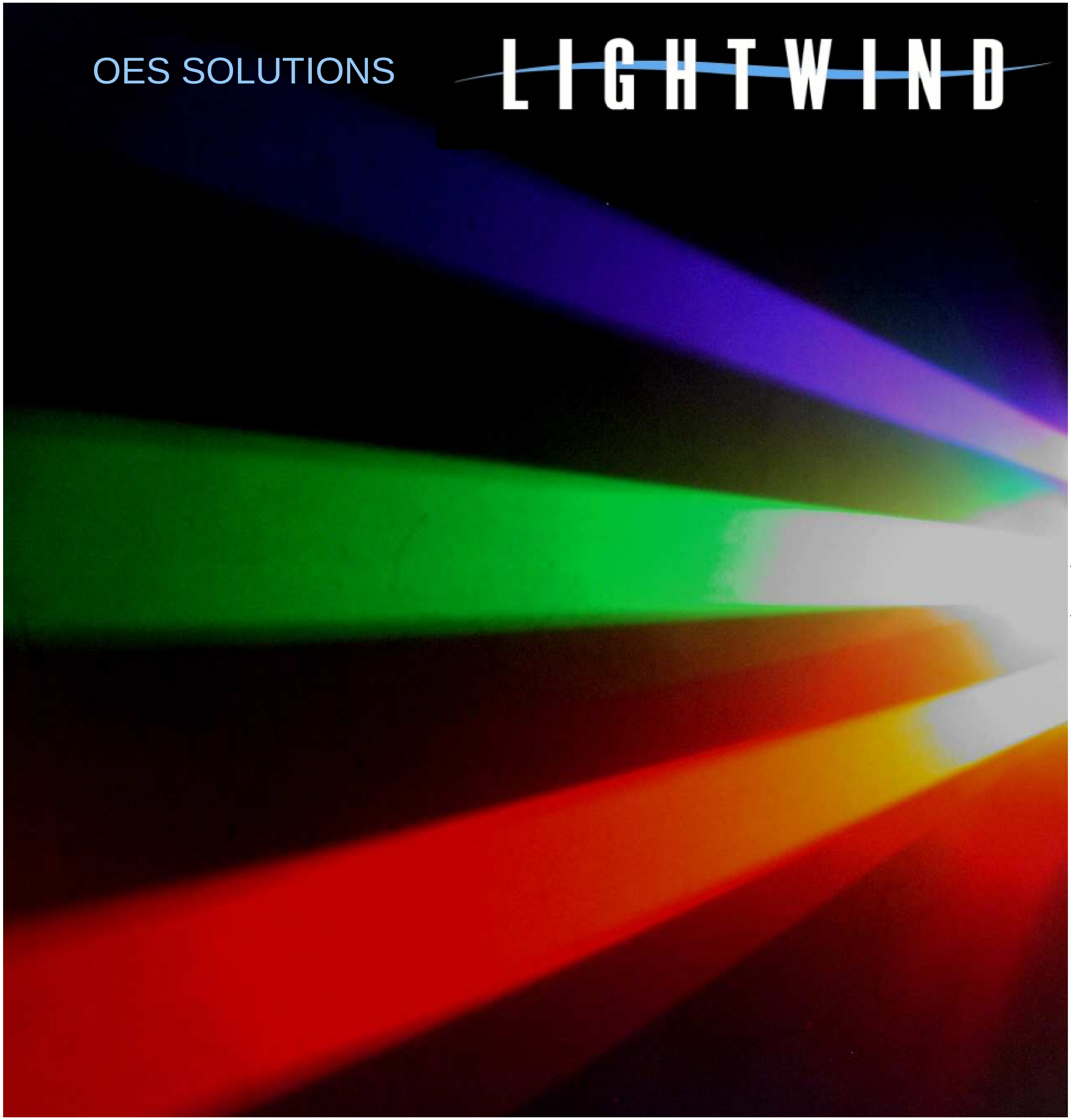


NEW APPLICATIONS FOR OPTICAL EMISSION SPECTROSCOPY

OVERVIEW

Different process solutions require different spectroscopy solutions. Sometimes the solution is simply a software reconfiguration, other times it may be a completely different hardware and software configuration.

This presentation will attempt to paint a broad stroke perspective of practical spectroscopy solutions and implementations.

Emphasis will be placed on individual applications suitable for continuous monitoring of “out of run” conditions; however “chamber matching”, which is an important and different metrology approach is included.

OPTICAL EMISSION APPLICATIONS

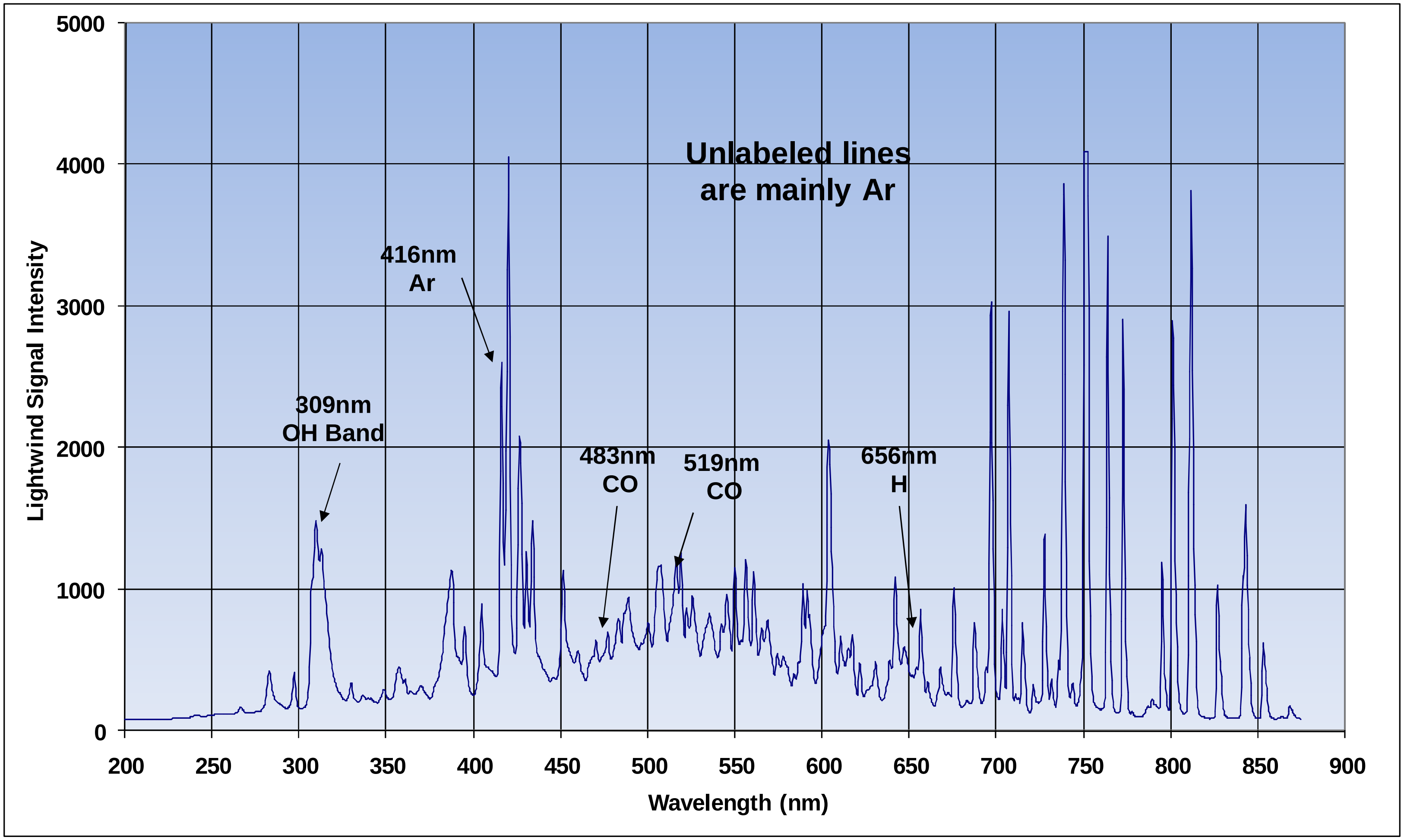
The general concept, examples and applicability as a process diagnostic will be discussed for the following technologies.

Downstream	OES	ICP OES	with a secondary plasma light source
Thru the window	OES	Std OES	where the process plasma is the light source
Thru the window	OES	RF OES	where the process plasma

LIGHTWIND

PRESENTATION OF TYPICAL OPTICAL EMISSION SPECTRA*

*CCD Multichannel Array



LIGHTWIND

THE REALITIES OF USING OES

Single wavelengths are many times but not always adequate

Full spectra can have overlapping information

Confounding chemistry: chemical reactions highly interactive

Information can be context dependent

Highly responsive to process chemistry changes

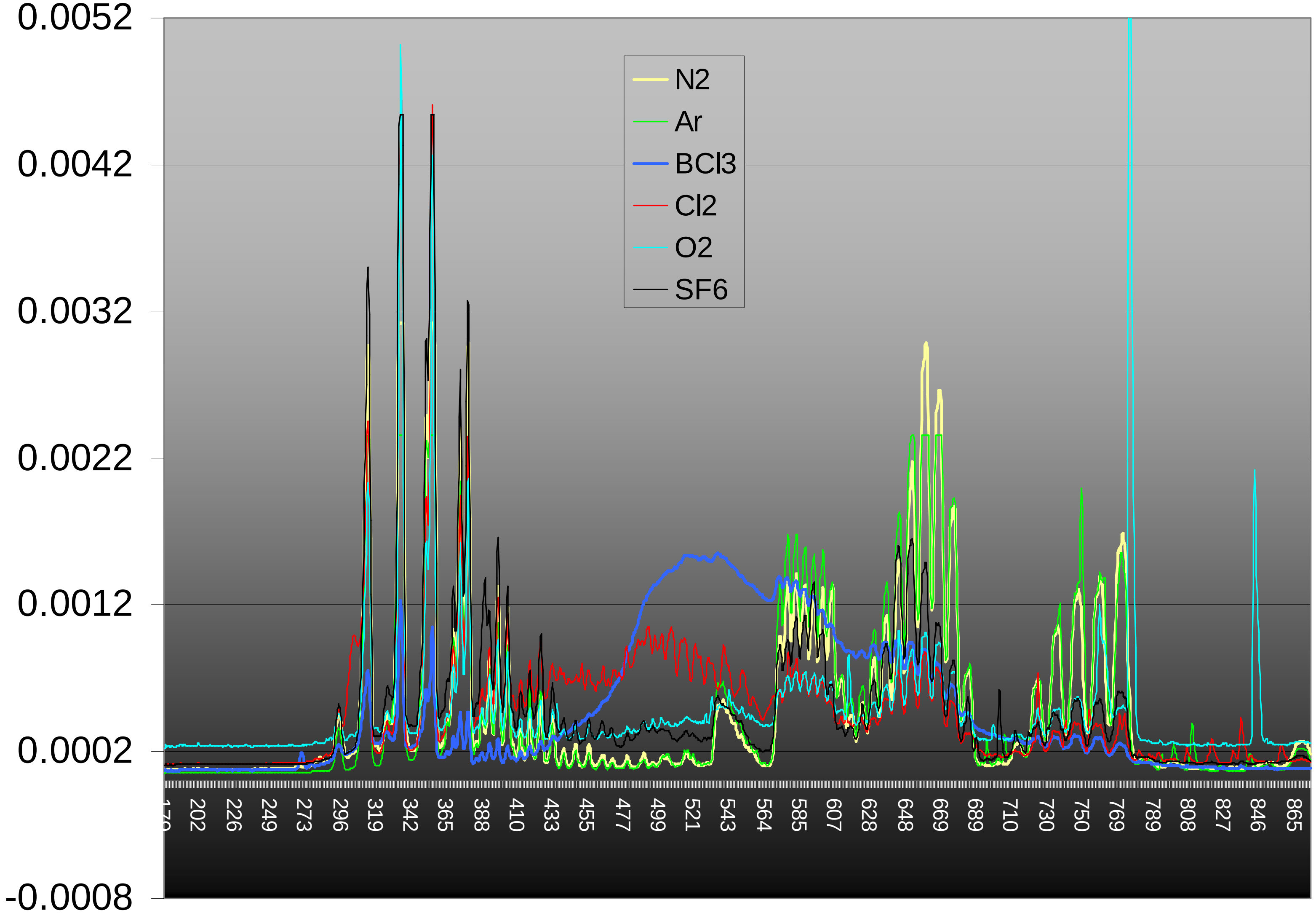
High density data

2 megabytes/minute acquisition rate

(based on a 3600 pixel spectrometer at 3 Hz)

LIGHTWIND

OVERLAY OF SPECTRA FOR SIX PROCESS GASES



LIGHTWIND

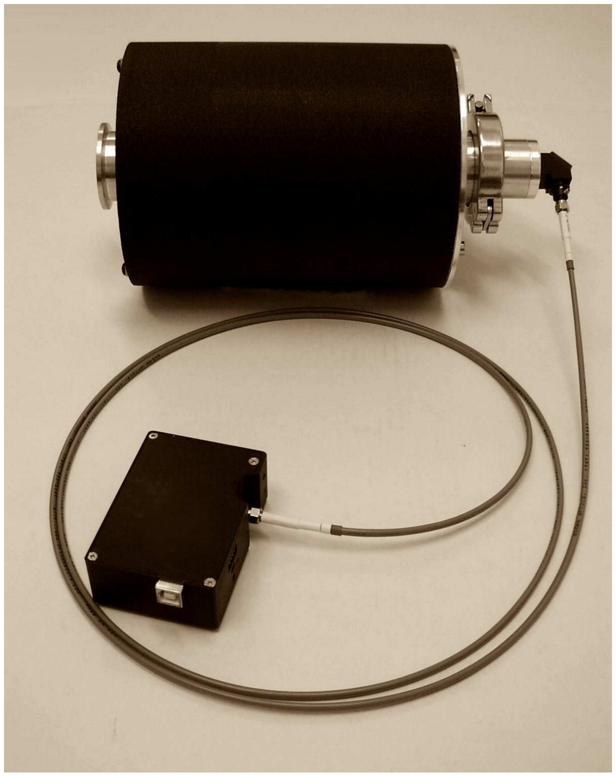
SO……WHY USE OES?

