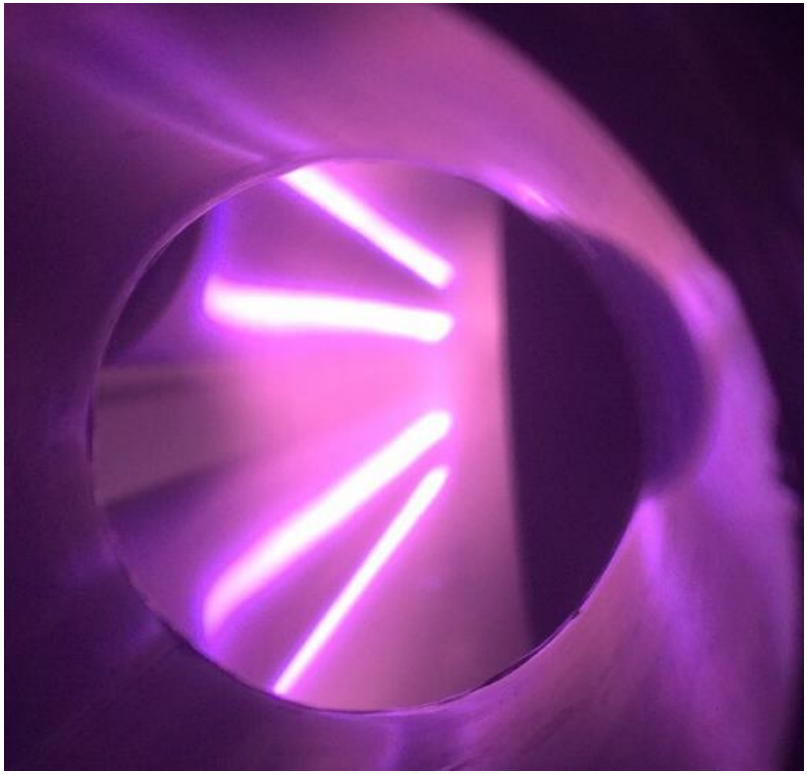


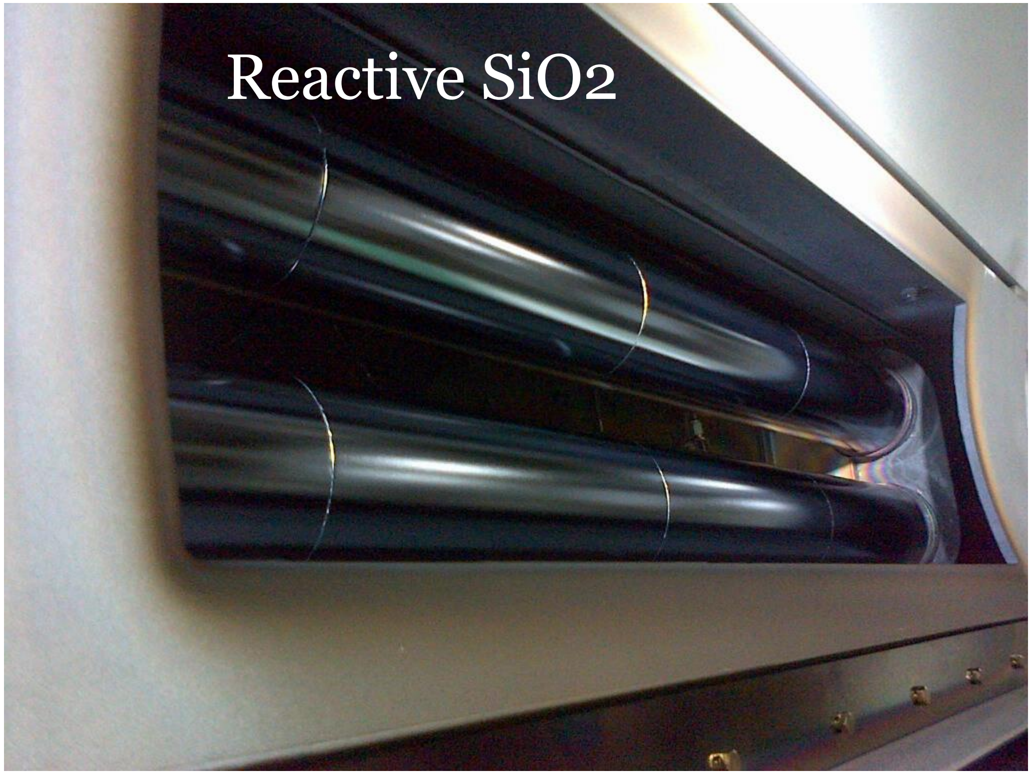
Muilti-zone reactive sputtering has the ability to improve coating uniformity by local feedback control loops



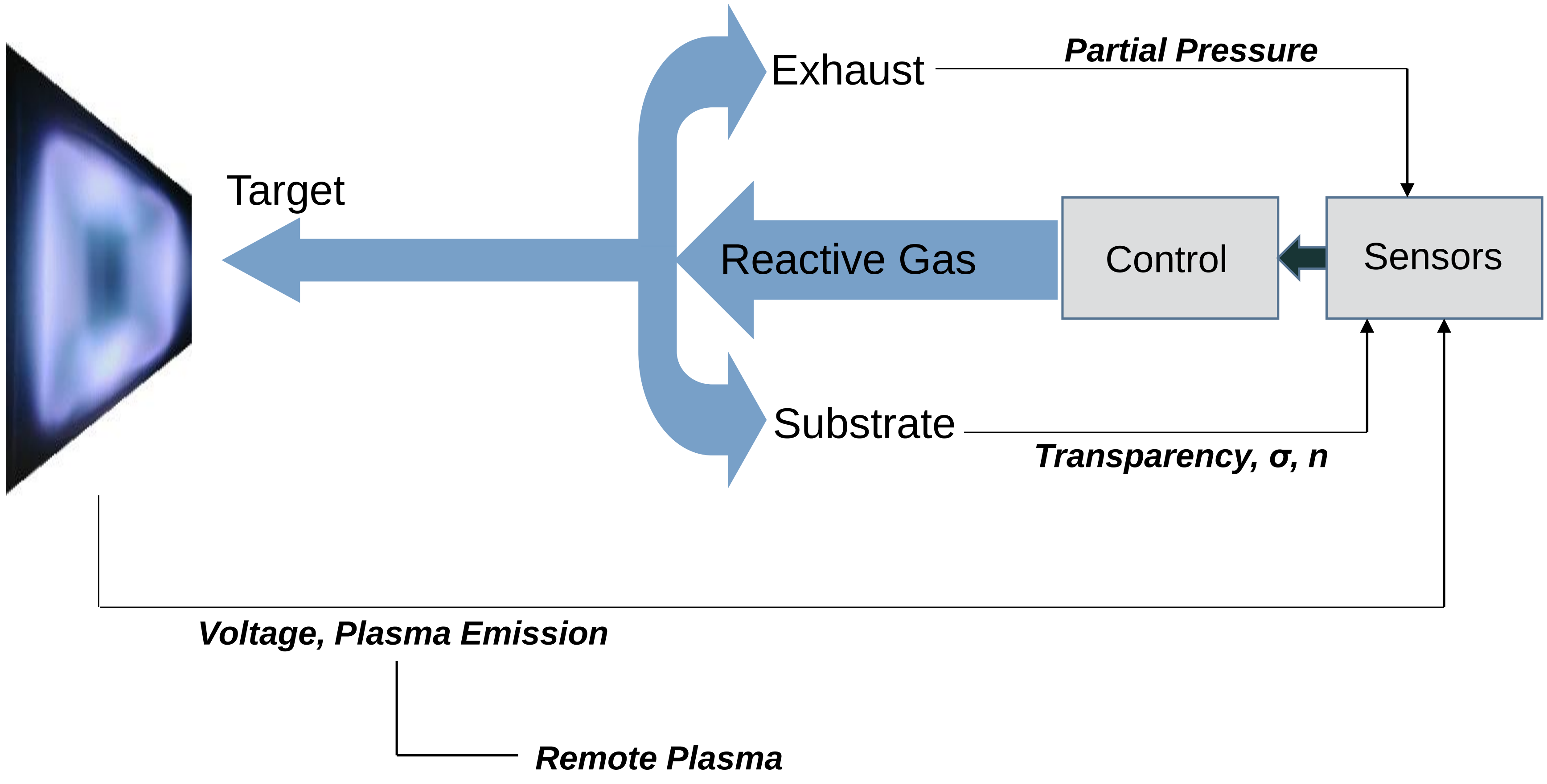
The most common material combination is Silicon Sputtering in the presence of Oxygen gas





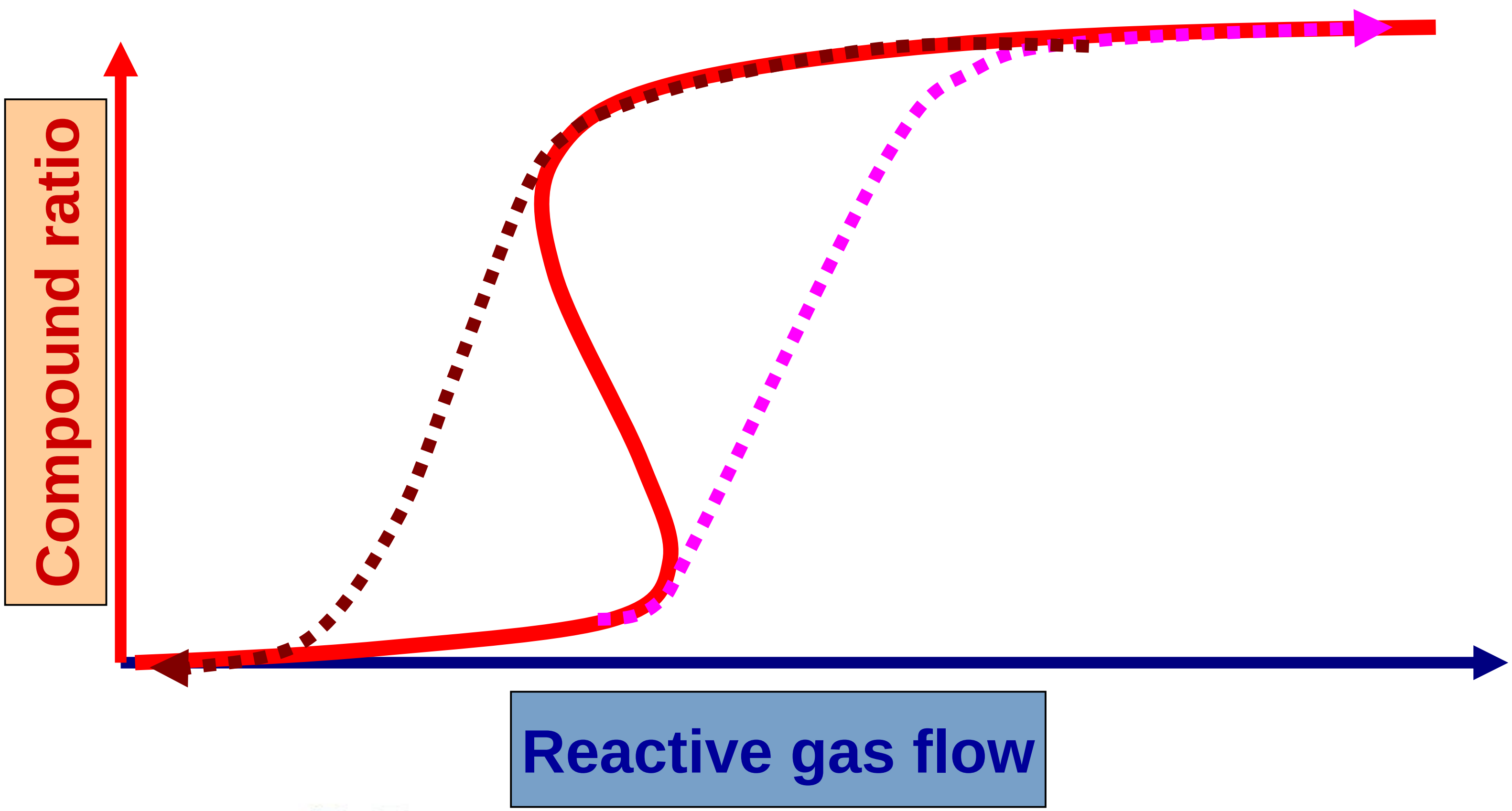


Reactive Sputtering Overview

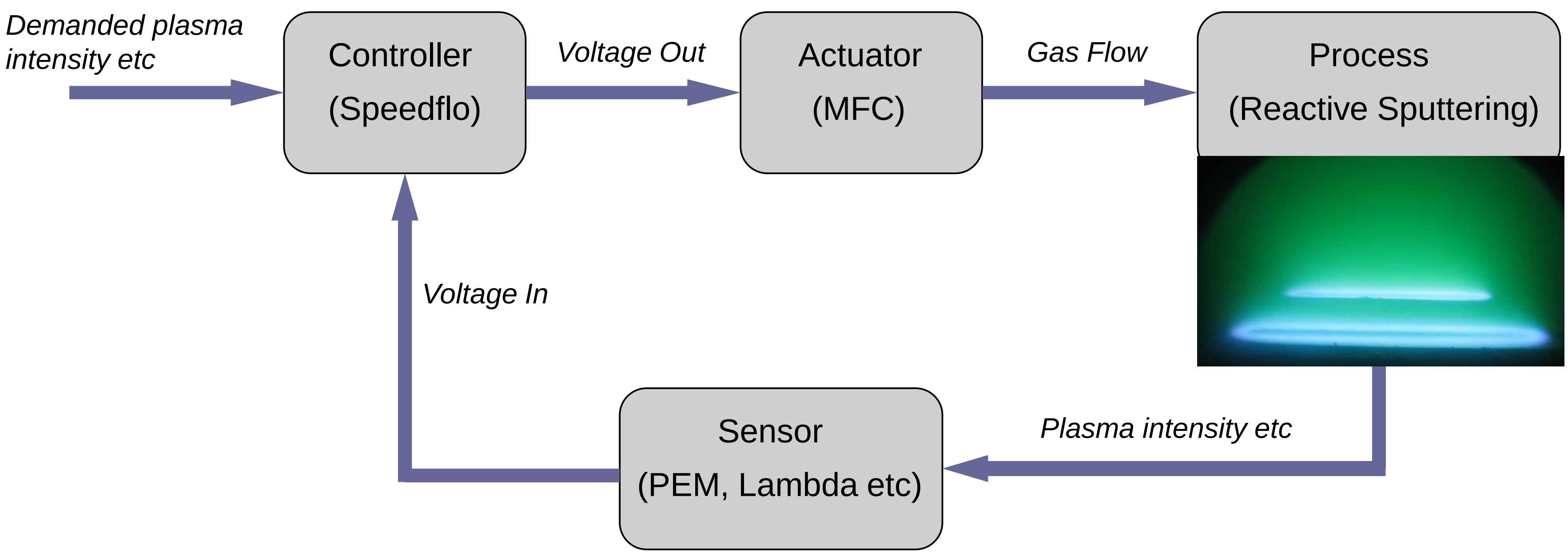


Hysteresis within a reactive sputtering process

Traditional view of S-curve / Hysteresis response.



Reactive sputtering – feedback controller principle of operation



- A feedback controller will stabilise the process – allowing for compound films with **a higher deposition rate.**

Speedflo controller - versions

Speedflo

Speedflo Mini

- 8 sensor inputs
- Maximum 4 PMT inputs
- 8 MFC outputs
- Spectrometer input option
- HiPIMS sensor option

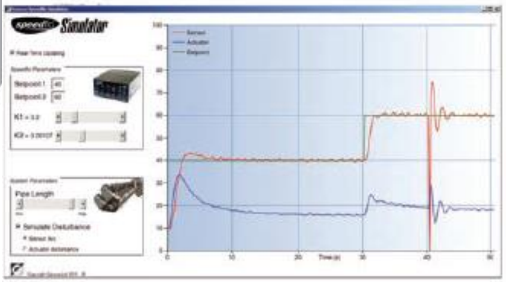
- 2 sensor inputs
- Maximum 1 PMT inputs
- 3 MFC outputs
- HiPIMS sensor option

Advanced user interface and control functionality

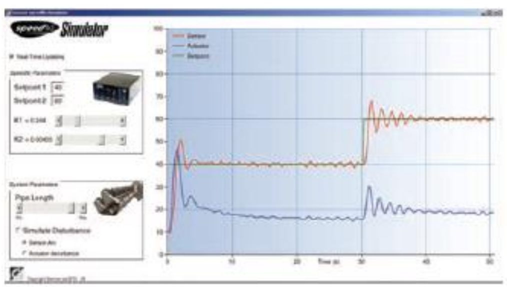
Software for easy process control setup and learning

GENCOA

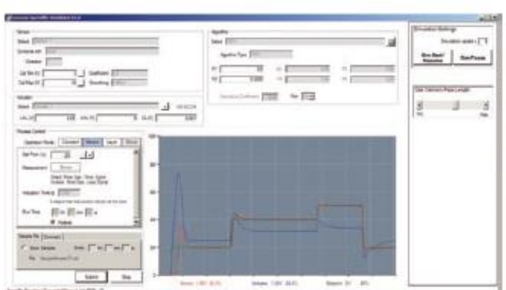
Gencoa Speedflo Simulator



Basic user interface



Basic user interface



Advanced user interface

Control algorithm

Speedflo utilizes a proprietary advanced PDF+ control algorithm that is capable of extremely fast and accurate feedback control. In addition to the PDF+ algorithm the Speedflo controller features a digital variable structure control law that is able to maintain fast-acting and stable control, even when the MFC becomes fully open or closed. This enables feedback control that is high performance, robust and reliable.

Multiple control channels

The Speedflo controller has up to eight fully featured and independent control channels. This allows for simultaneous feedback control of eight MFCs, with options to combine various sensors and duplicate control channels. This powerful capability is especially useful for large target areas, where precise deposition uniformity must be achieved.

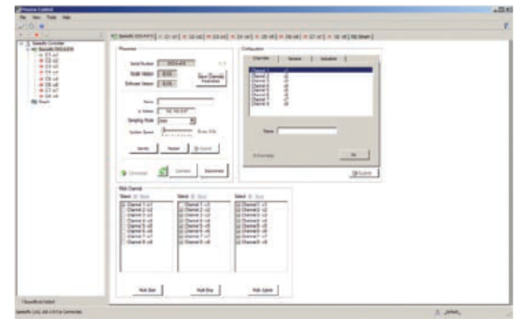
Auto-calibration and controller tuning

The time-consuming process of sensor calibration and controller tuning has been eliminated with Gencoa's latest Speedflo development. An automatic calibration and tuning procedure – unique to Speedflo – automatically detects the sensor levels corresponding to poisoned and fully metal states. The optimum controller parameters for the current sensor and process are then automatically calculated to ensure fast, accurate and robust feedback control.

Advanced user interface

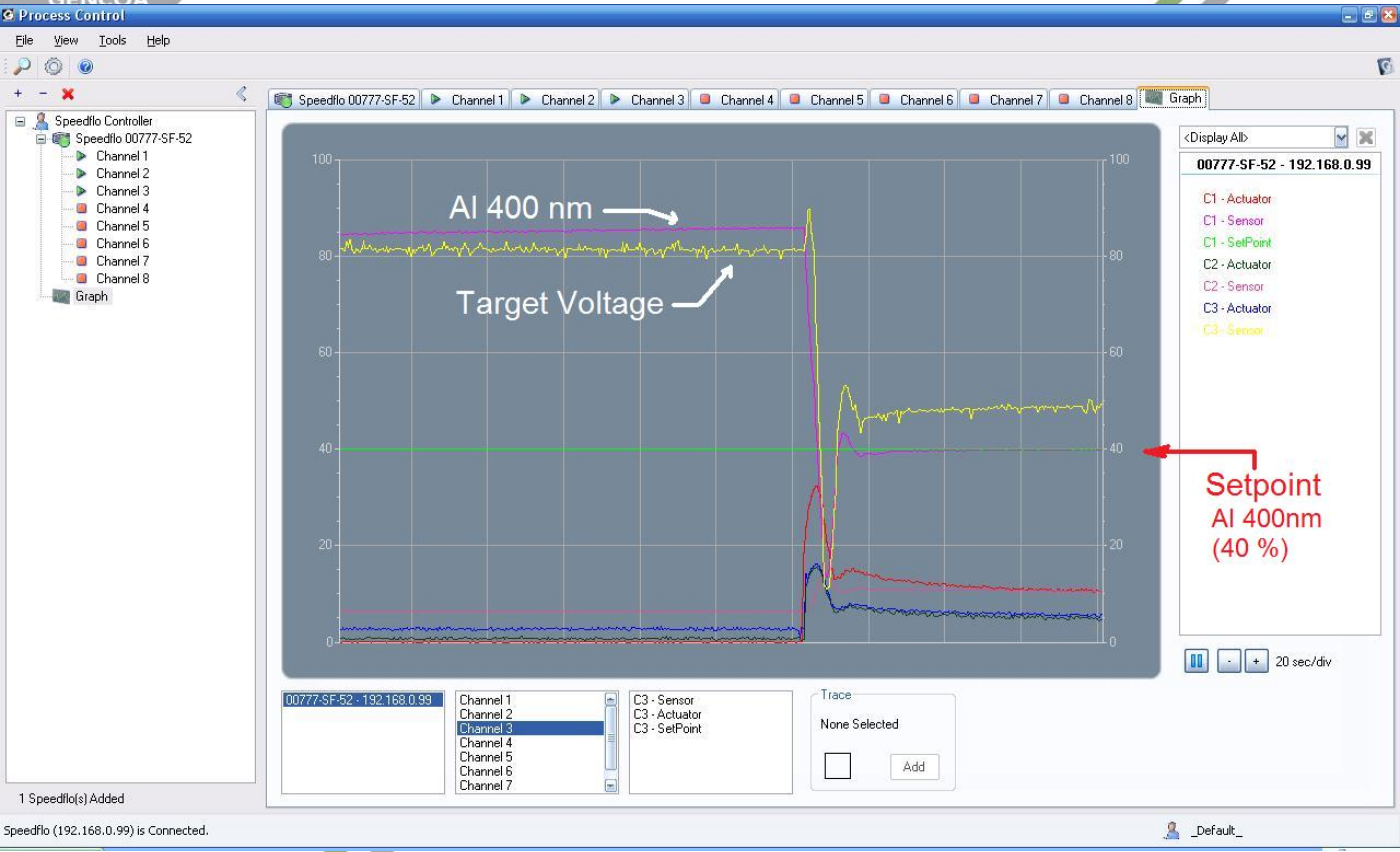
A highly developed software interface includes many powerful functions to allow different methods of configuring the process control and combating difficult control situations. All of the software functions can be seamlessly incorporated into an existing PLC system.