1 It provides a high definition metric for the actual process

2 It is a count of the atoms and molecules in the process
instead of a tool control readout; i.e. it is a direct
measure of the process

Three examples:

1 Endpoint (process control)
2 A small chamber leak can effect a process
without being detected during
normal tool operations: all tool controls function correctly
2 Precursor flow problems in ALD: carrier flow gas is measured,
the actual precursor delivered/consumed is not measured



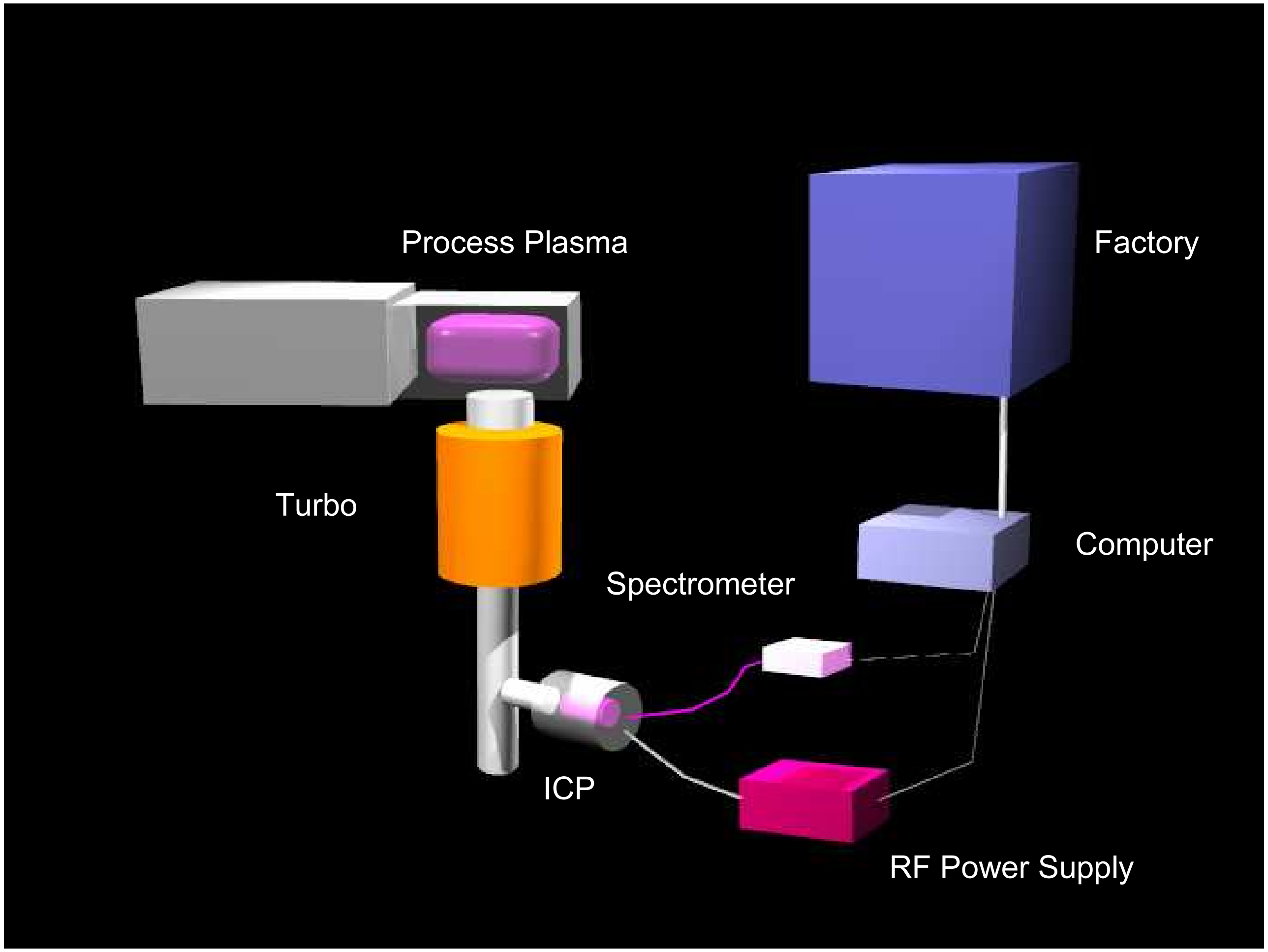
OES WITH SECONDARY PLASMA SOURCE

HIGH SENSITIVITY TO CHEMISTRY
NON INVASIVE
DOES NOT REQUIRE PROCESS PLASMA

APPLICATIONS:
CVD
ALD
CHEMISTRY: ETCH OR CVD
ENDPOINT
TROUBLESHOOTING ALL NON RF PROBLEMS
FAULT DETECTION
LEAK DETECTION
SEASONING

SYSTEM CROSS SECTION

ICP OES L3



CCD Spectrometer
200 to 800 nm
3600 pixels CCD
1.3nm resolution
Full spectra scan 20 msec

ICP Plasma Source
No internal electrodes
Halogen resistant materials
Outstanding signal stability:
> 350k mfg hours ALD with no recalibration

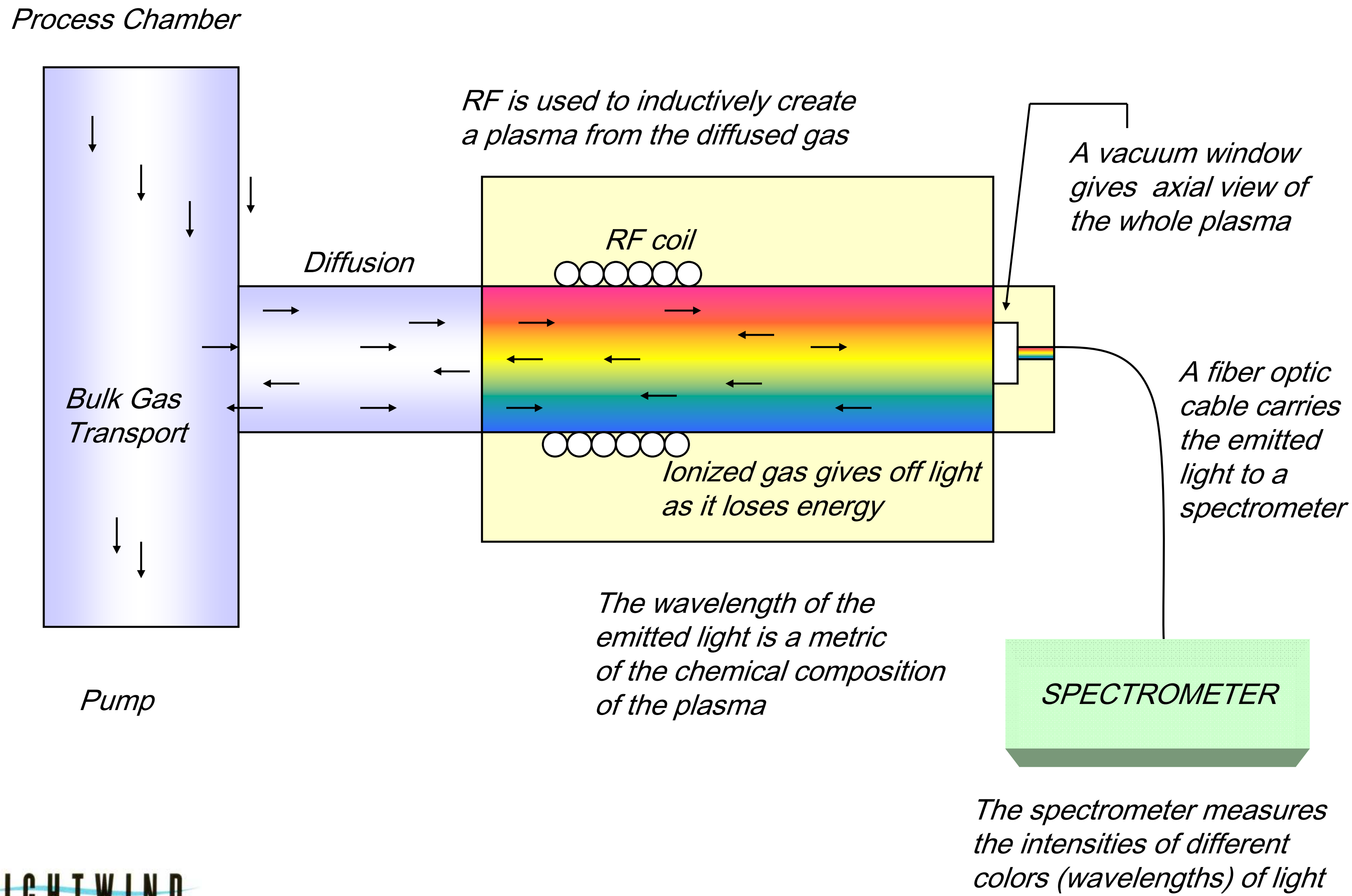
Separate components:

1. window change 5 min no recalibration
2. spectrometers with different capabilities are easy to implement
3. ICP can be heated to >70 c with no electronic degradation or drift

LIGHTWIND

L3 THEORY OF OPERATION

ICPOES L3



LIGHTWIND

ICP IN EXHAUST (Heated)

Heated plasma source for minimal or no maintenance

PROCESS DIAGNOSTICS: CHAMBER MATCHING ICPOES L3

While OES is ideally suited for continuous process monitoring it also has high value in troubleshooting processes and chamber matching. Because of the complexity of current processes it is not realistic to think a single sensor is sufficient. Troubleshooting requires a paradigm shift both in using new tool metrology as well as a consistent hierarchical approach: a plan of attack is required.

Module 1 Process Chemistry Only

Module 2 RF Separate from the Process Chemistry

Module 3 Interactions of RF and Chemistry

LIGHTWIND

PROCESS DIAGNOSTICS*

ICPOES L3

TEST VARIABLE	Parameter Change	ICP OES Sensitivity
Electrode Spacing Variation	Electrode gap	5 – 10 % change in gap
Process Chemistry	Pure gases no plasma required in process chamber	1% (1 sccm)
Pressure		4 to 5%
RF Power		4 to 5%

ICPOES is sensitive to all significant process changes

ICPOES can have very high sensitivity to process chemistry without an active Process

It is not the most sensitive metrology for all process changes

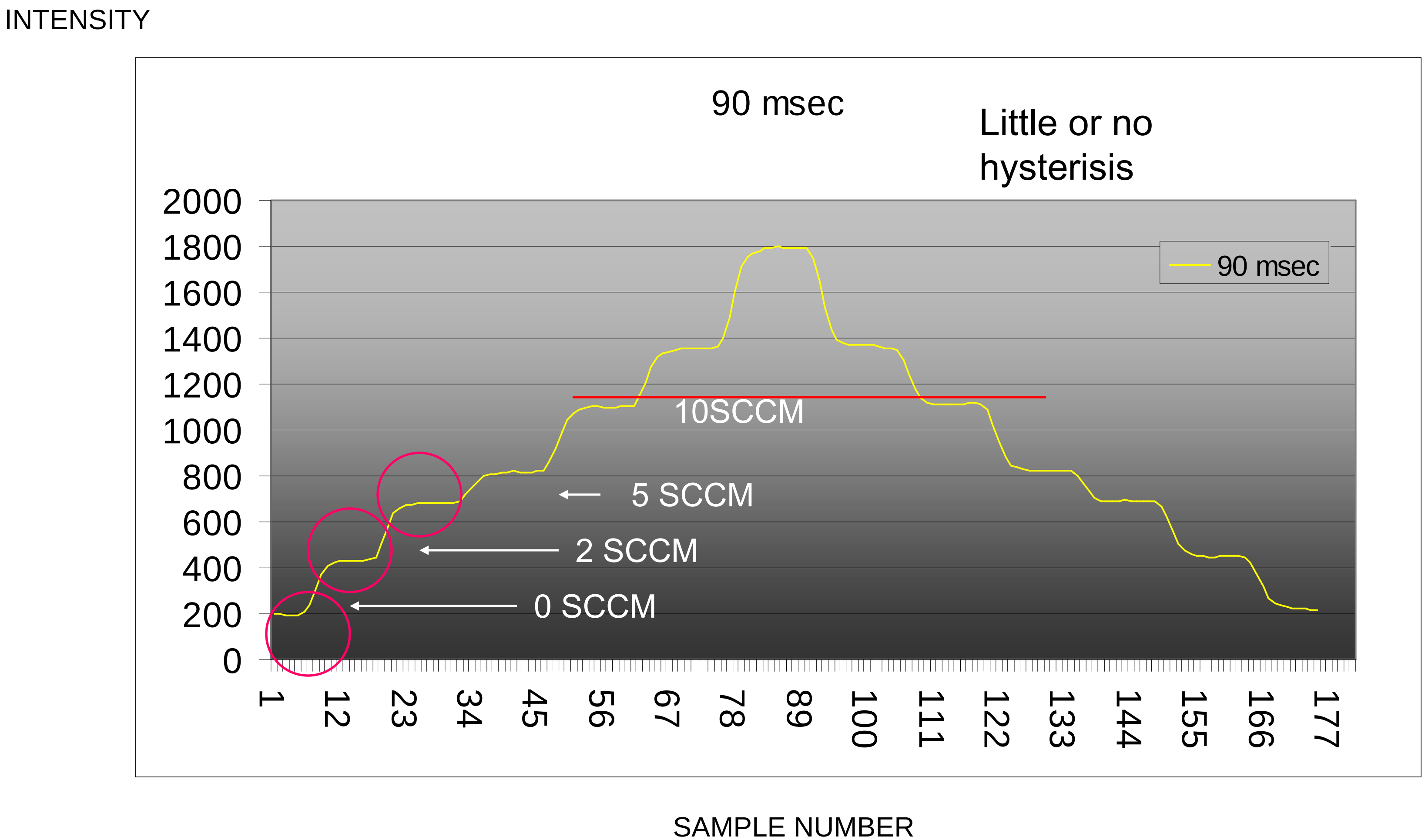
* *Oct 2-4, 2006 AEC/APC XVIII Symposium: David Dotan, Intel*

Module 1 Process Chemistry Only

LIGHTWIND

PROCESS GAS FLOW MEASUREMENT

ICPOES L3

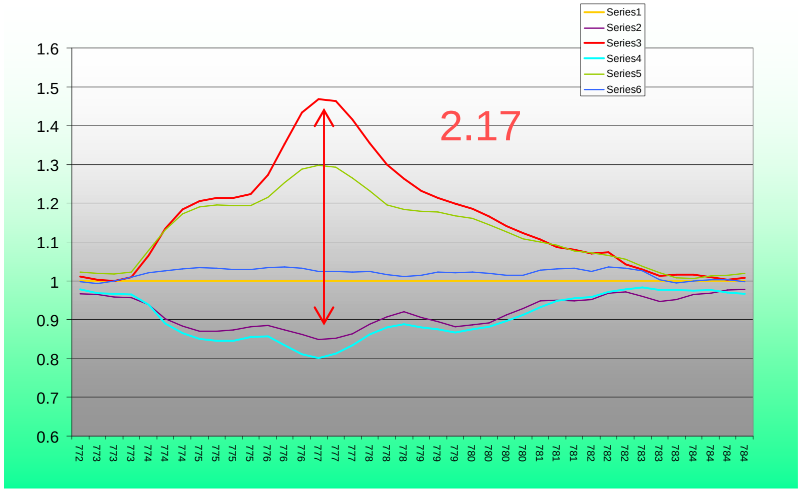


777 Oxygen Intensity change vs flow test

LIGHTWIND

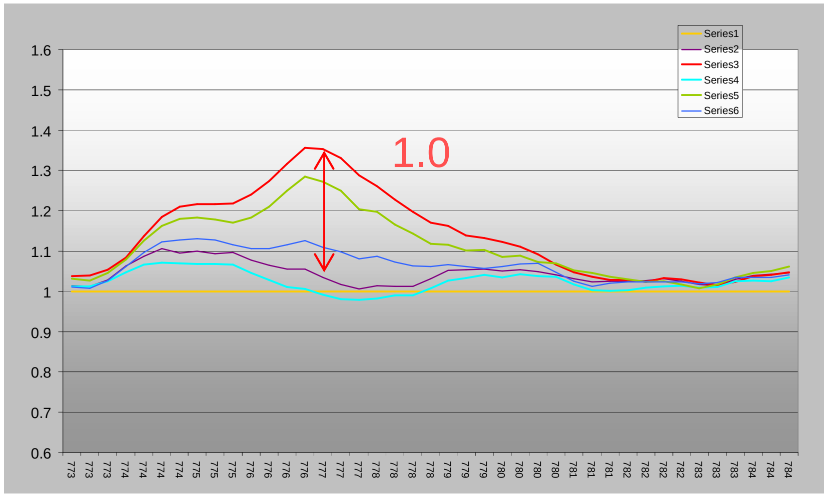
COMPARISON IN SITU TO EX SITU

ICPOES L3



Gas Only No Chamber RF

772 nm 784 nm



Standard "Through the Window" OES

Test Condition*	**Compared to Reference**
Thru the window	1.00
Exhaust NO process in chamber	2.17