Highly developed software interface



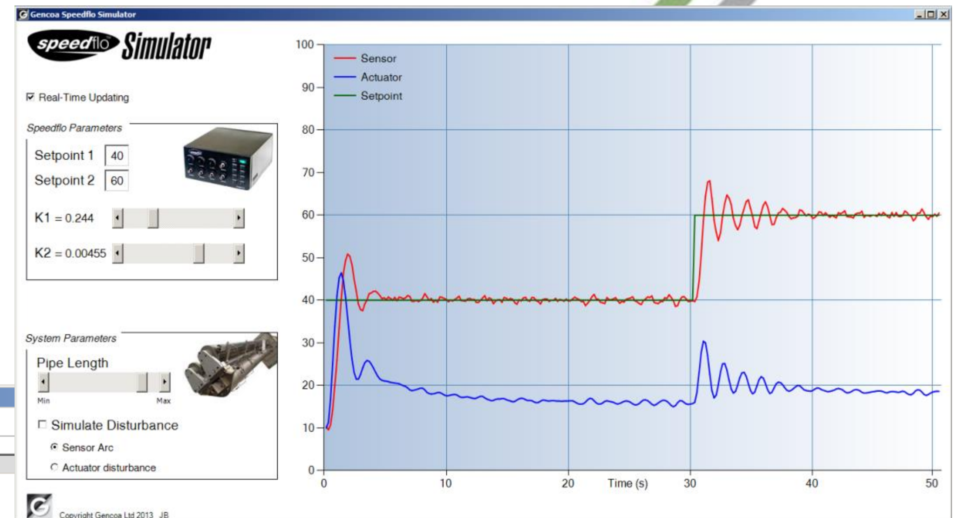
speedflo™

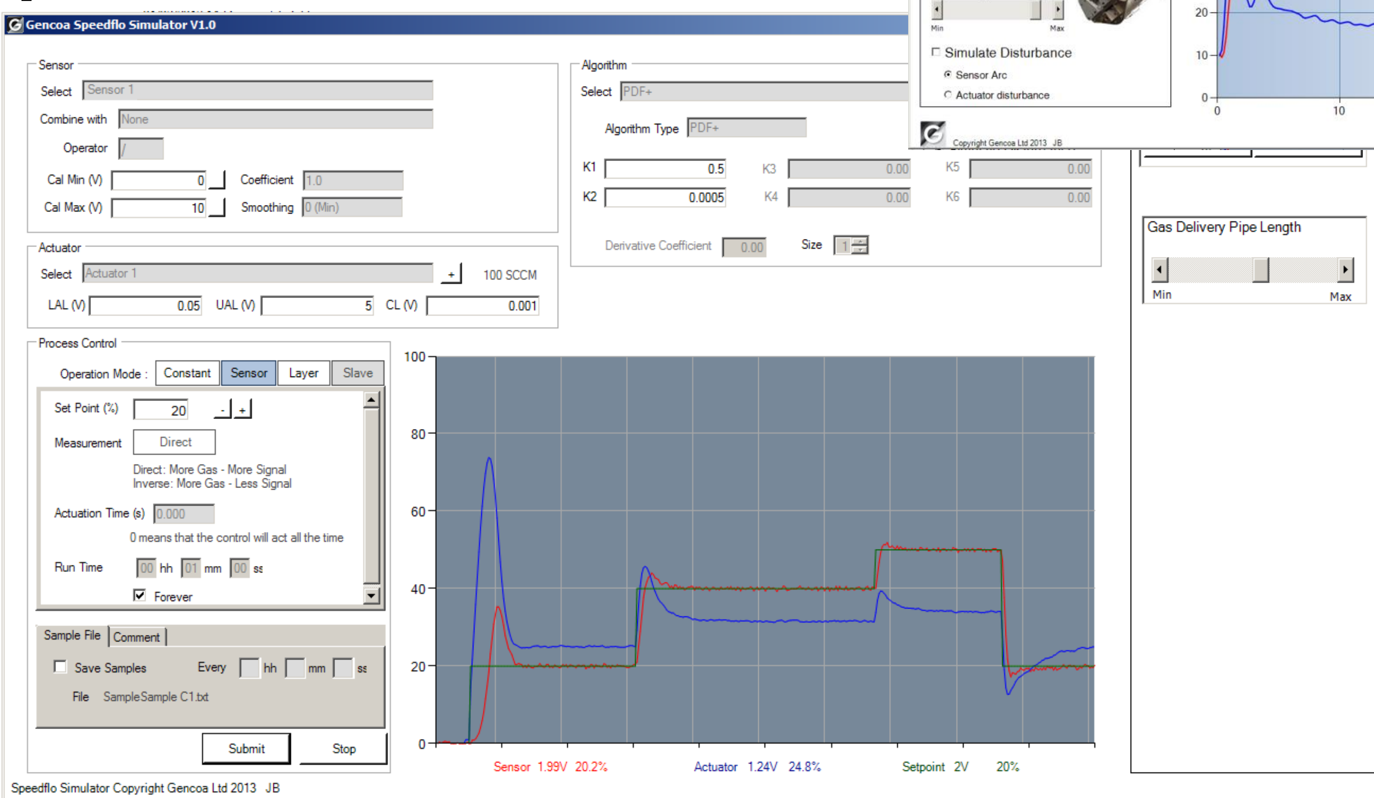
Example of reactive gas control for Al2O3 on web for ultra-barrier applications



Gencoa Speedflo Simulator & process tuning aids

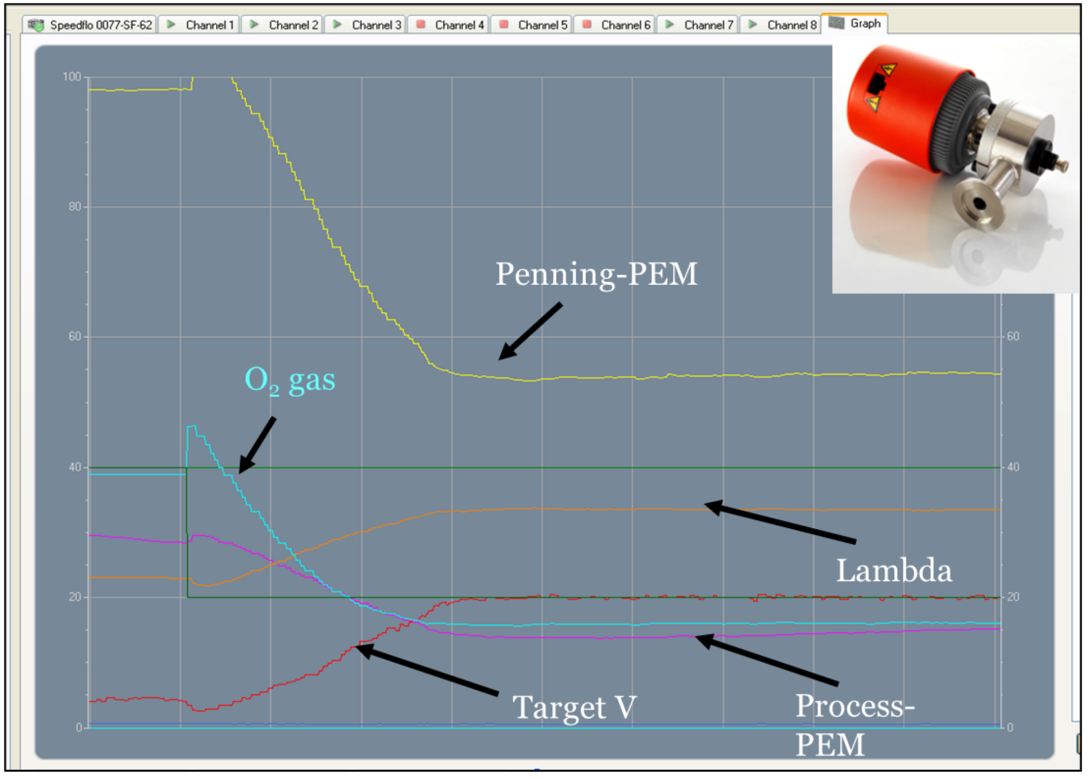
Two simulation tools have been designed to offer a virtual experience of tuning and operating the Speedflo control system. The aim being to interactively teach the skills required for faster and more effective control system tuning and commissioning. The basic version teaches tuning the algorithm and the advanced tools includes other parameter variables





Speedflo controller – a suitable signal is required from the process as the input into the control system - sensor options

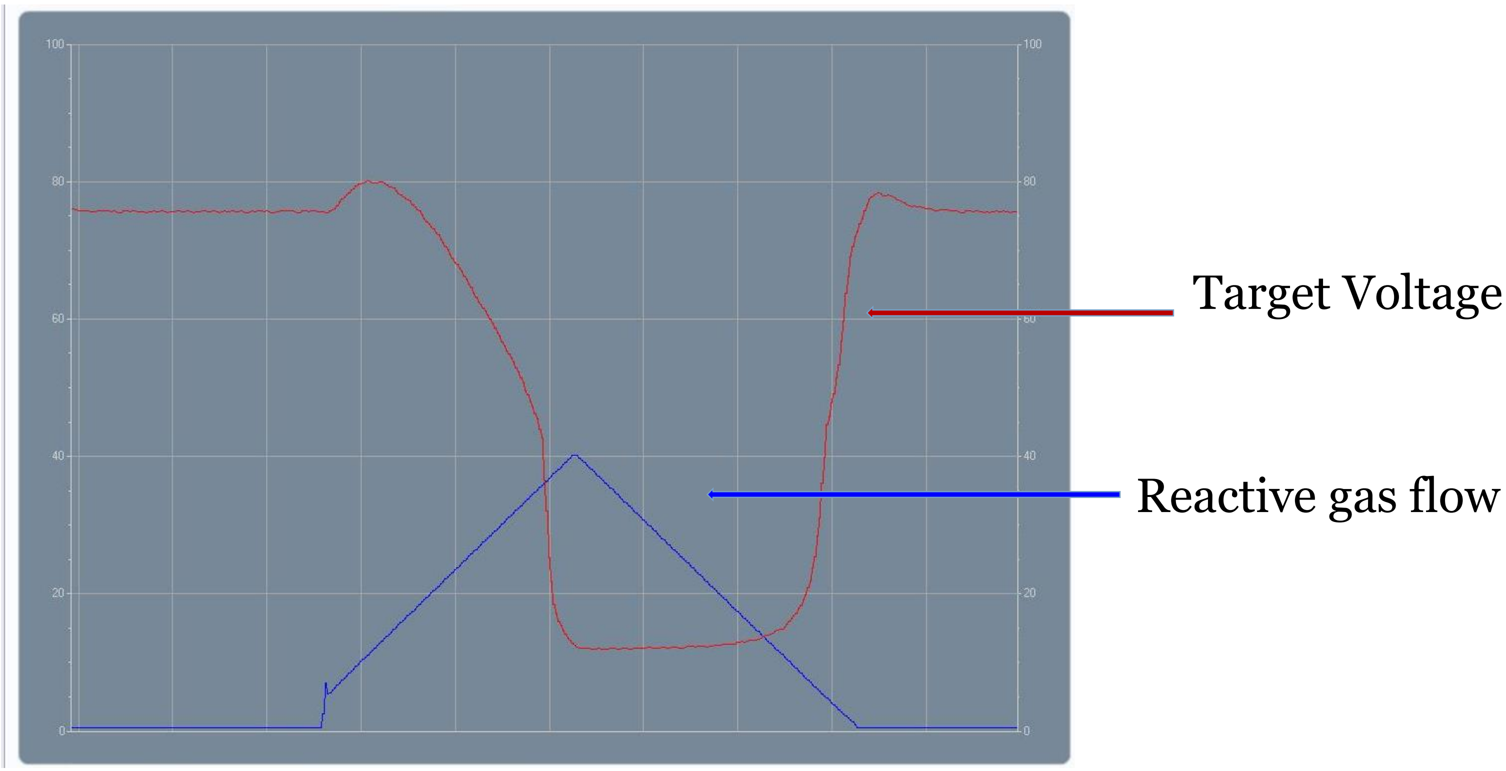
- Target voltage from the power supply
- Plasma Emission Monitoring – PEM
  - Metal line
  - Reactive gas line – O_2, N_2
  - Argon line
  - Ratios of Me/gas lines
  - Plasma spectrum
- Partial pressure
  - Lambda sensor
  - PEM - Penning



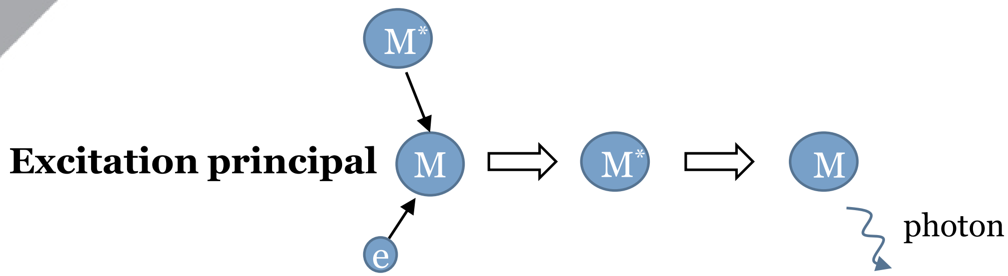
Speedflo controller – voltage sensor

Sensor options – **Target voltage**

- Often easily available
- Only works for some materials (e.g. Cu, Si, Al)
- Not possible to use for uniformity control



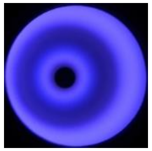
Light emission in plasma to sense species present – can be gas or sputtered metals



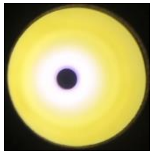
The same technique is used to analyse the composition of stars

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

Different gases in plasma emit different "colours"