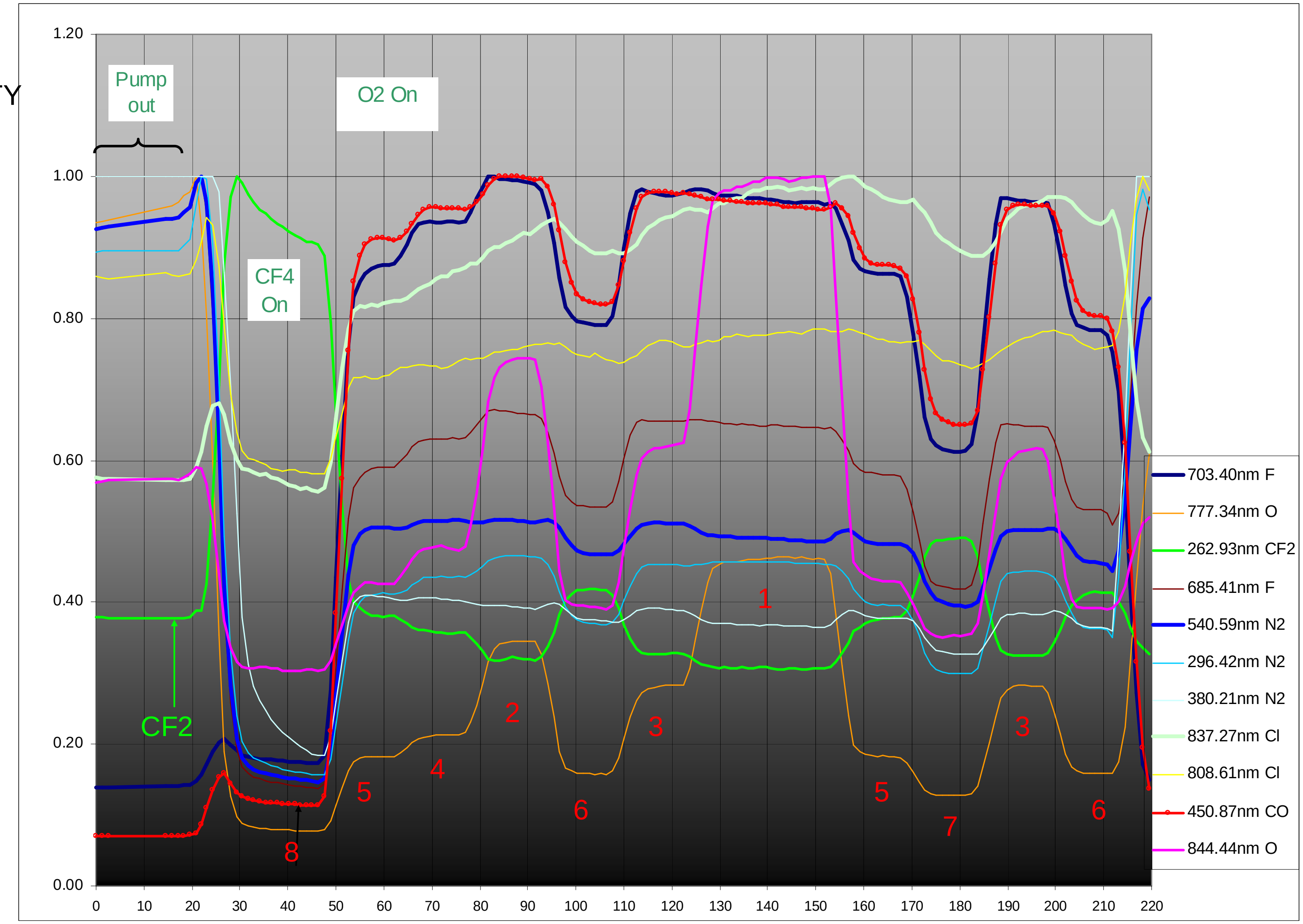
*Same gas flows, pressure, and spectrometer were used

LIGHTWIND

OES CHANGES VS PROCESS CHEMISTRY CHANGES

ICPOES L3

INTENSITY



TIME

11 DIFFERENT TEST CONDITIONS FOR OXYGEN FLOW, 777 O NUMBERED BY MAGNITUDE

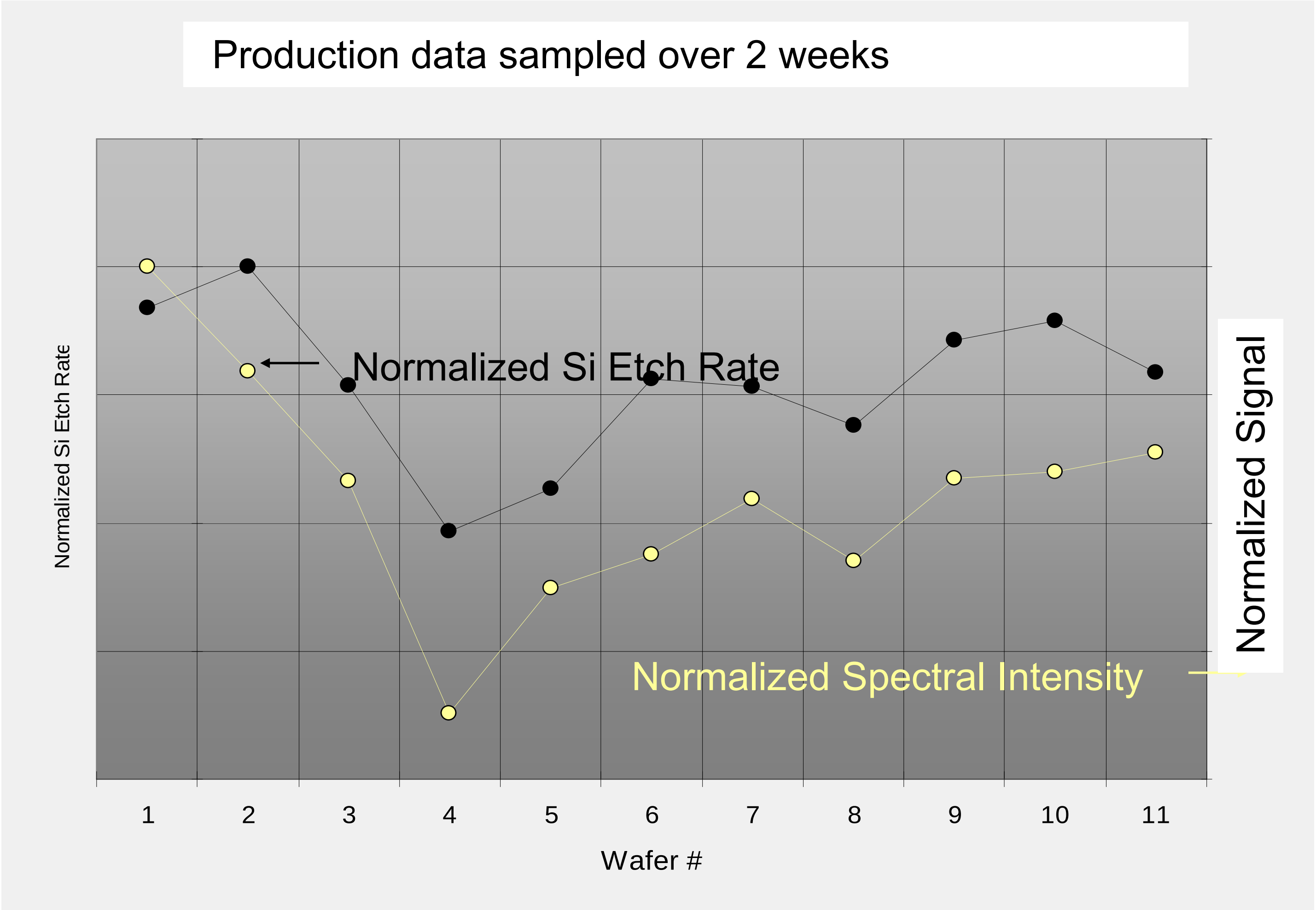
NOTE:
CF2 IS GOOD INDICATOR FOR POLYMER FORMATION:
NOTE THAT IT IS INVERSE OF O

SPECTRAL CHANGES THAT CORRESPOND TO OXYGEN FLOW CHANGES

LIGHTWIND

SI TEST ETCH RATE VS SPECTRAL INTENSITY

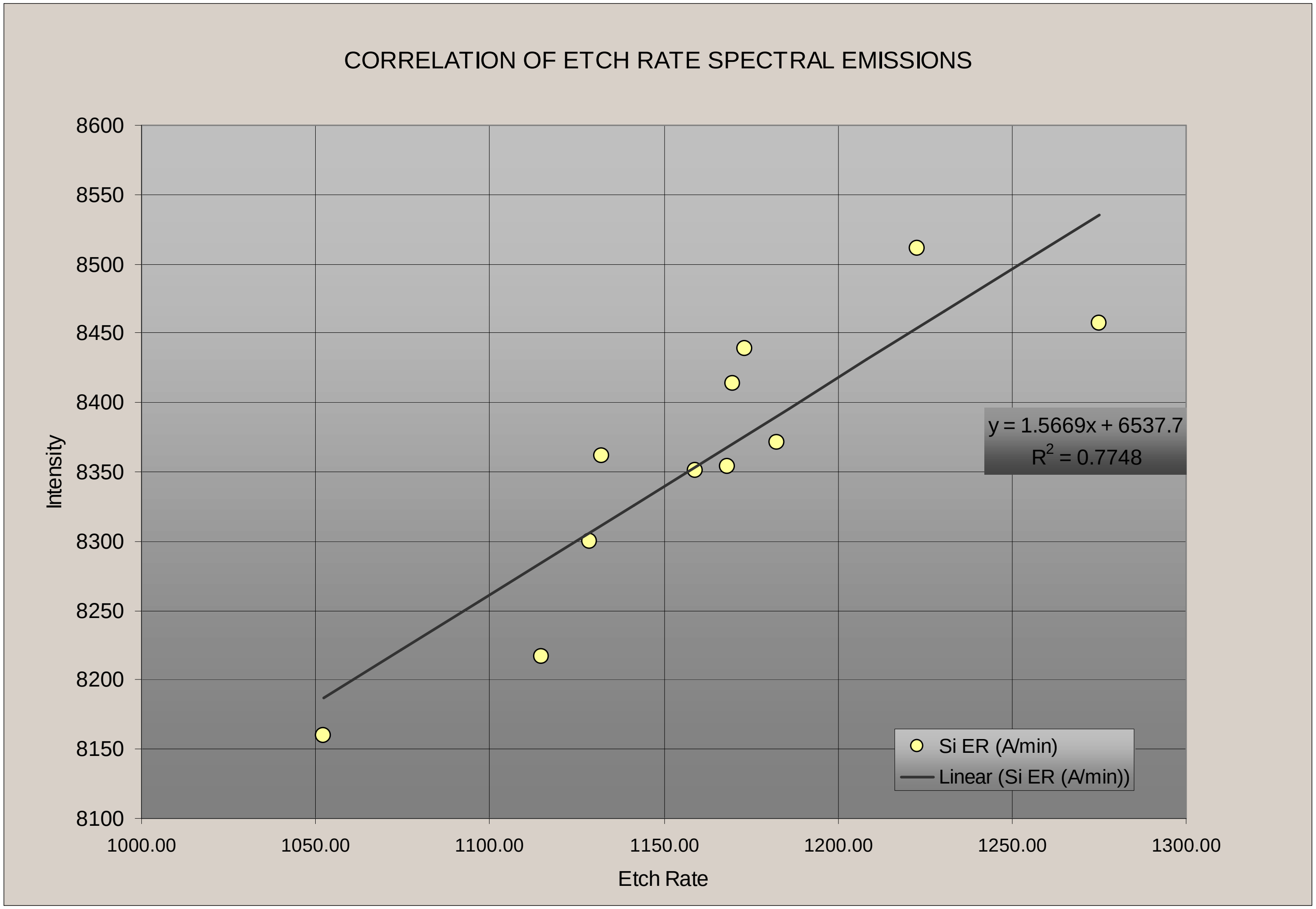
ICPOES L3



LIGHTWIND

ETCH RATE VS EMISSION INTENSITY

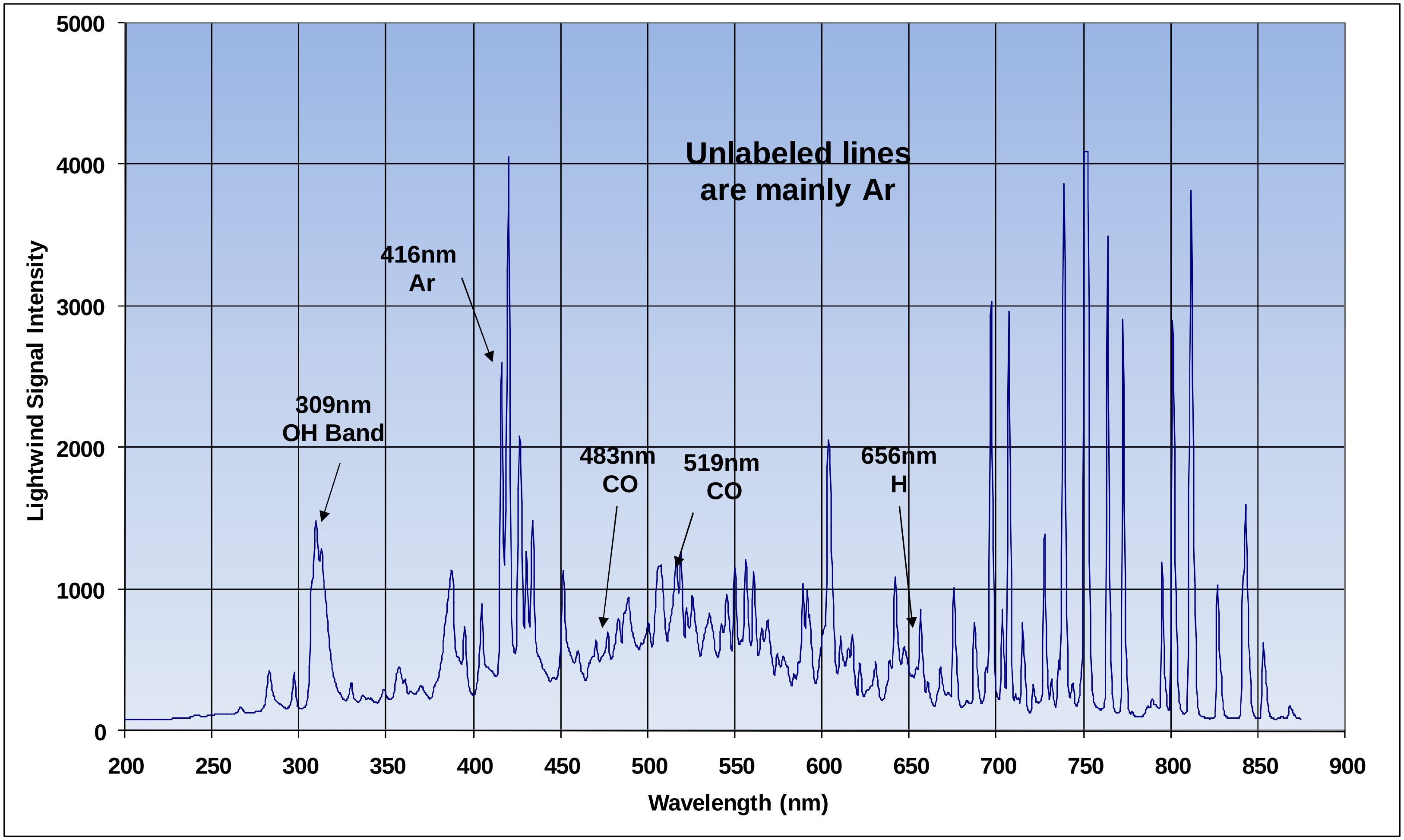
ICPOES L3



LIGHTWIND

Al2O3 ALD PROCESS (Typical Spectra)