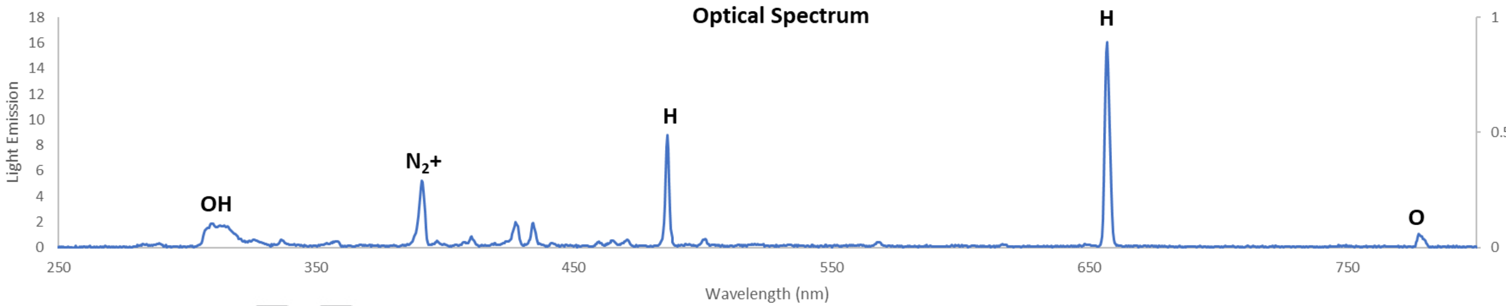


Argon



Oxygen

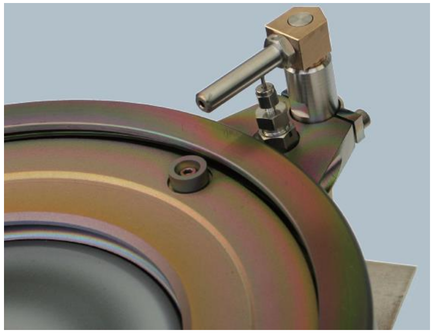
Air



Speedflo controller – plasma emission from the process

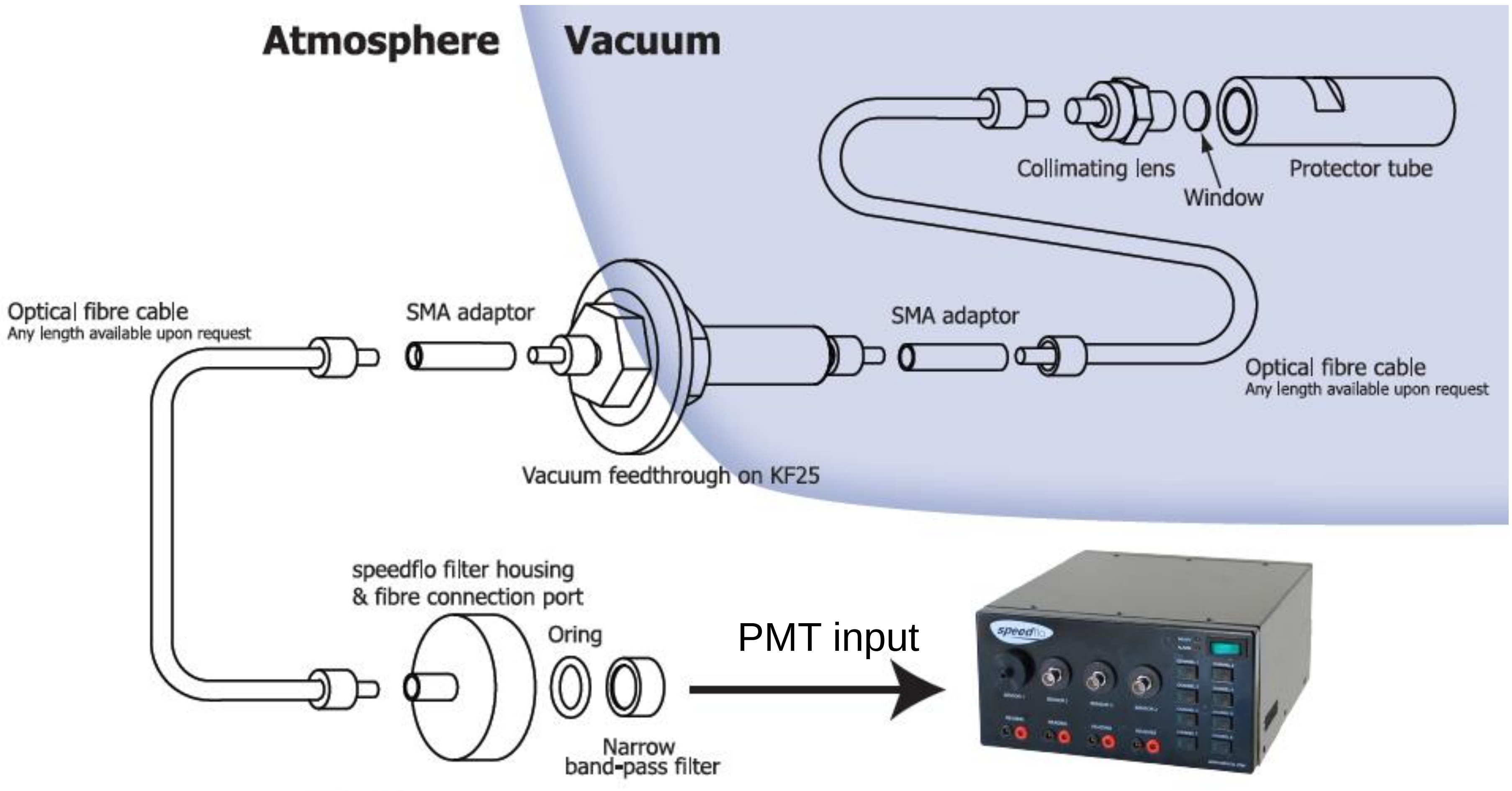
Sensor options – **Plasma Emission Monitoring (PEM)**

- Very fast response time – speed of light
- Large area uniformity control possible
- Easily disturbed by moving substrates / plasma

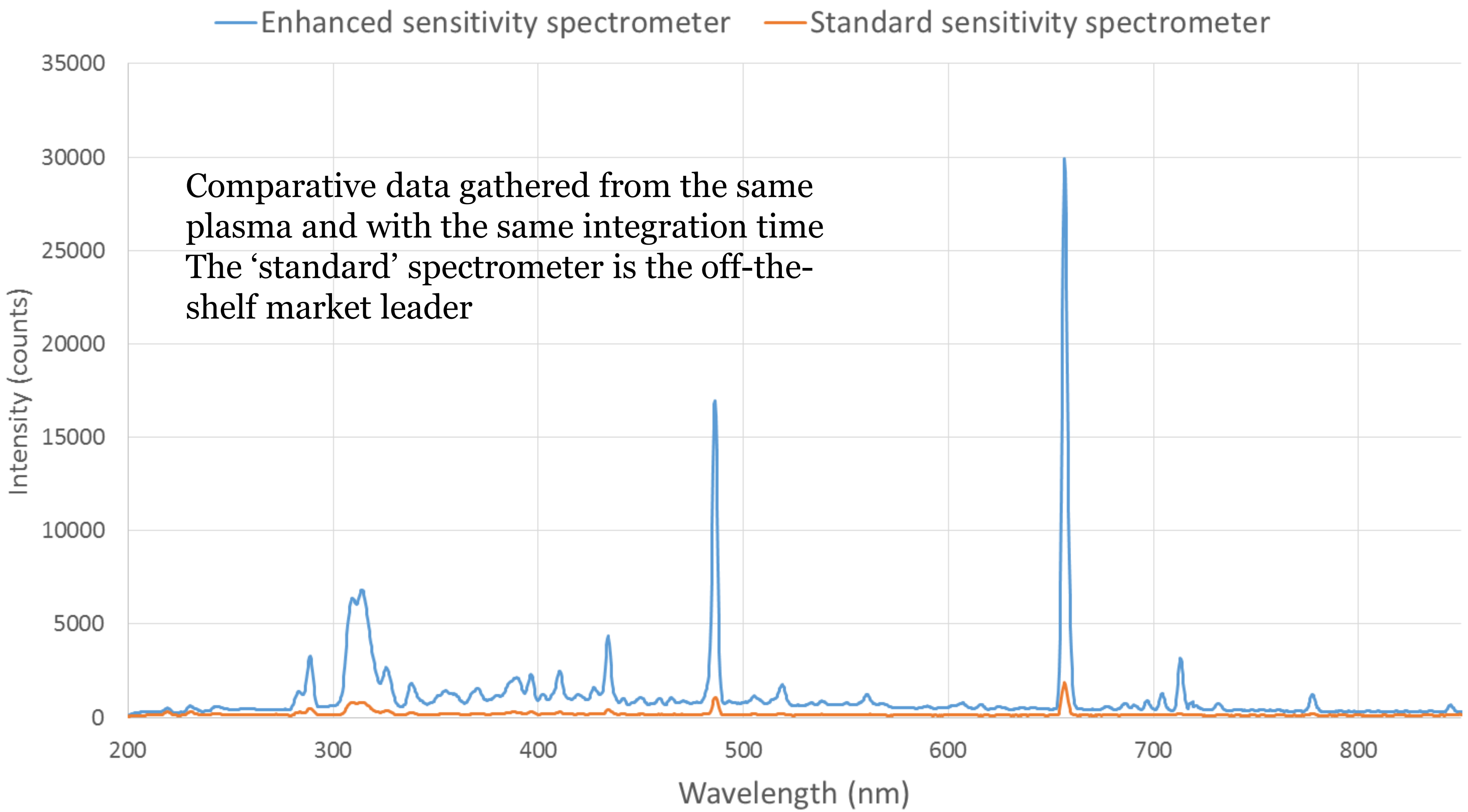


The intensity of the light emission at the wavelength relevant for a particular species is directly proportional to the amount present

Typical method to connect a fibre-optic link to the plasma process & use a narrow bandpass filter to select the to species to be monitored by a highly sensitive photomultiplier (PMT)

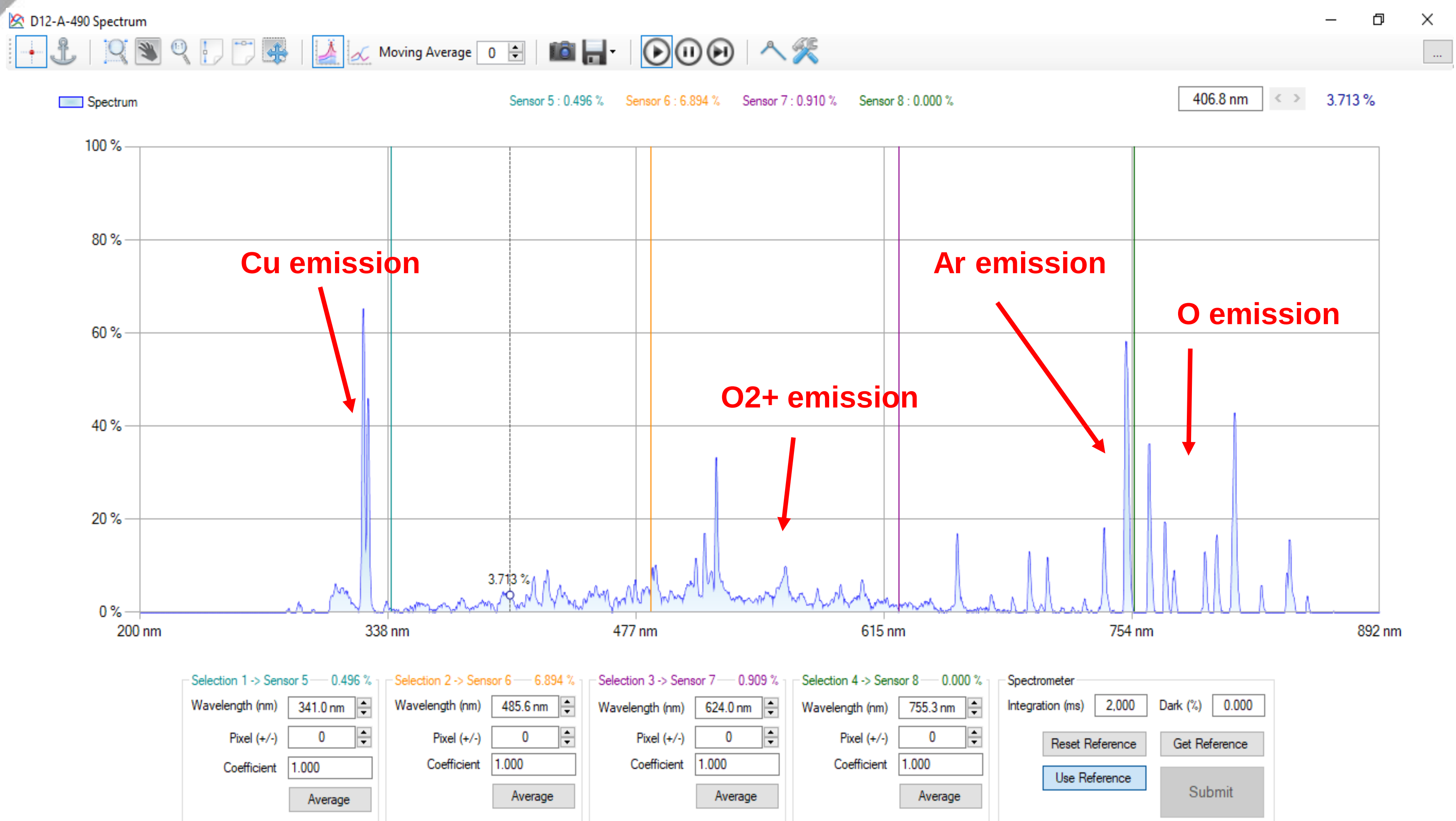


The plasma light can also be read by a CCD type spectrometer and Speedflo is configured to enhance the sensitivity of data collection from plasma systems