ICPOES L3

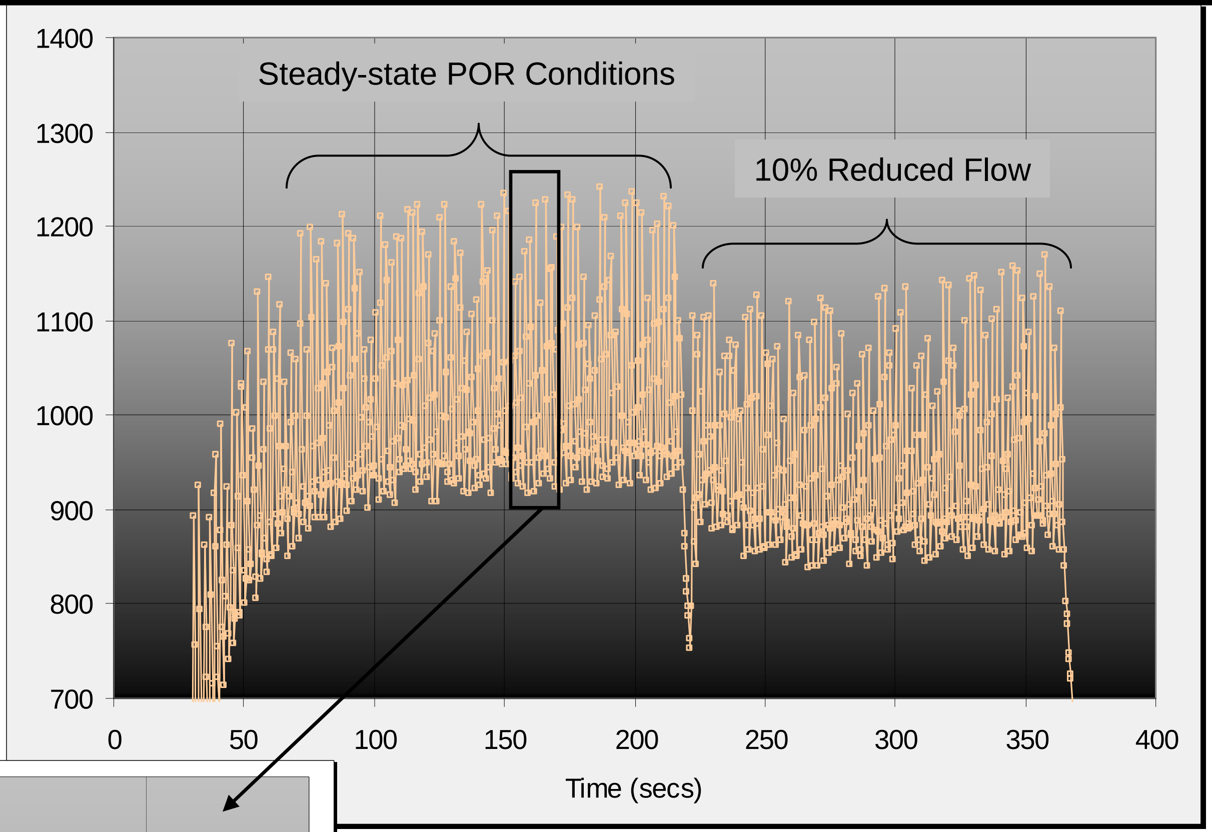


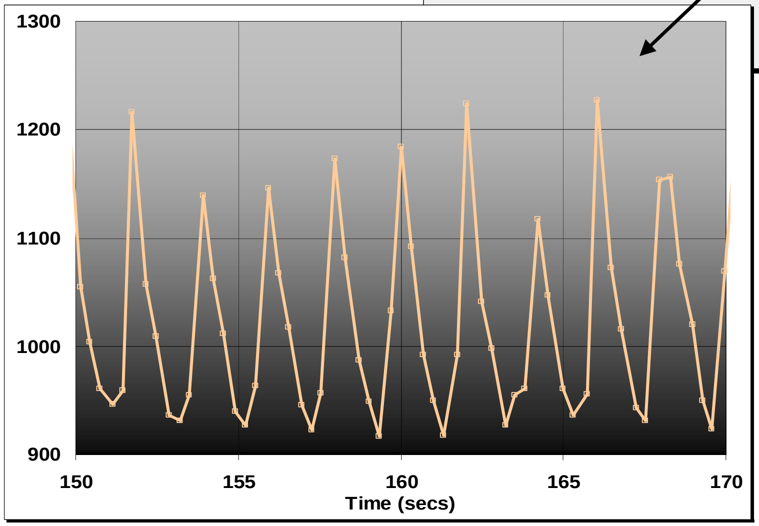
Module 1 Process Chemistry Only

LIGHTWIND

SIMULATION OF A COMMON FLOW FAULT ALD

ICPOES L3

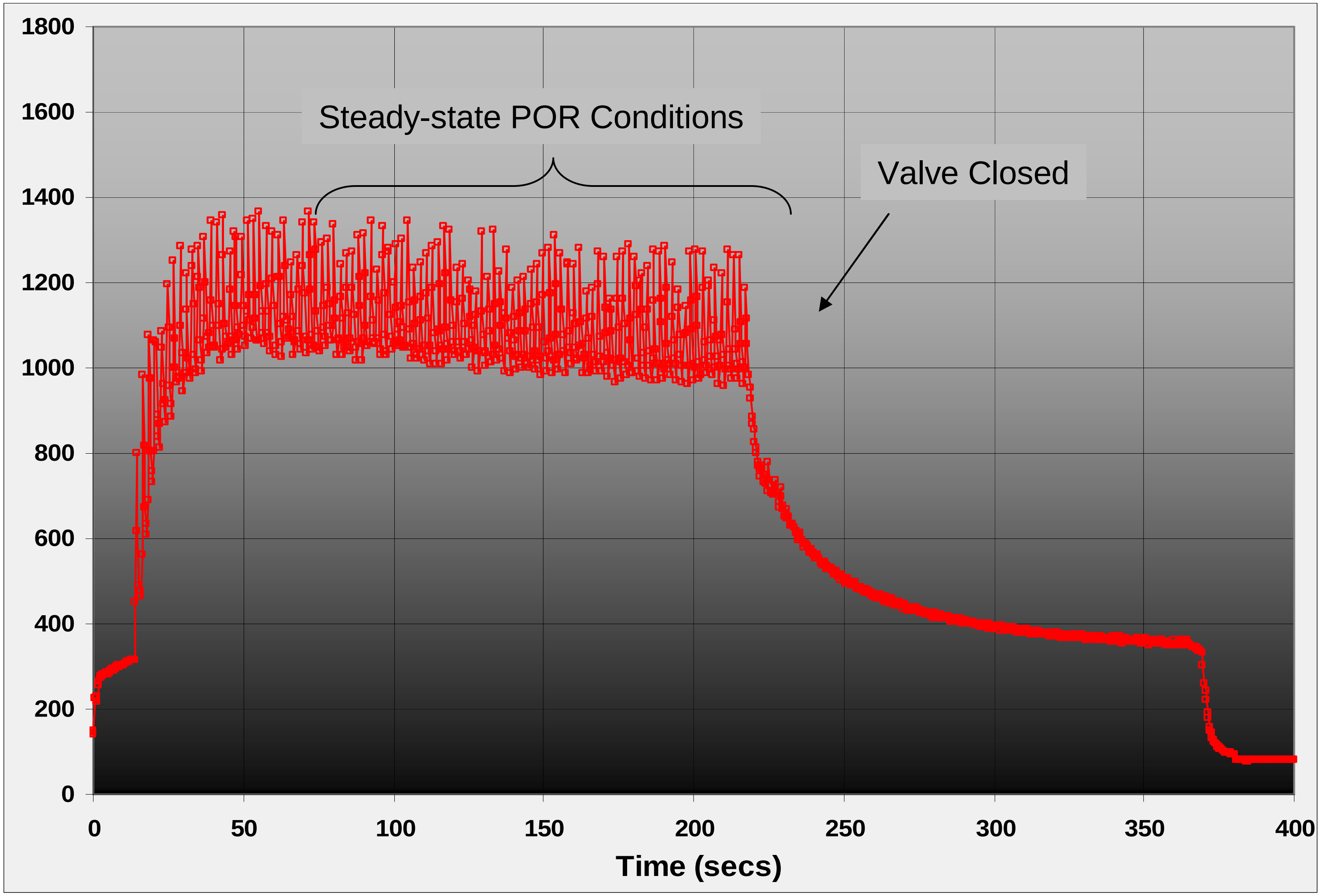




Expanded scale shows individual ALD cycles

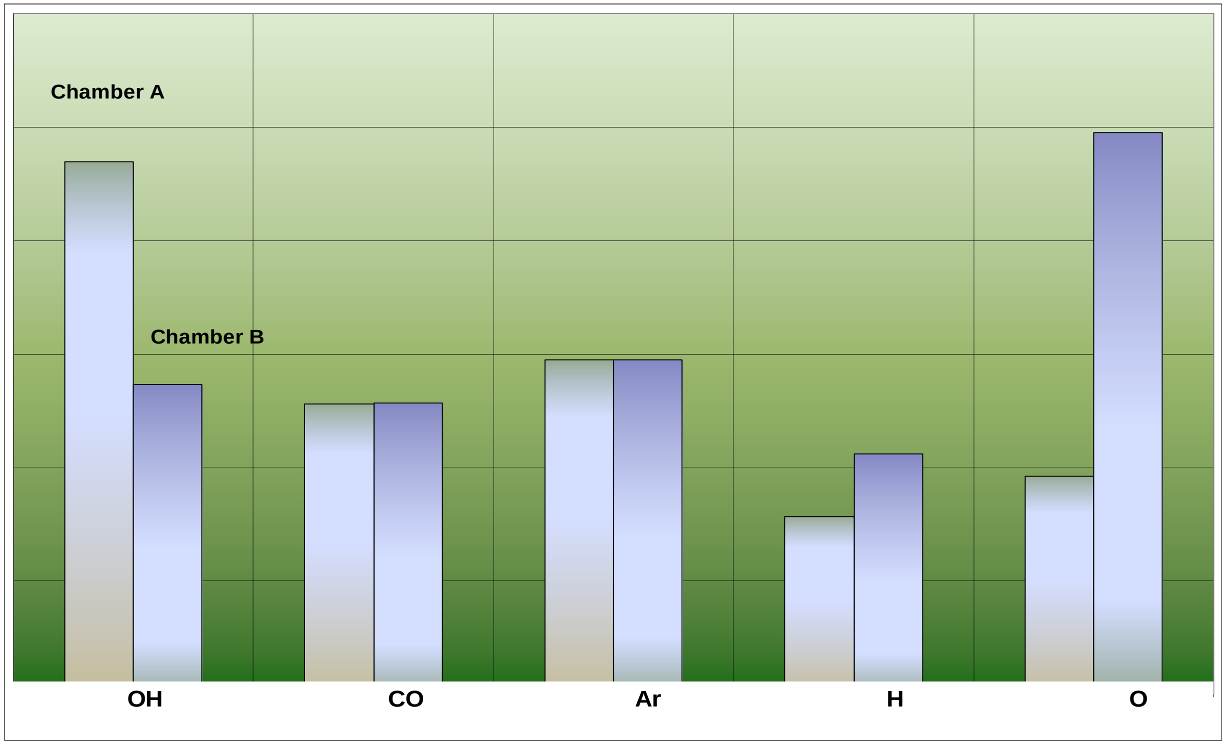
SIMULATION OF A COMMON VALVE FAULT ALD

ICPOES L3



LIGHTWIND

CHAMBER MATCHING PROCESS CHEMISTRY

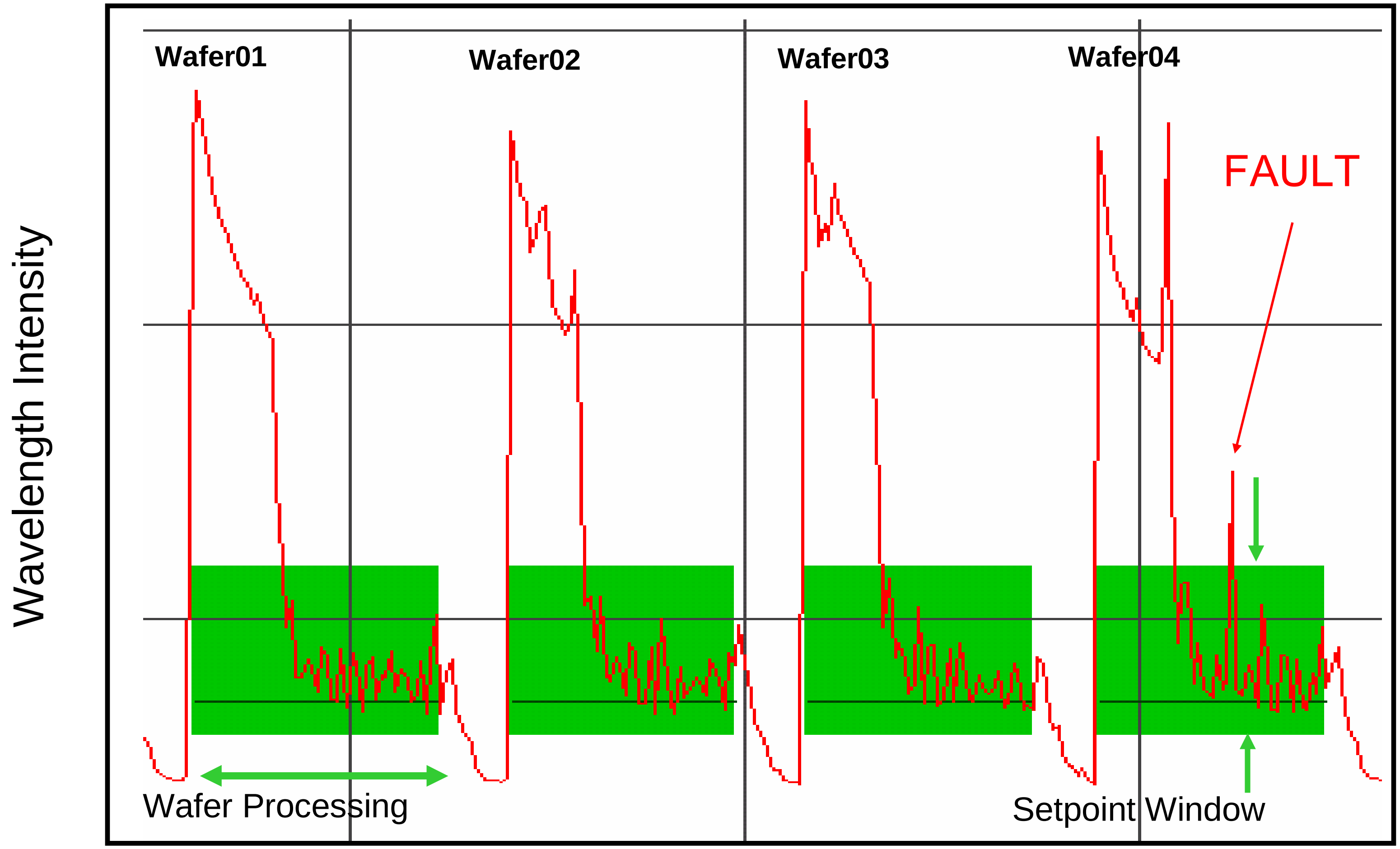


- Higher OH in Chamber A
- Higher O in Chamber B
- CO, Ar nearly identical
- Chamber B may be showing chemical residuals from a different process chemistry

NOTE: This is a measurement of the "Delivered" process chemistry, Not the "Requested" process chemistry

Module 1 Process Chemistry Only

Single Wavelength (Univariate) Fault Detection in ALD*



* John Loo

LIGHTWIND

OES DATA IS MULTIVARIATE

MULTIVARIATE DATA IN GENERAL IS:

MORE COMPLEX THAT UNIVARIATE
LESS INTUITIVE
HAS GREATER DEFINITION OF PROCESS INTERACTIONS
MODEL BASED

Major Premise:

Spectral data can easily become complex
Spectral data is generally viewed as data rather than chemistry
Evaluating spectral data (except in simpler cases) can be non intuitive

Minor Premise:

There may be a different approach that may be better suited to OES data?