Comparative data gathered from the same plasma and with the same integration time
The 'standard' spectrometer is the off-the-shelf market leader

The Speedflo ccd software can select 4 intensities as control inputs in any combination or ratio

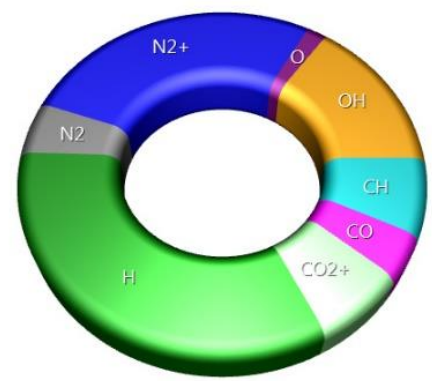


Vacuum monitoring and control
Residual gas analysis (RGA)

Easy detection of gas species for feedback control

Selections

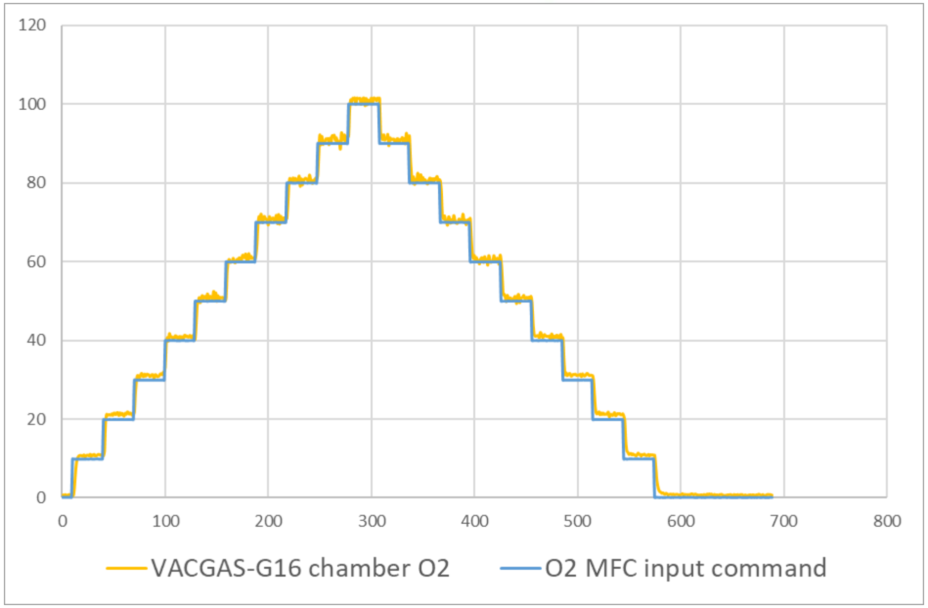
Pressure			1E-6	1E-2
CH		416.4	150.0	6,000.0
CO		234.3	150.0	3,000.0
CO2+		394.8	150.0	6,000.0
H		1,937.9	150.0	9,000.0
N2		294.2	150.0	21,000.0
N2+		1,629.8	150.0	21,000.0
O		105.6	150.0	3,000.0
OH		894.0	150.0	3,000.0

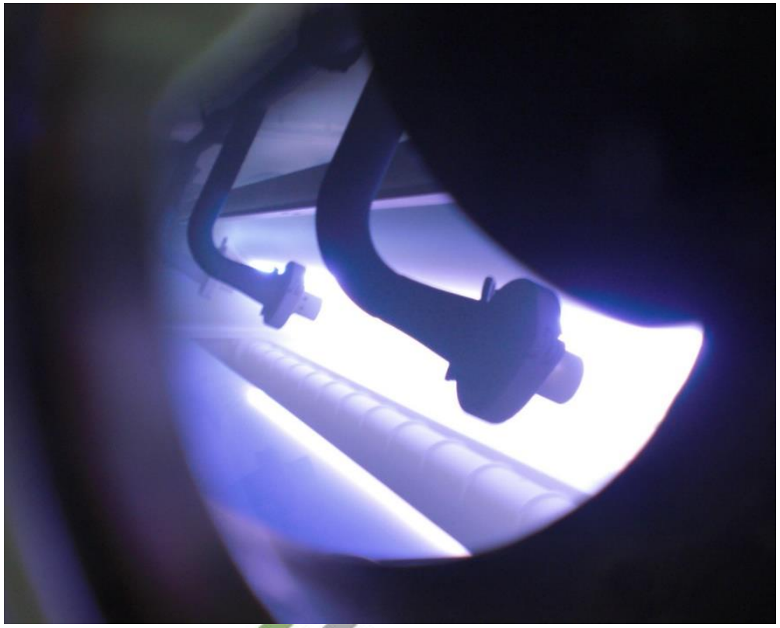


- Unique level of industrial robustness and sensitivity
- Portable – easily moved to any KF25 port on system
- Does not require differential pumping 0.5 mbar to 10-6 mbar range
- More sensitive detect of moisture than differentially pumped RGAs
- Powerful software suite and automatic detection of species in real-time
- Full range spectrometer 250-800nm for universal detection of all gases
- High Dynamic Range HDR light capture feature for enhanced sensitivity

Gencoa VACGAS-G16 - vacuum gas sensing for Chalcogen species
VACGAS-G16 Sensor

- The VACGAS-G16 combines fast feedback control of the sensor temperature with gas correction to provide the O_2 level as a precise partial pressure.

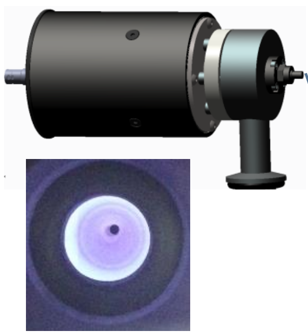




Various Hardware for Success

speedflo™

Control software suite with patented Auto-Tune

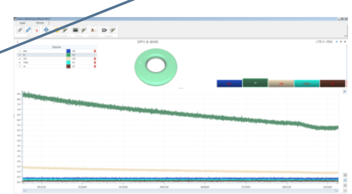


UPTO 3 MFC's can be powered and controlled by the mini

In chamber sensing alternatives

Linking by a fibre-optic cable from the OPTIX plasma generator to a Speedflo Mini:

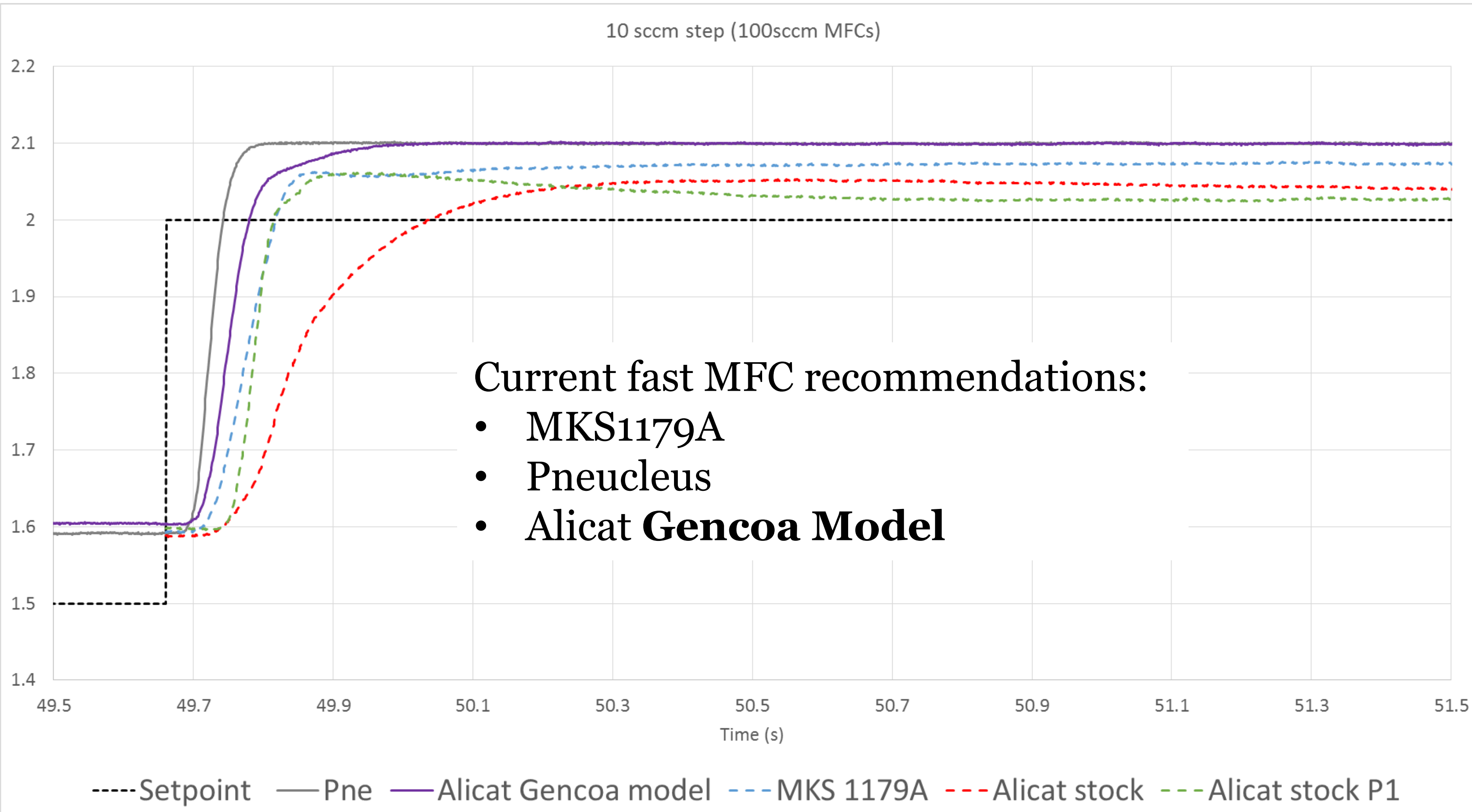
- Single gas line intensity as the input signal
- Avoids plasma disturbance from the chamber
- Highest Speed – Lowest Cost
- Any gas by changing the optical filter on the Mini
- ALD or CVD type process with pulsed plasma mode



Linking by a voltage cable from the OPTIX to a Speedflo Mini:

- Single gas line intensity as the input signal – or can be a gas ratio O2/Ar
- Avoids plasma disturbance from the chamber
- Lower Speed – Higher Cost
- Any gas by changing the output from the spectrometer
- ALD or CVD type process with pulsed plasma mode
- Retains all the extra OPTIX capabilities to monitor the vacuum chamber and process