Conclusion:

Evaluate an "expert" approach to modeling (replace one black box with shinier black box)

Comment: "Experts" have been demonstrated* to:
1 require small data sets for model building
2 be more tolerant of noisy data sets

*A good survey can be found in: Optical Diagnostics for Thin Film Processing, Irving P. Herman, Academic Press, Chapter 19

What We Did

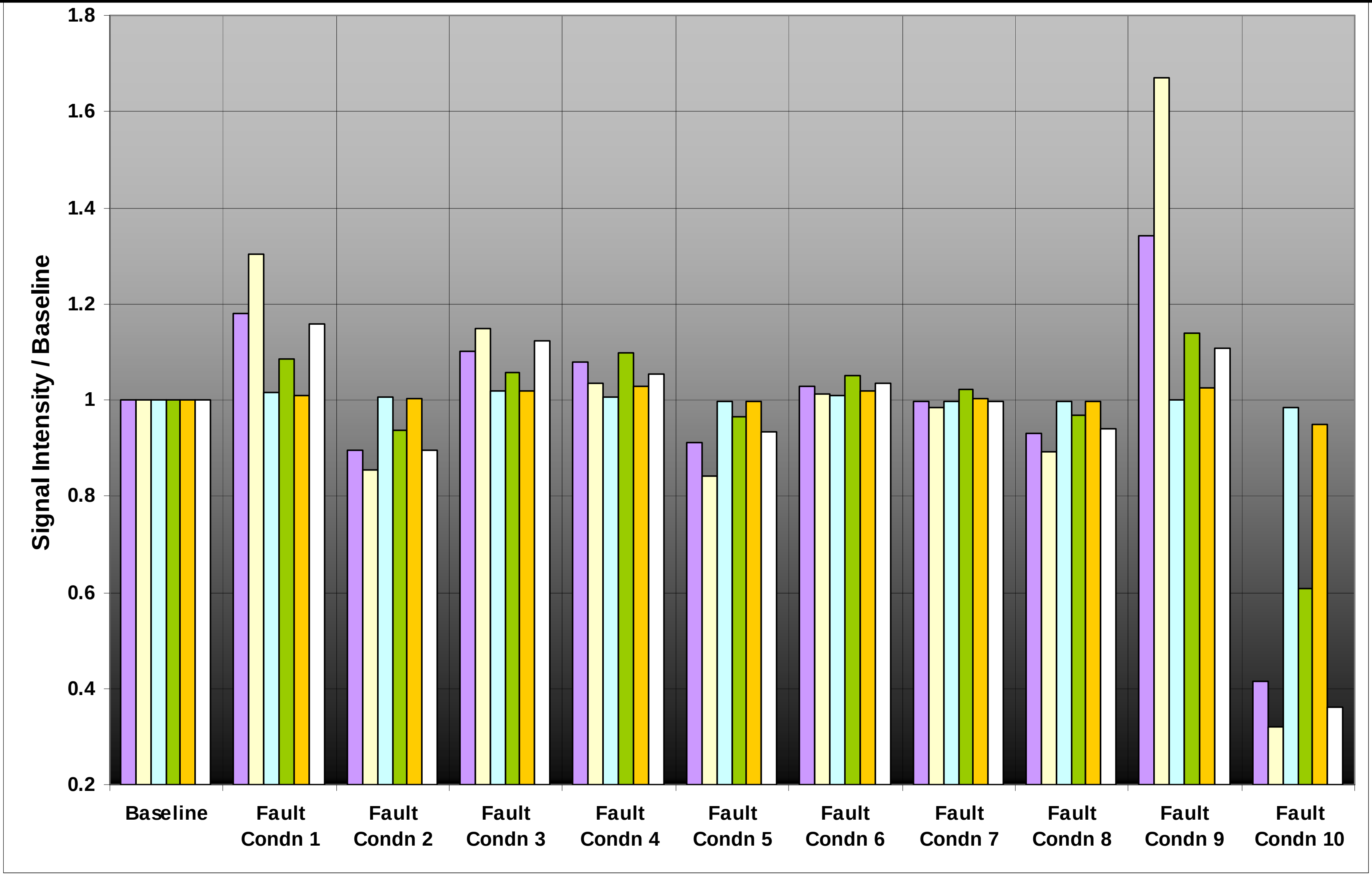
Single wafer ALD system
Collected baseline information
Ran simulated fault
Repeated baseline and then new fault
Combined Baseline data as part of training set

Comments

System was not completely recovered after each fault
So the new baseline would show larger variance than usual

SELECTED OES PEAK INTENSITIES DURING FAULTS

ICPOES L3



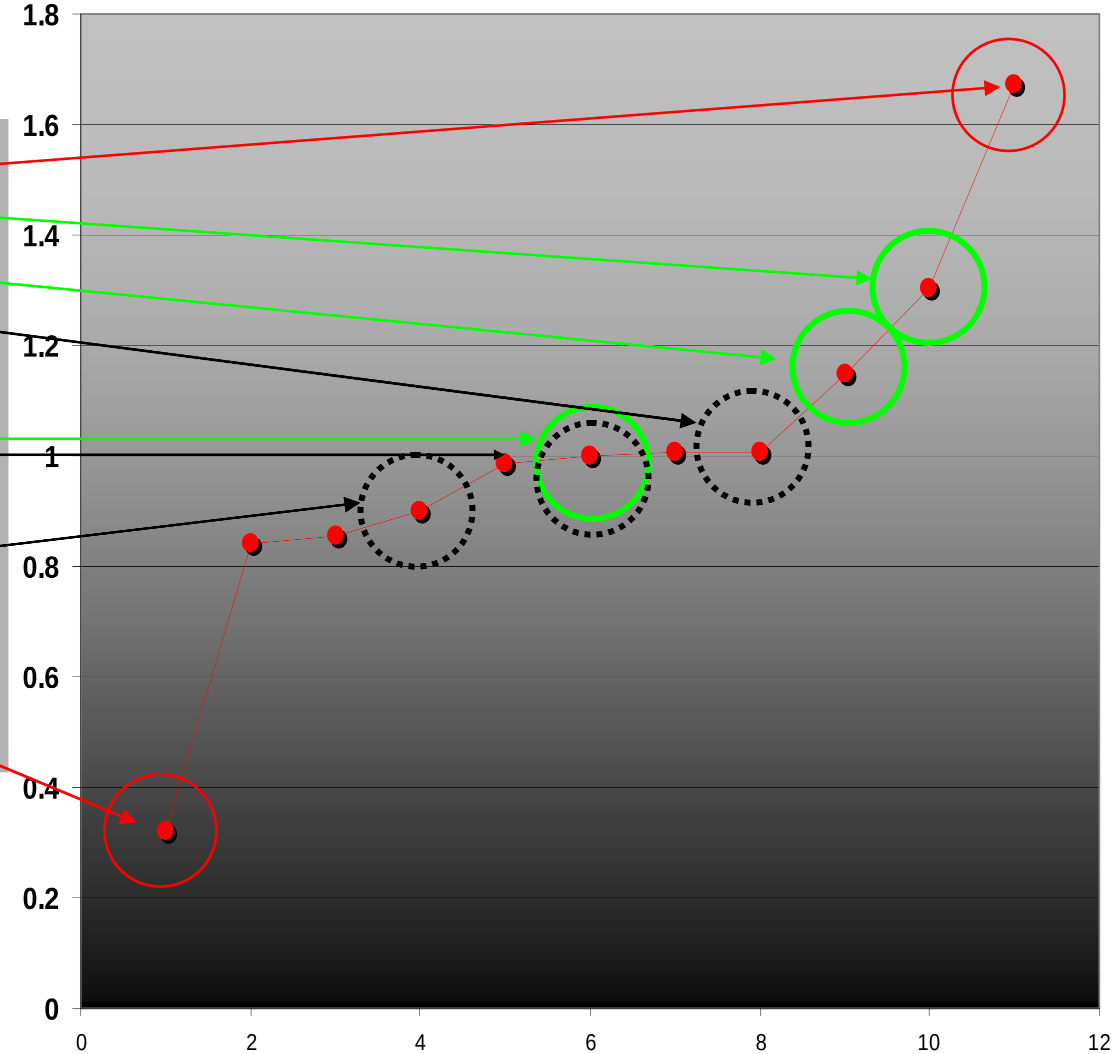
LIGHTWIND

OES PEAK HEIGHT VS FAULT SIMULATION TESTS 1 - 10

ICPOES L3

The Univariate View
(Single Wavelength

Precursor Valve Failure
Precursor Pulse - 10%
Precursor Pulse + 10%
Reactant Carrier - 10%
Reactant Pulse + 10%
Baseline
Precursor Carrier + 10%
Reactant Carrier + 10%
Reactant Pulse - 10%
Precursor Carrier - 10%
Reactant Valve Fail



LIGHTWIND

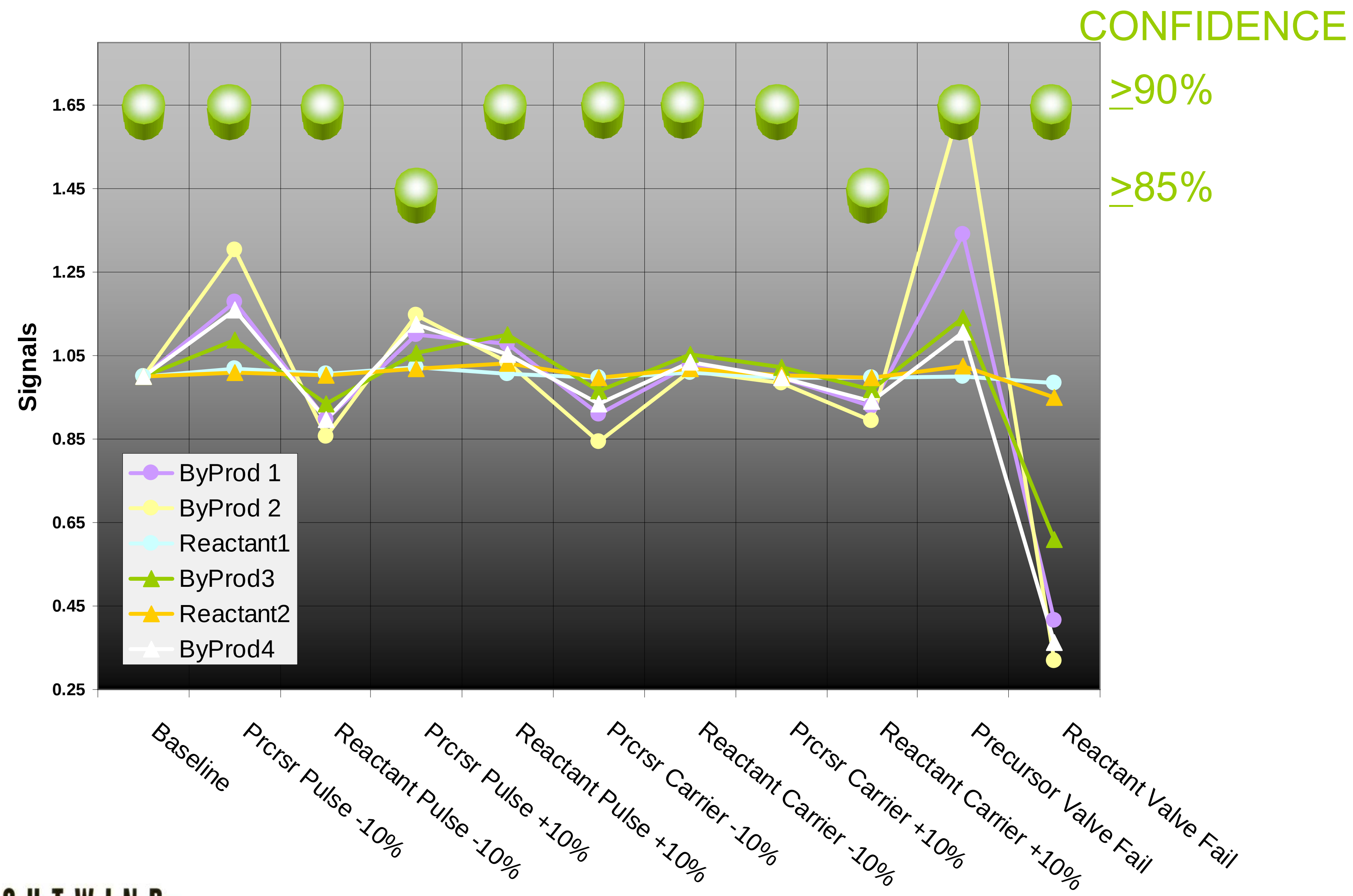
AN EXPERT INSTEAD OF A MULTIVARIATE MODEL

RATHER THAN USE THE TYPICAL APPROACH OF GENERATING A MULTIVARIATE MODEL FOR THE “TEST” FAULTS AN EXPERT SYSTEM WAS CREATED:

A NEURAL NET WAS GENERATED TO RECOGNIZE HIGHLY INTERACTED OES DATA.