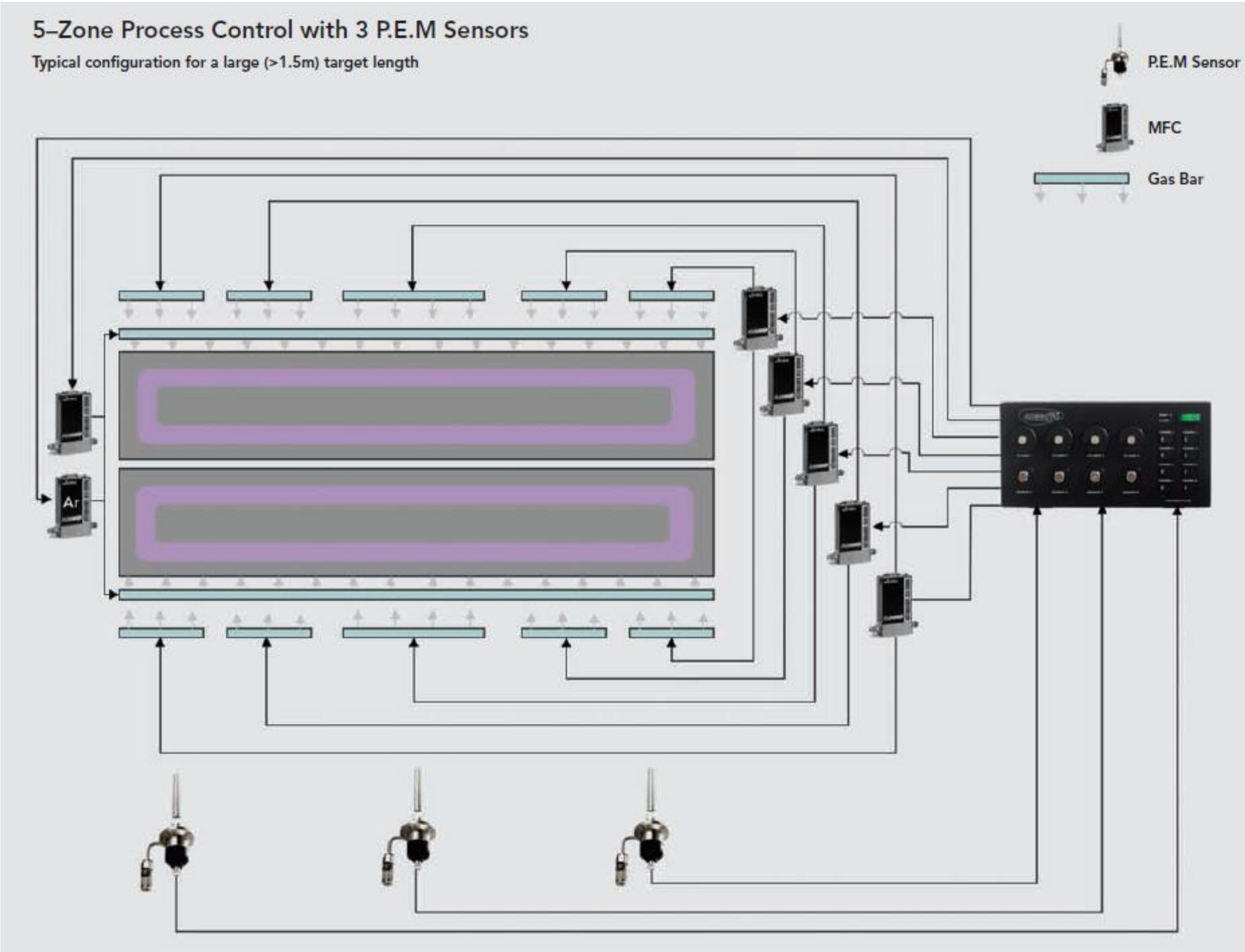
Care is required to ensure the MFCs have a fast enough response time and the gas line lengths are as small as possible



Current fast MFC recommendations:

- MKS1179A
- Pneucleus
- Alicat **Gencoa Model**

Gencoa provide process setup assistance, gas delivery bars, flow rate calculations and expert advise



On-site or remote tuning support is available worldwide

Speedflo is based upon a PDF (Pseudo Derivative Feedback) Algorithm which is ideal for reactive sputtering feedback control applications

- Historically used in aerospace and robotics due to the reduced overshoot and improved disturbance rejection.

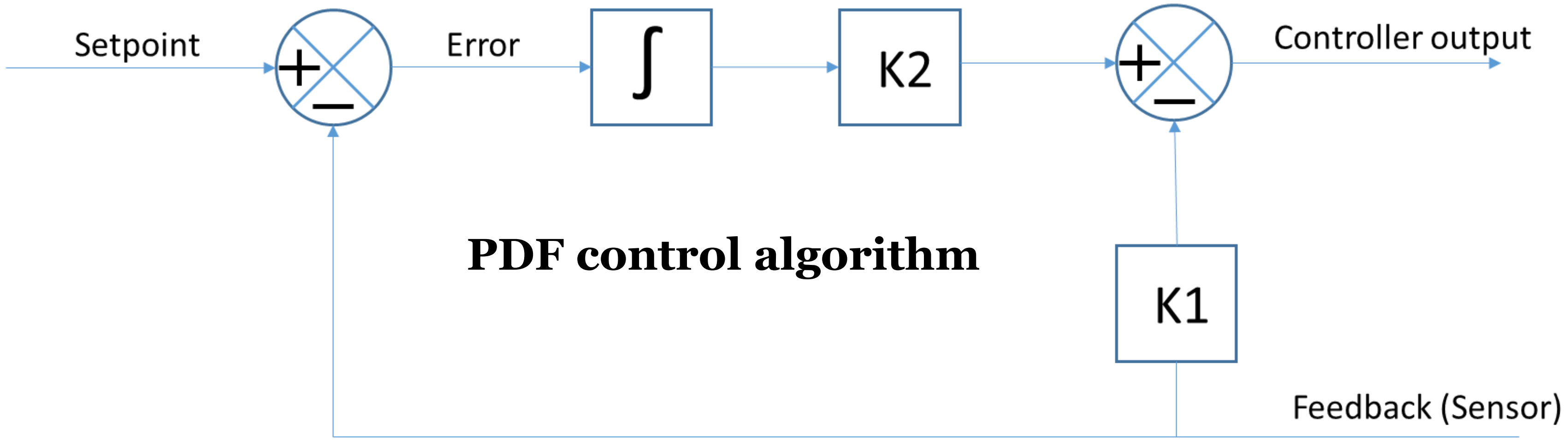
- Has two parameters to be tuned, K1 and K2 – a proportional gain and an integral gain.

- The position of the proportional parameter is different to PID – **acts directly on the feedback.**

- The proportional action in PDF has a similar effect to derivative action in PID – hence "Pseudo Derivative"

- Means you have the benefits of derivative (reduced oscillations) – but without drawbacks (more parameters, sensitivity to noise and problems with step-changes).

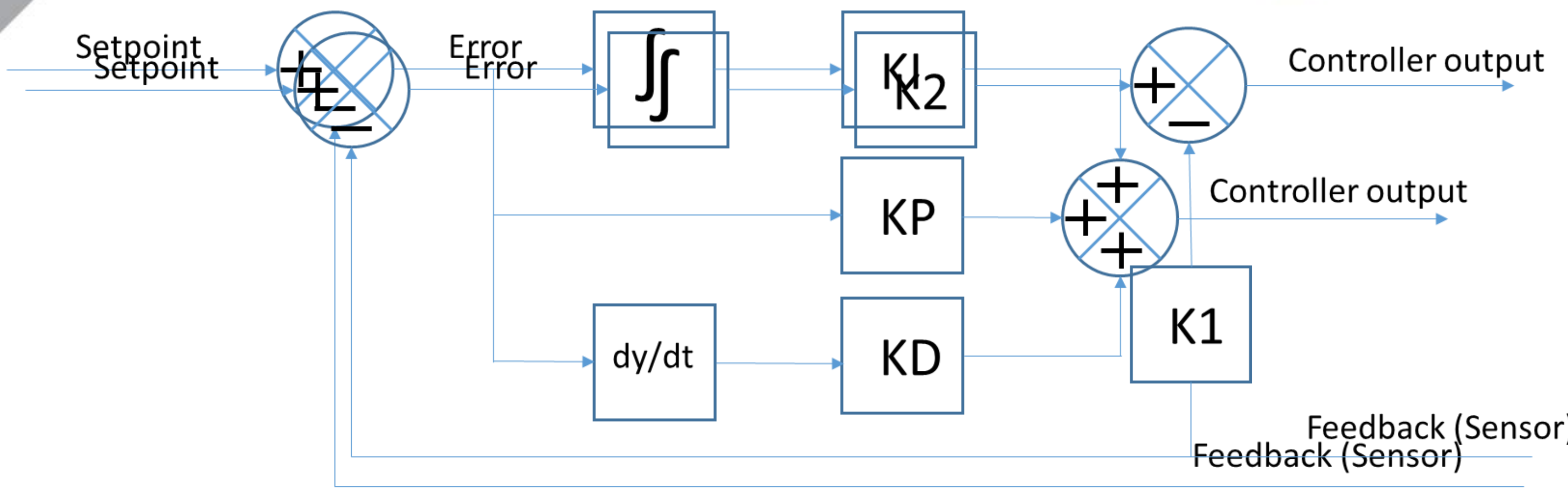
Speedflo controller – tuning



PDF control algorithm

- PDF (Pseudo-Derivative Feedback control) gives similar control capabilities to PID control but uses **one less parameter →Easier to tune.**

PID is the 'standard' algorithm for feedback control applications vs. PDF Algorithm

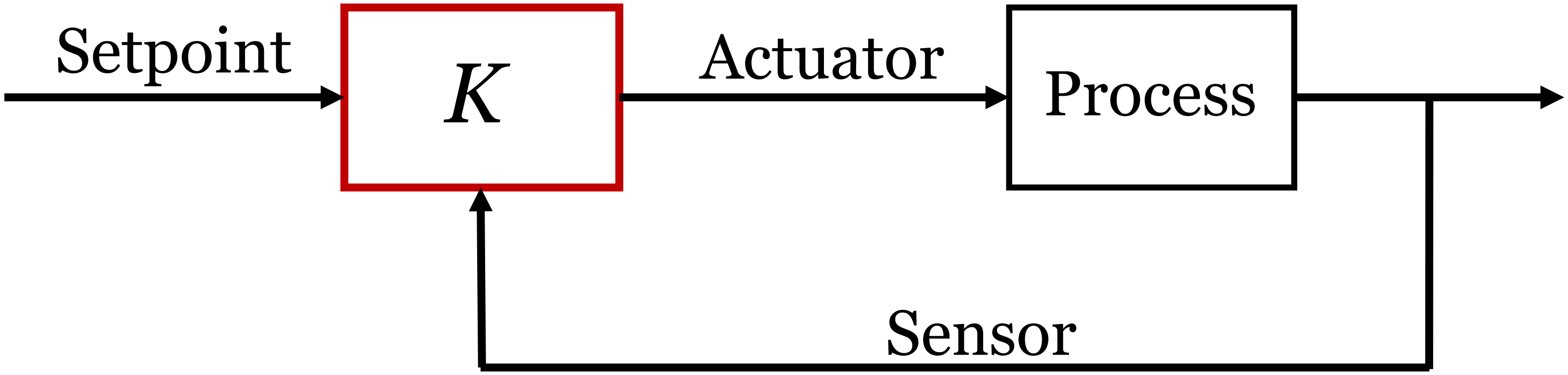


- PDF (Pseudo-Derivative Feedback control) gives similar control capabilities to PID control but uses one less parameter →Easier to tune.

- Traditionally PID is underdamped,.. However PDF allows for improved damping, therefore FASTER response and ability to IGNORE LOADS, i.e. it is more stable and easier to work with in MULTICHANNEL arrangement.

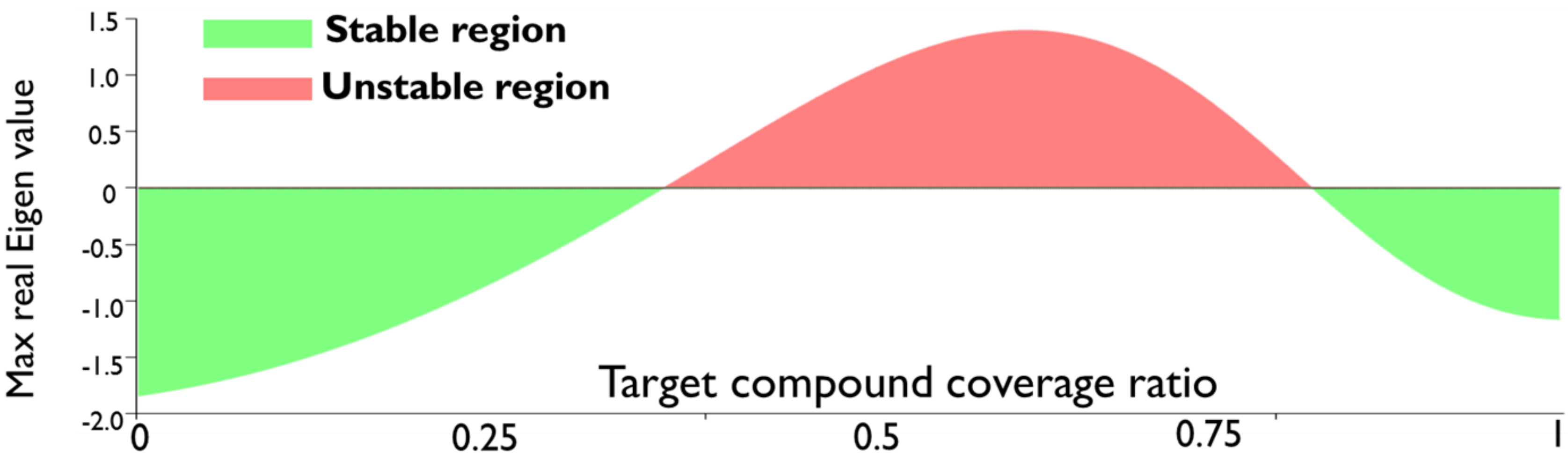
Controller Parameters and the need to tune for different circumstances

- All controllers have parameters that must be adjusted to meet performance requirements.
- These parameters determine how the controller responds to sensor signals.



Reactive sputtering – stability problem

Open loop reactive sputtering



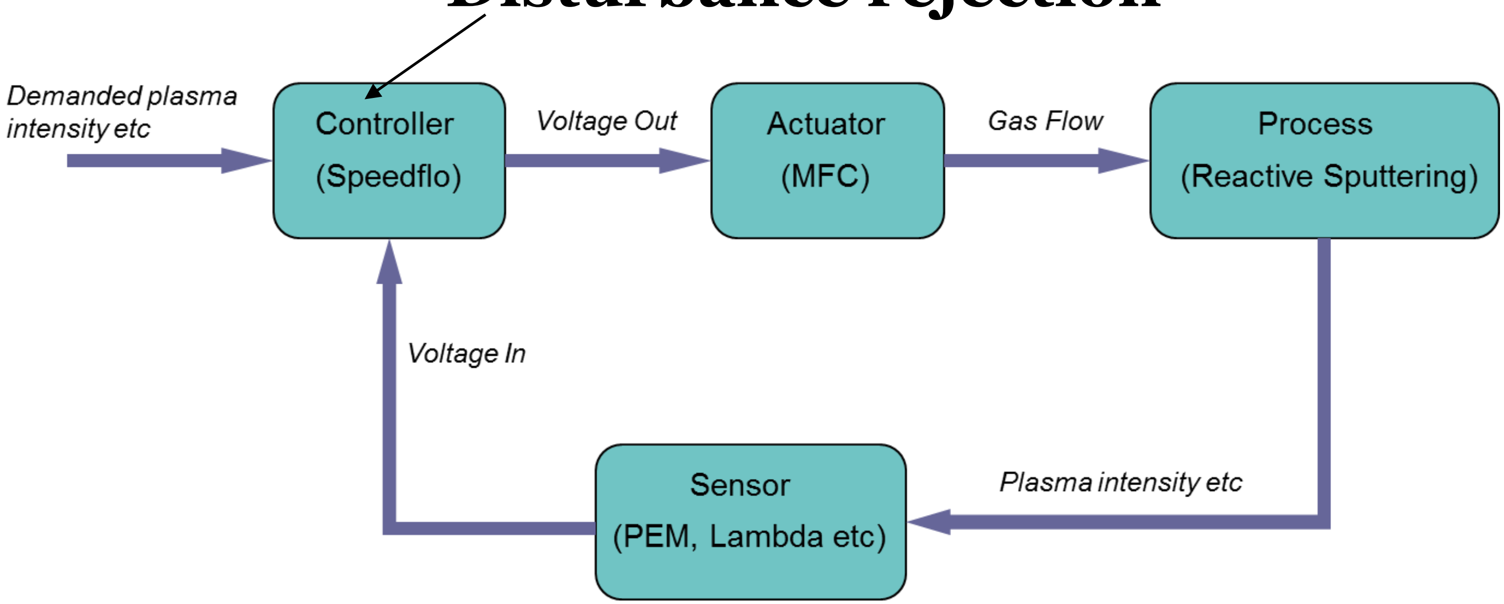
Metallic

Poisoned

Speedflo controller – tuning

Needs to be tuned for:

- **Stability**
- **Fast response**
- **Disturbance rejection**



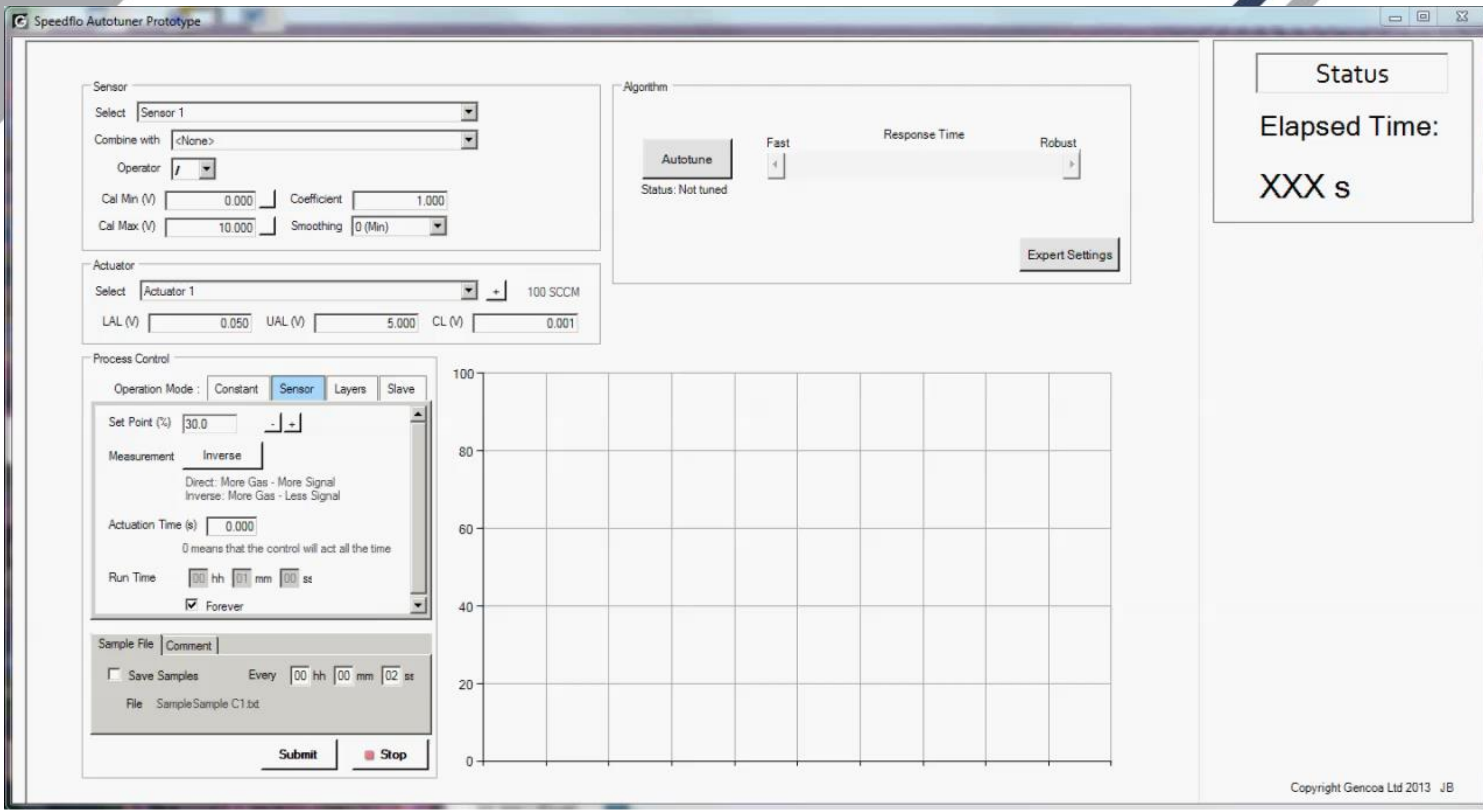
Automated Tuning has the largest impact to making Reactive Sputtering Easy

- The benefits of **automated** tuning:
  - Reduced set-up time
    - Minutes instead of hours!
  - Reduced reliance on technical support
    - Intuitive setup
  - Improved process stability
    - Optimized parameters based on real data – not "feeling"

Background to the problem

- Types of tuning method
  - Iterative – “cause and effect” – will converge on optimum but **can be slow**
  - Empirical – data based – limited by quality and extent of data
  - Analytical – theoretical model based – reliant on accurate model of process
  - Combination of **empirical and analytical** most suited to reactive sputtering due to:
    - Process unknowns
    - Tuning time

Auto Tuning a reactive sputtering process in real-time



Plasma Emission
Cathode Voltage

Fine tuning

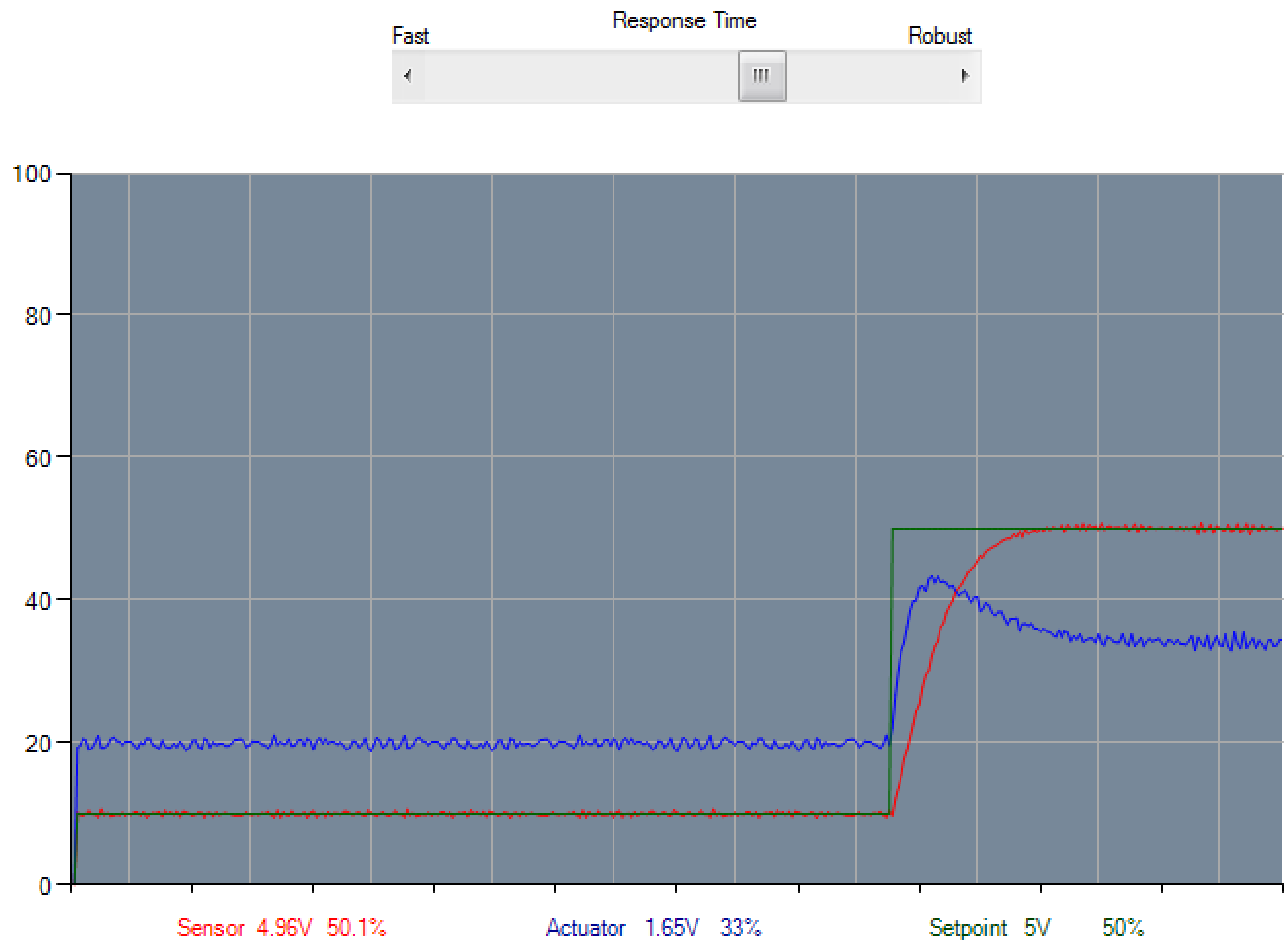
- Autotuner defaults to a safe response speed.