ACTUAL FAULT CLASSIFICATION RESULTS

ICPOES L3



LIGHTWIND

ADDITIONAL OES PATTERN RECOGNITION TESTS

ICPOES L3

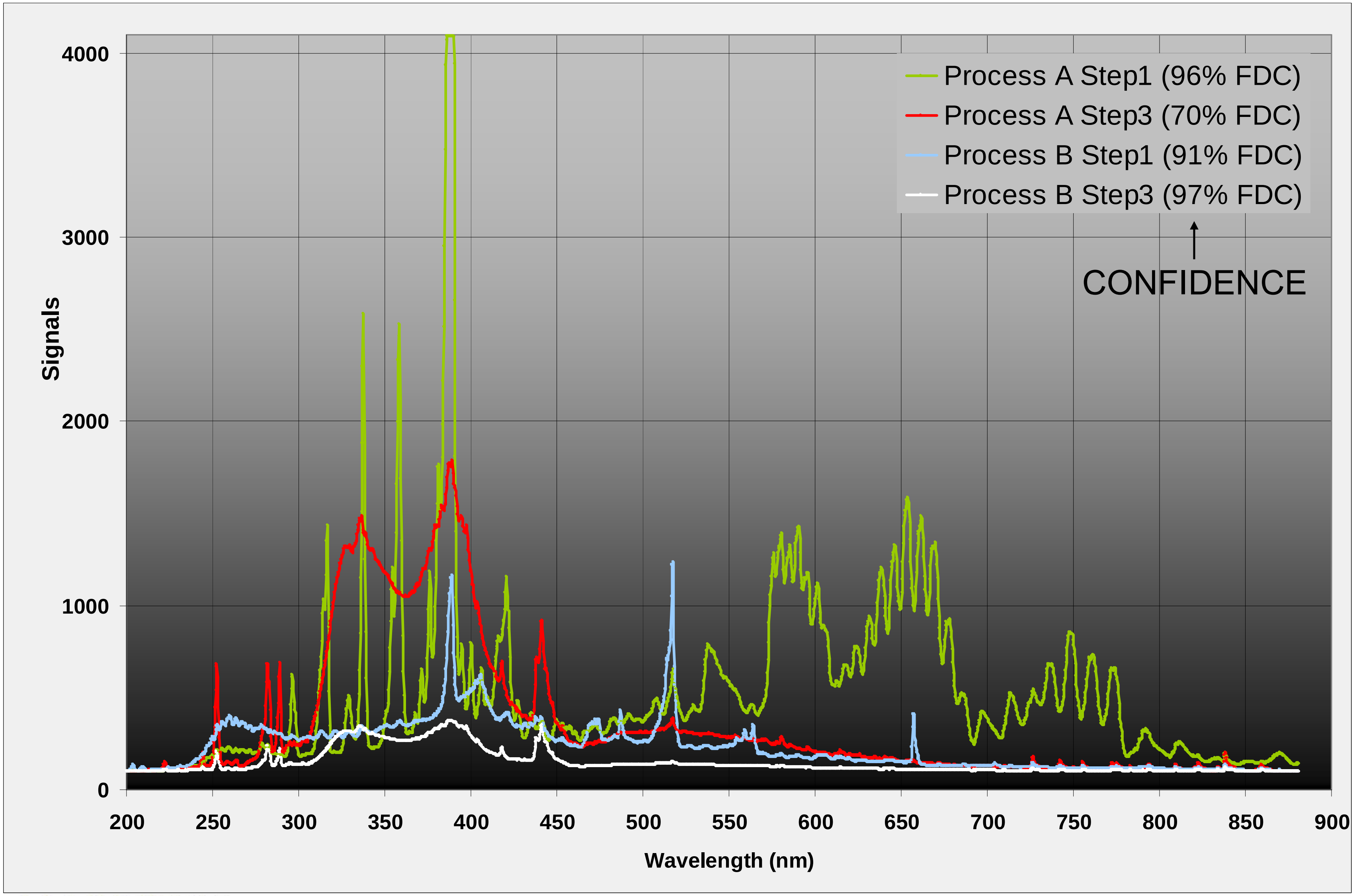
What We Did

Production Data was selected for typical process conditions
An expert was trained to recognize multiple start conditions
We tested the ability of (IT which shall go un named)
to detect the actual process step

LIGHTWIND

RECOGNIZING THE PROCESS FROM THE SPECTA

ICPOES L3



LIGHTWIND

THOUGHTS ON OES EXPERTS

Tests with "expert" models have shown great promise for OES data. While there are many challenges associated with this different approach they are, nevertheless, the same problems that confront other modeling techniques:

1 fundamental immunity to noise
2 ease of modeling
3 ability to generalize results

Limited function experts appear to be very compatible with OES data as a means to reduce complicated information sets and enable rapid decision making with respect to the cause of process failures.

CLASSICAL OES: THROUGH THE WINDOW

OES S3

BENEFIT:
SENSITIVE TO CHEMISTRY
BUT SIGNIFICANTLY INTERACTS
WITH PROCESS RF

APPLICATIONS:
ENDPOINT
TROUBLESHOOTING
CHAMBER MATCHING
FAULT DETECTION

LIGHTWIND

SPECTROMETERS

OES S3

There is no “perfect” spectrometer: there is a “reasonable” spectrometer for the application.

U4000
3600 Pixels
1.3 nm
20 milliseconds
Range 200 to 850 nm

Good general purpose spectrometer

UR2000
2048 Pixels
1.0 nm
20 millisecond sample time
Range 200 to 1100 nm

Higher resolution, higher range less sensitivity per pixel

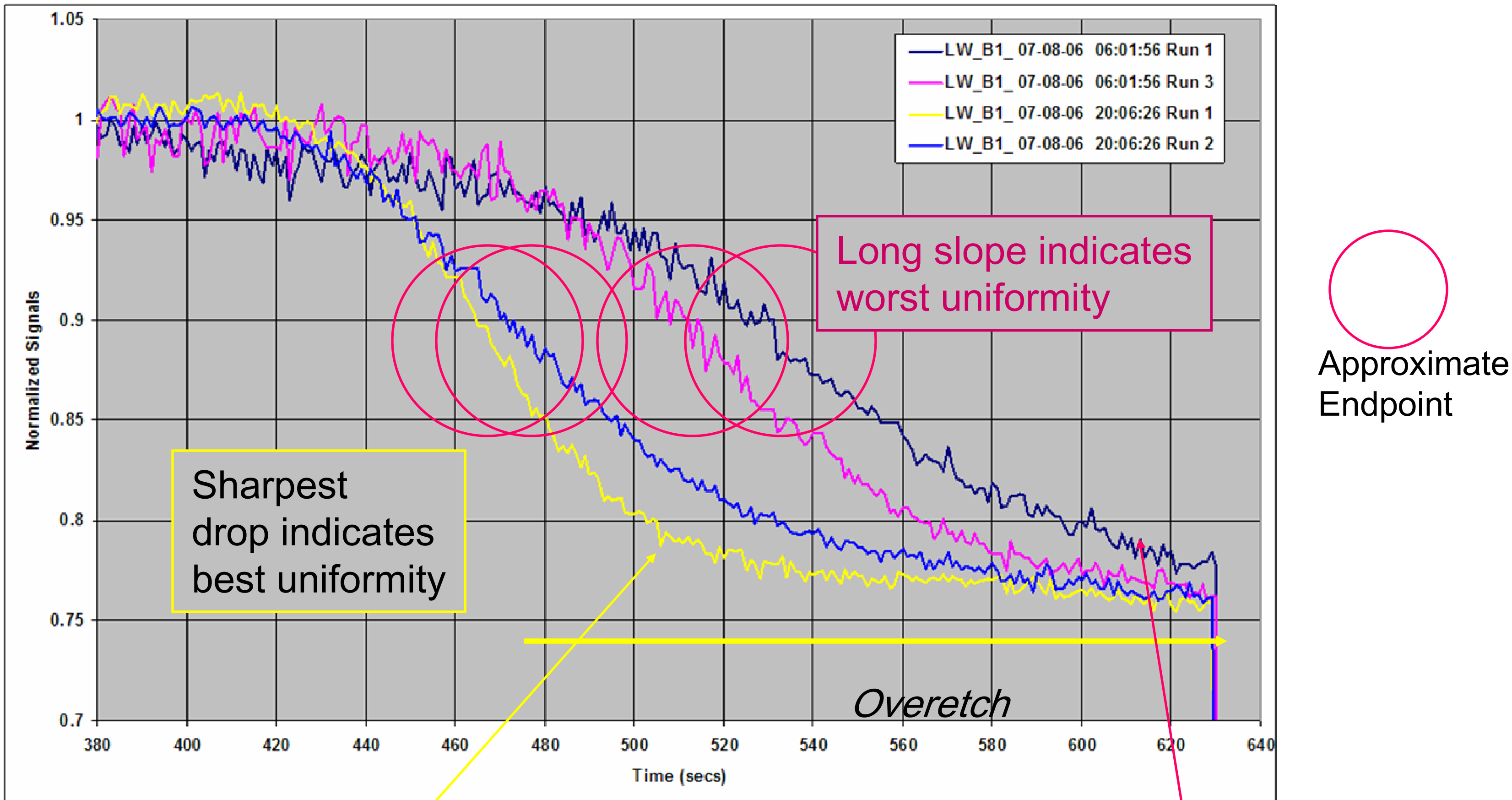
UR4000
3600 Pixels
.5 nm
20 millisecond sample time
Range 200 to 850 nm

Higher resolution, higher range least sensitivity per pixel

LIGHTWIND

OES CLASSIC: THROUGH WINDOW ENDPOINT

OES S3



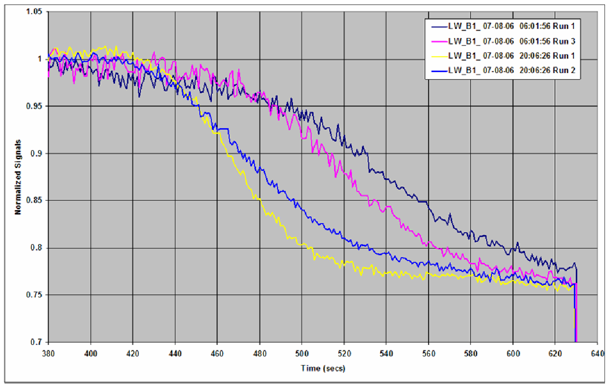
Most uniform etch has greatest overetch for all wafers