- This can be increased or decreased by moving a single slider.
  - Previously had to tune 2 **interacting** parameters!
  - There is still the option to tune K1 and K2 individually if you are an “expert”

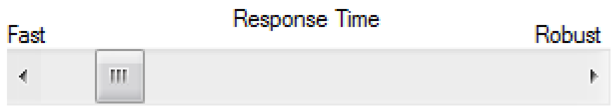
- As the response time is changed the “shape” of the response should remain the same.

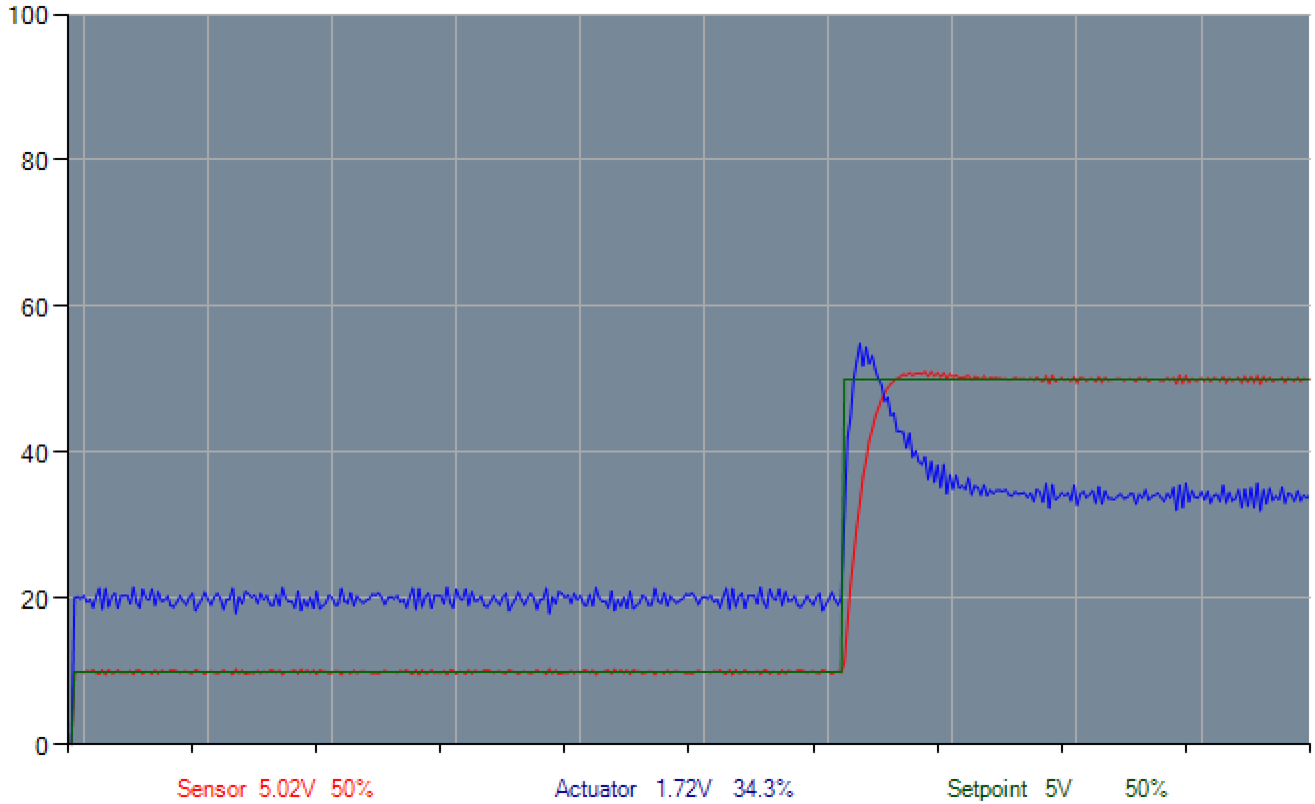
- Always a trade-off between stability and speed – fine tuning can find the edge of this trade-off.

Fine tuning via mouse and slider

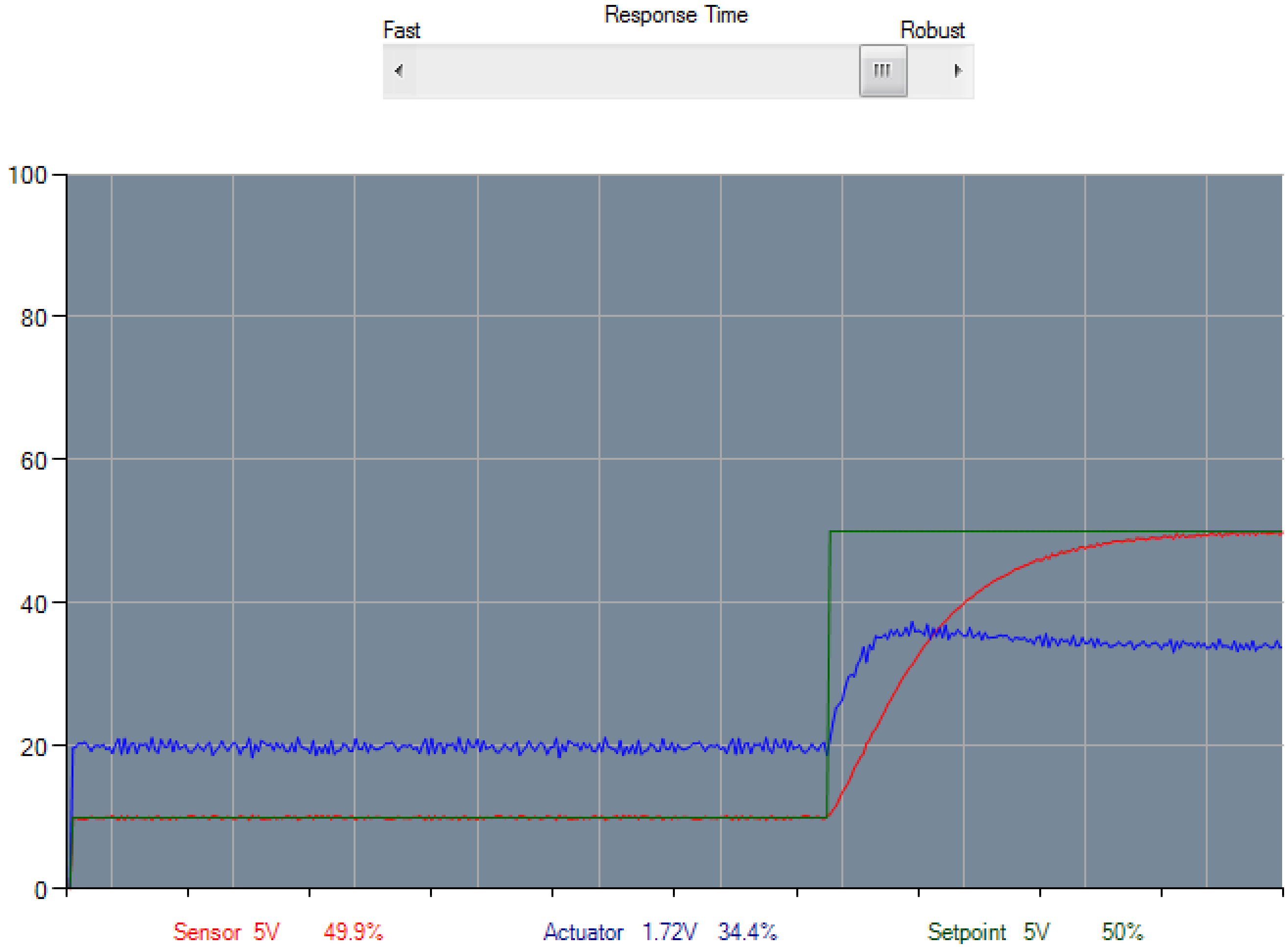


Fine tuning via mouse and slider





Fine tuning via mouse and slider

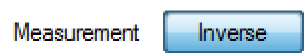


Speedflo controller – tuning – Reactive Sputtering Made Easy

Tools – Autotuner

1. Select Set Point

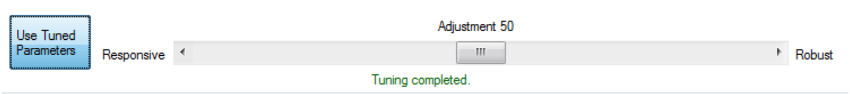
2. Select mode (inverse or direct)



3. Wait 60 seconds

4. **Tuned!**

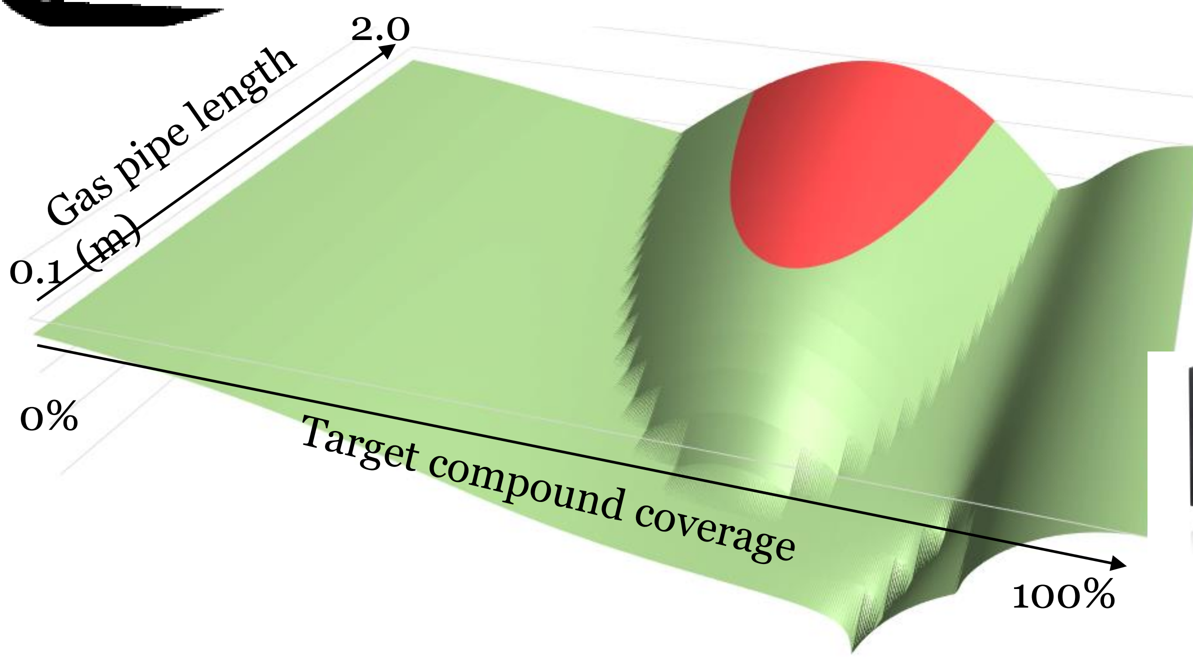
5. (Optional) – adjust speed of response

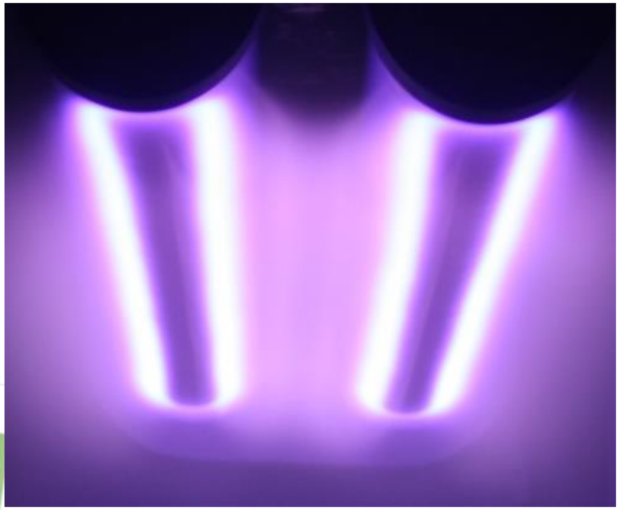


Highly advanced technology based upon the experience and know how of 1000's of units controlling industrial plasma processes

Gencoa can predict and simulate the controllable areas of any sputter process with different sensor types – based upon real process data taken into the modelling

Target Voltage





Auto-tuner developed for simplified control of reactive sputtering processes

- A control science based method is used to determine controller parameters

- Reduced time and cost to set-up process
  - Minutes instead of hours/days
  - Flexibility with regards process changes

Thank you for your attention, please come to talk to us **at booth 413**

gencoa: perfect your process