Some wafers may not be etched enough some may be incomplete

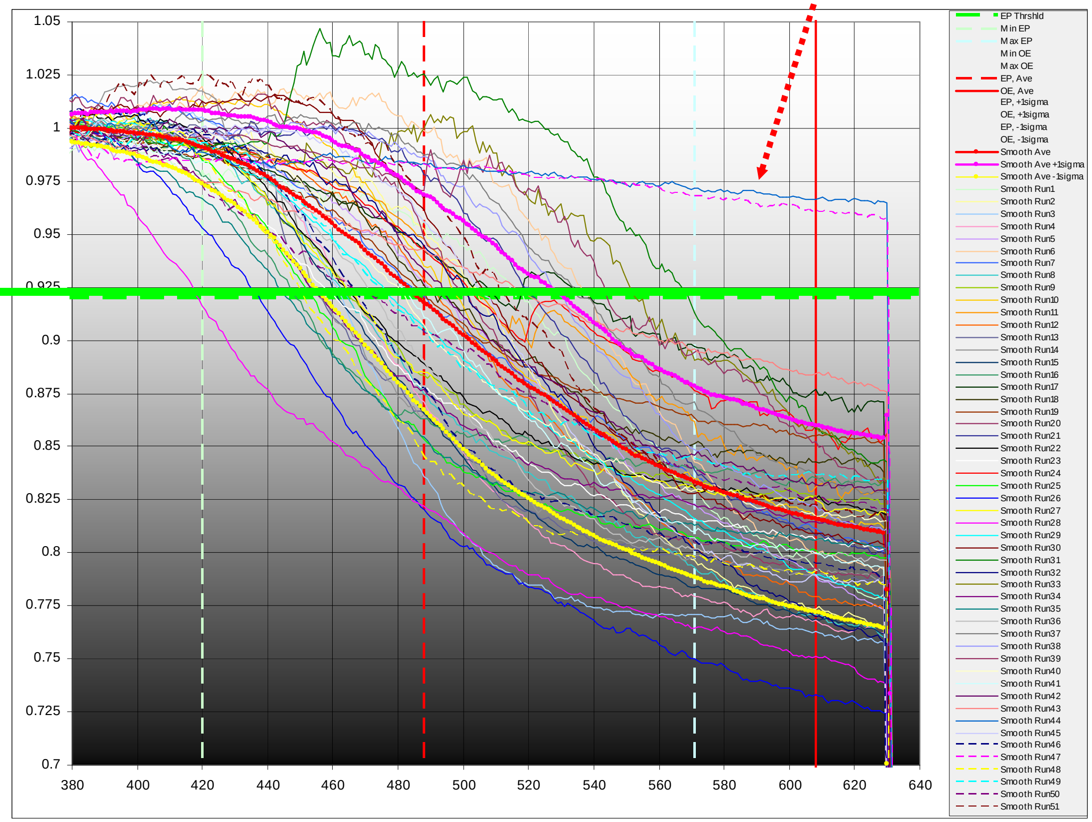
LIGHTWIND

ENDPOINT VARIABILITY

OES S3

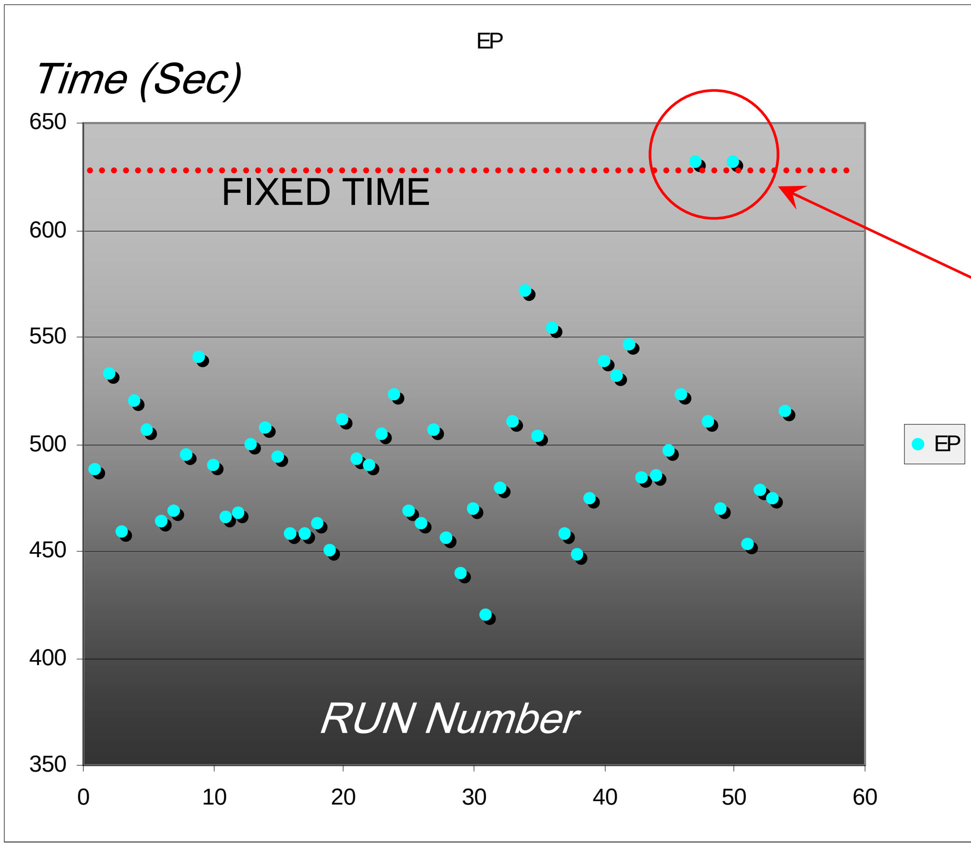


Problem runs

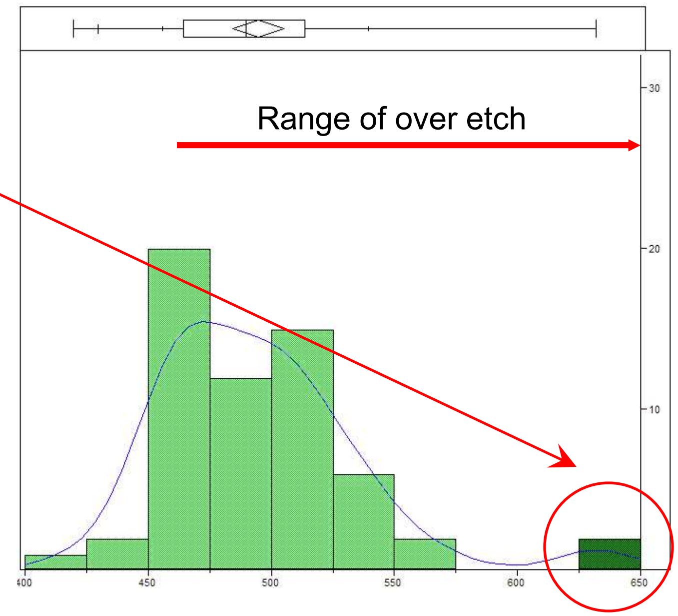


Sample Endpoint Threshold

LIGHTWIND



Distribution of Times

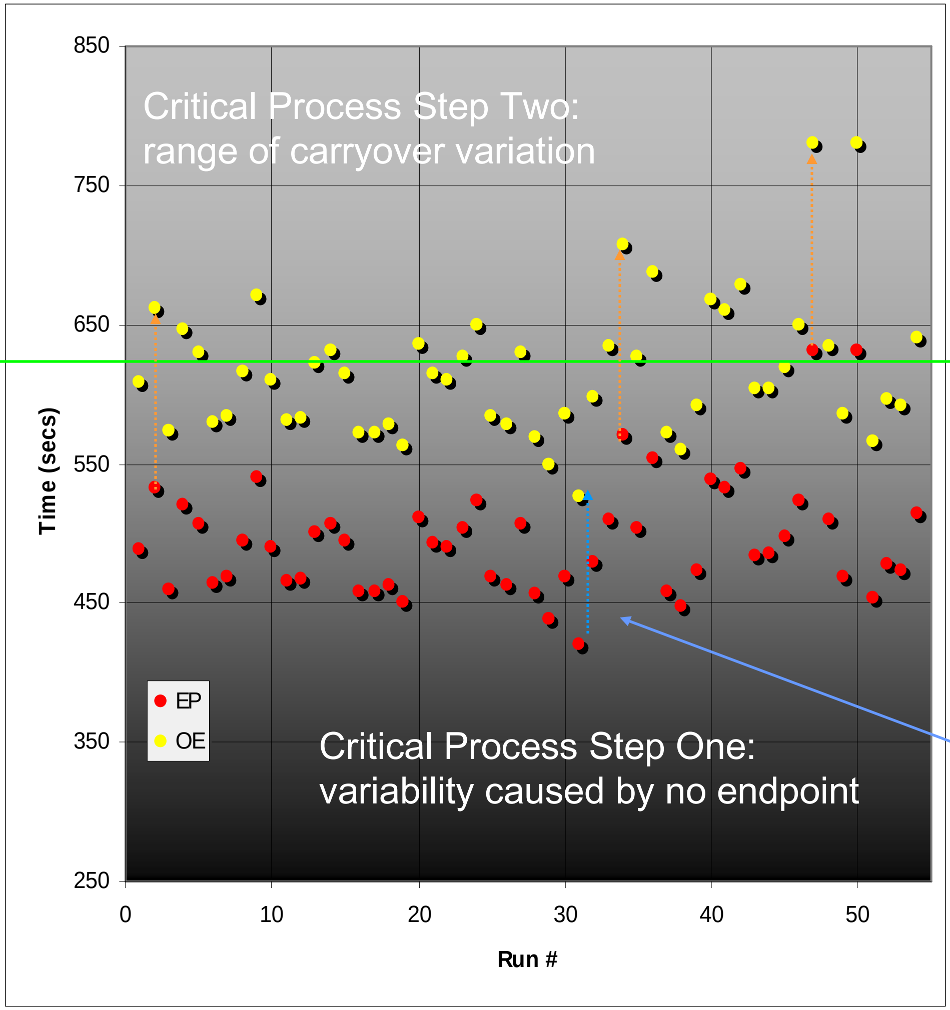


$$\frac{\text{Max-min}}{\text{Mean}} = 43\%$$

LIGHTWIND

CONSEQUENCES OF FIXED TIME PROCESSES

OES S3



Runs potentially requiring additional etch time

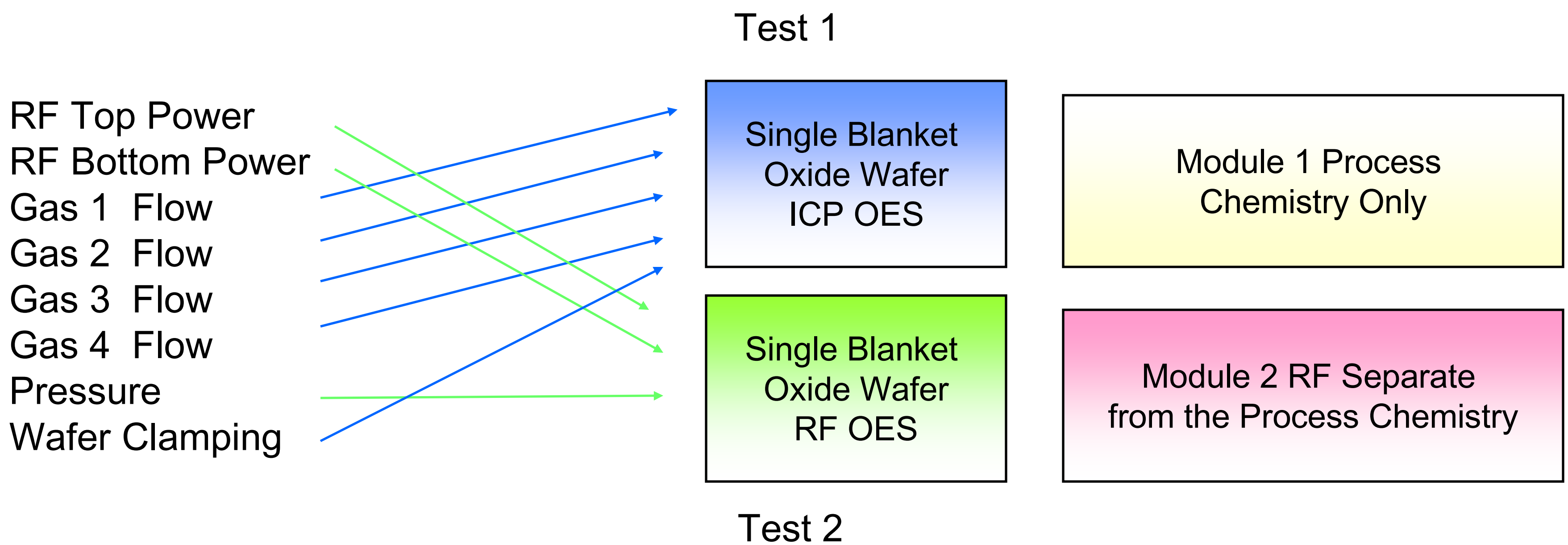
Process cutoff time

Runs potentially requiring less etch time

LIGHTWIND

CHAMBER MATCHING MIXED SENSORS OES AND ICP OES L3

TWO TEST CYCLES TO CONVERGE ON CHAMBER DIFFERENCES

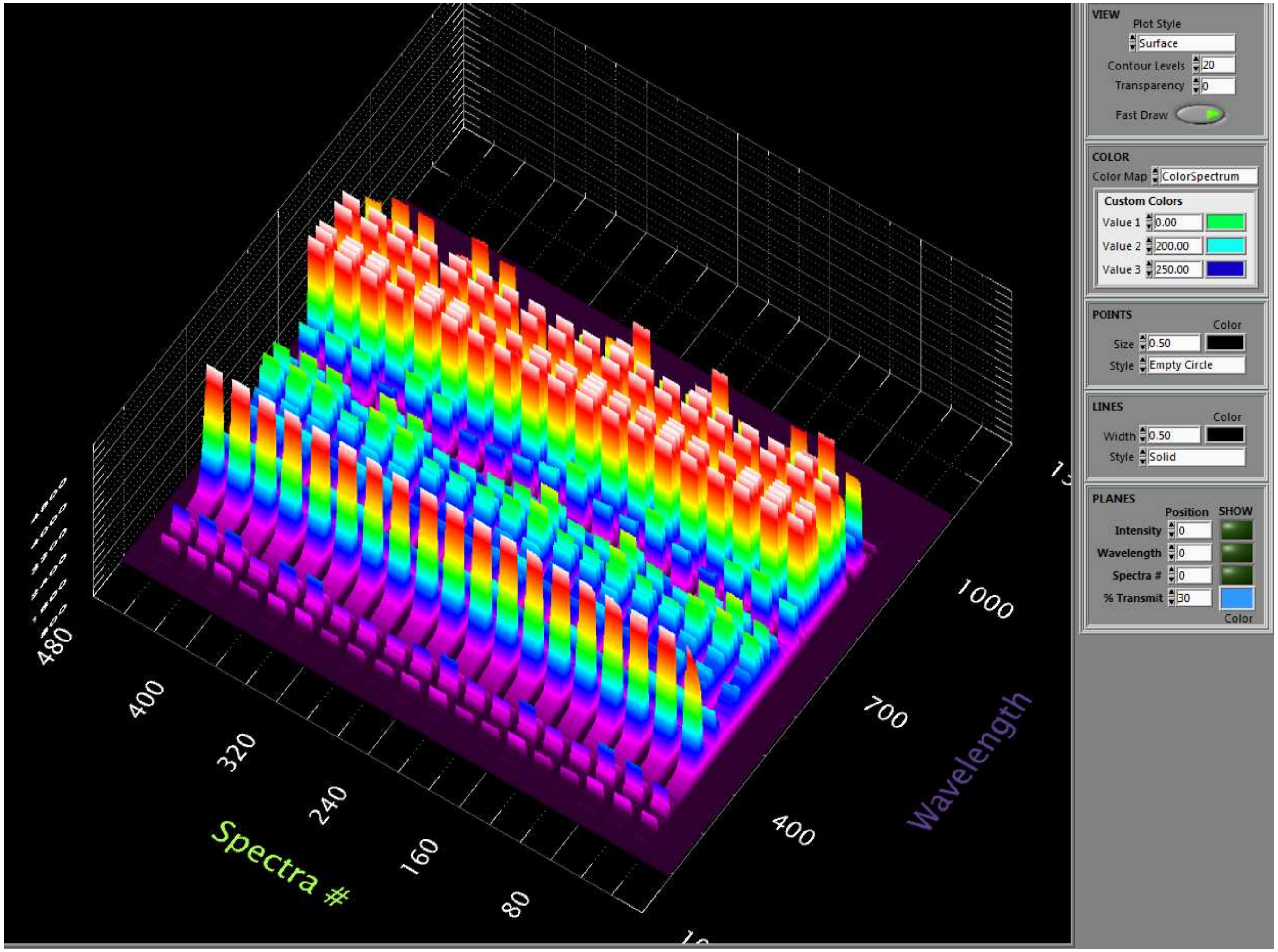


LIGHTWIND

TEST 2 FOR RF POWER

OES S3

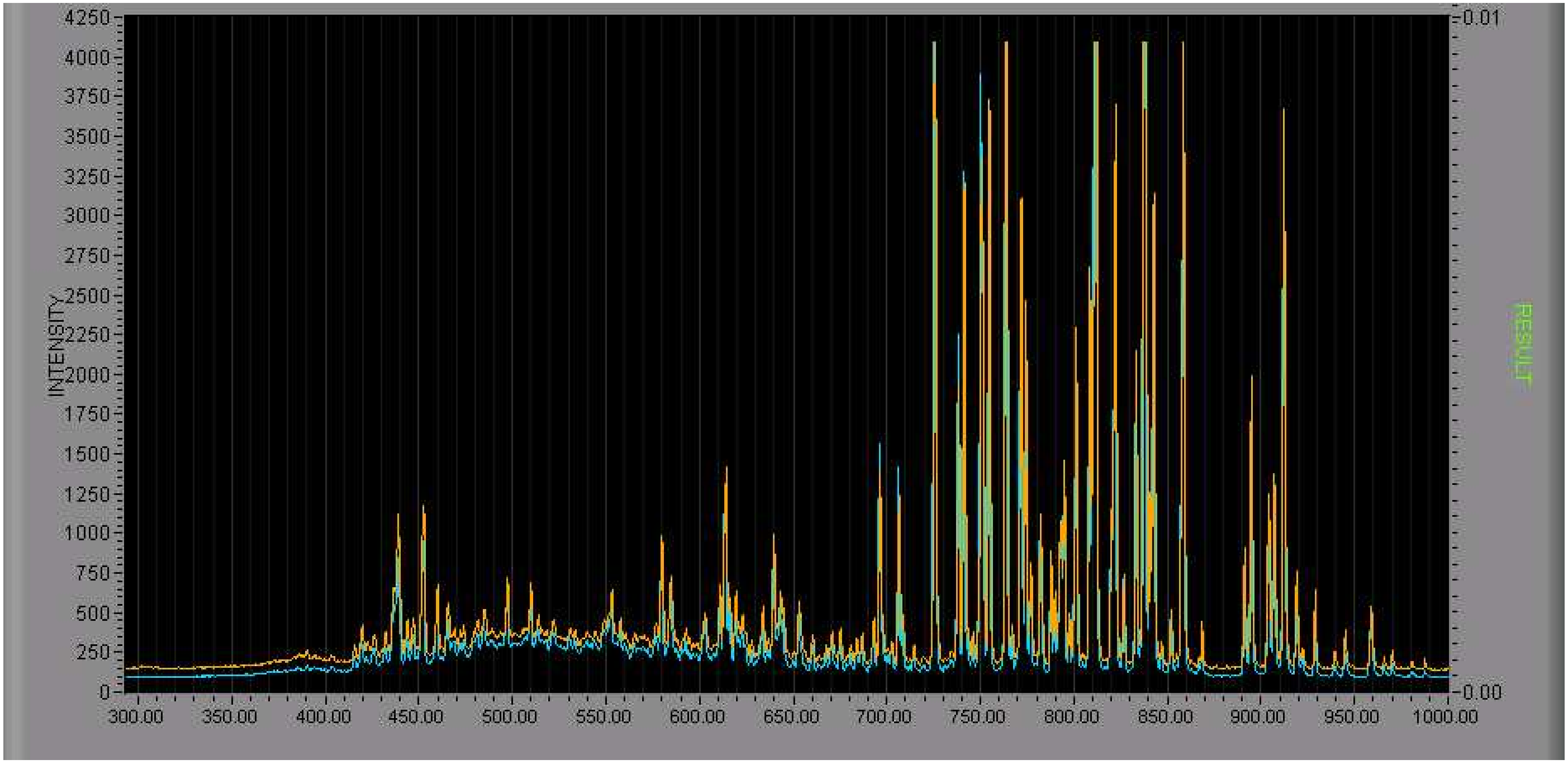
16 Different Process Conditions with 3 Repeats: Full Spectral map for each process condition



LIGHTWIND

RAW SPECTRA CHAMBER 2 AND CHAMBER 1

OES S3

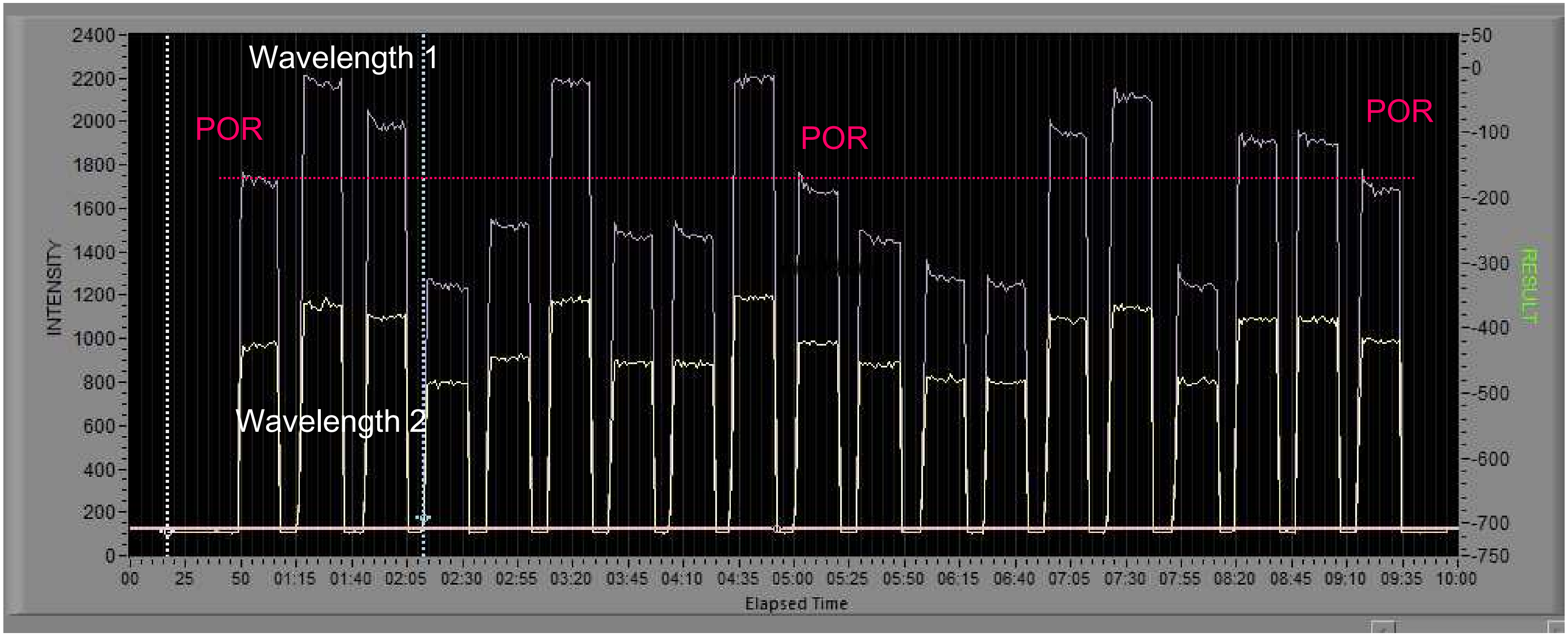


LIGHTWIND

VARIATION IN ETCH

OES S3

Selected Lines show how emission levels change with each different process condition



LIGHTWIND

Module 1 Process Chemistry Only

This test does not require an “active” rf process

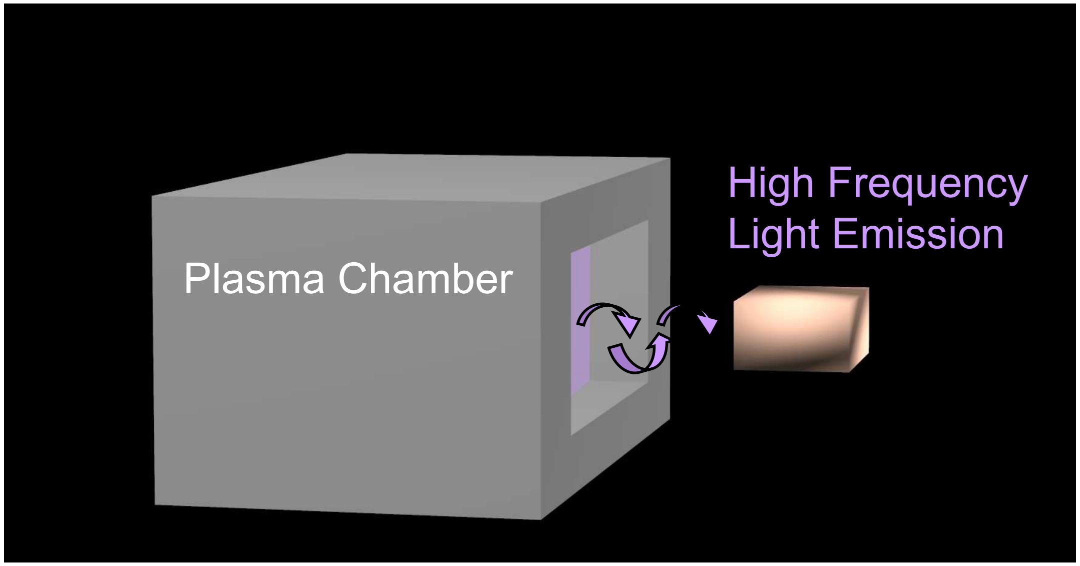
Module 2 RF Separate from the Process Chemistry

Module 3 Interactions of RF and Chemistry

This test requires an active RF process, but traditional OES will typically have a lot of interaction between the system RF and the chemistry

BACKGROUND:

RF related problems one of the most common in manufacturing
RF problems can be difficult to diagnose and time consuming
Existing VI probe technology is viewed as “perturbing” the RF path
and perhaps the process: it is considered invasive
Existing tool readouts (sensors) measure only Vpp or Bias
and these measurements can be inaccurate or misleading.
For example: there are many ways to adjust the process to produce the same Vpp and Bias but the processes are not equivalent.



TIME RESOLVED
SPECTROSCOPY *

BENEFIT:
NON INVASIVE
MUCH BETTER TEST OF RF
SEPARATE FROM CHEMISTRY

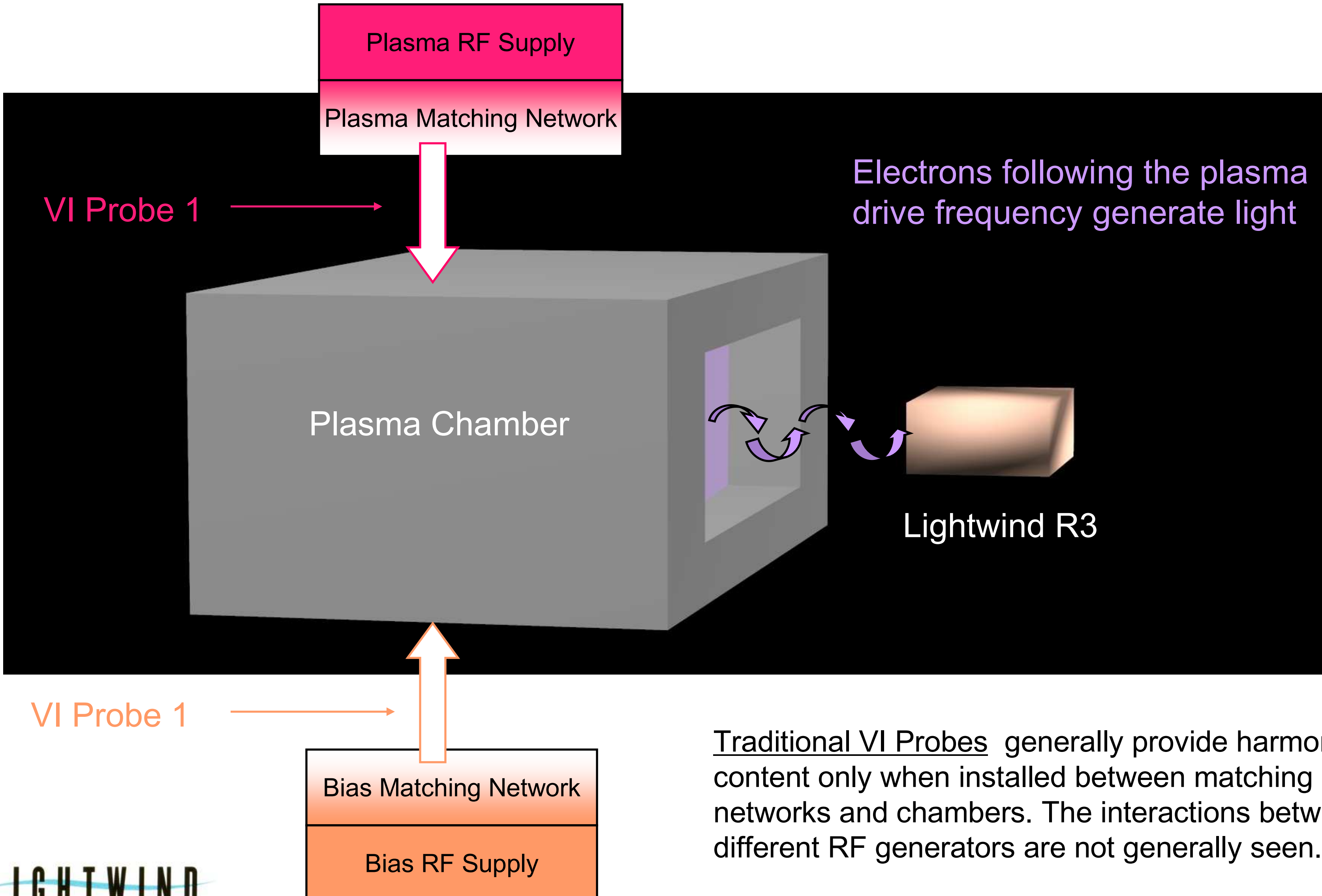
APPLICATIONS:
MOST RF SYSTEMS
DIAGNOSTICS
FAULT DETECTION

*This technique was originally demonstrated by Flamm and Donnelly

LIGHTWIND

THEORY OF OPERATION: OPTICAL RF

RF OES R3



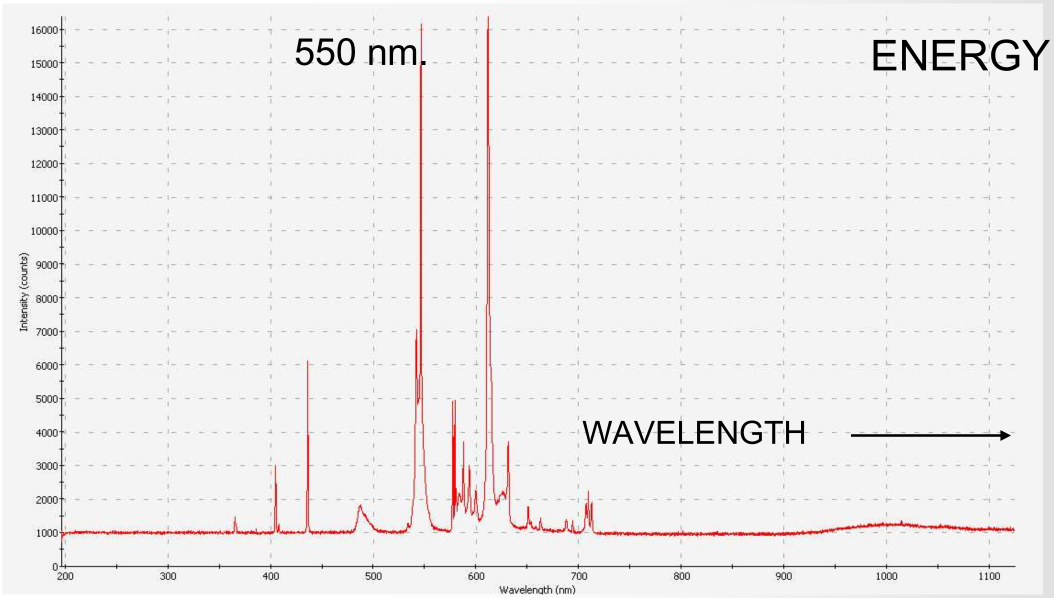
<u>Traditional VI Probes</u> generally provide harmonic content only when installed between matching networks and chambers. The interactions between different RF generators are not generally seen.

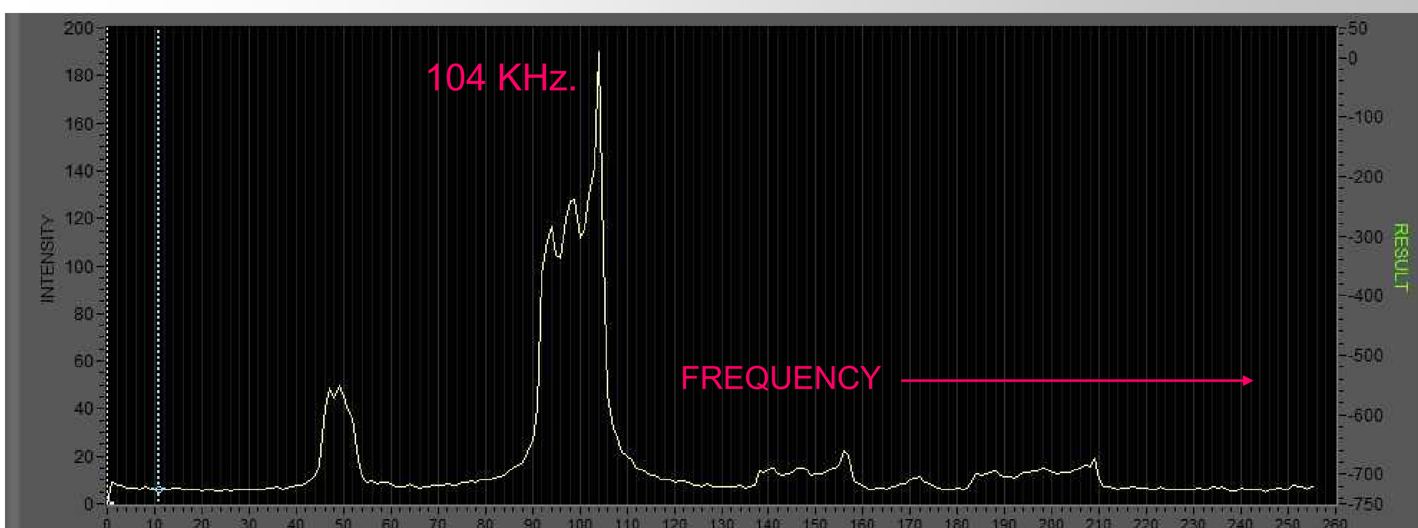
LIGHTWIND

A PARADIGM SHIFT: OPTICAL RF

RF OES R3

ENERGY SAVING FLUORESCENT BULB

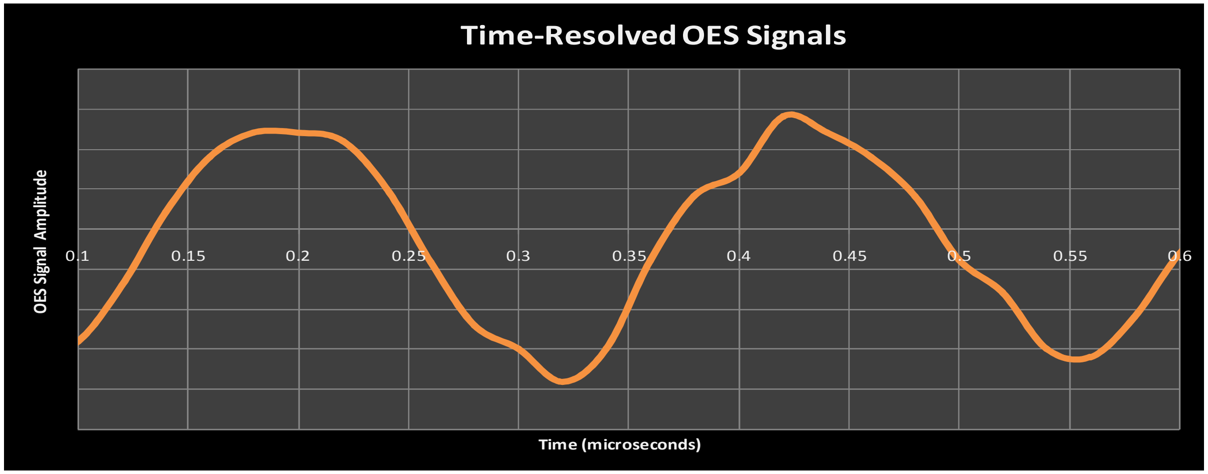




LIGHTWIND

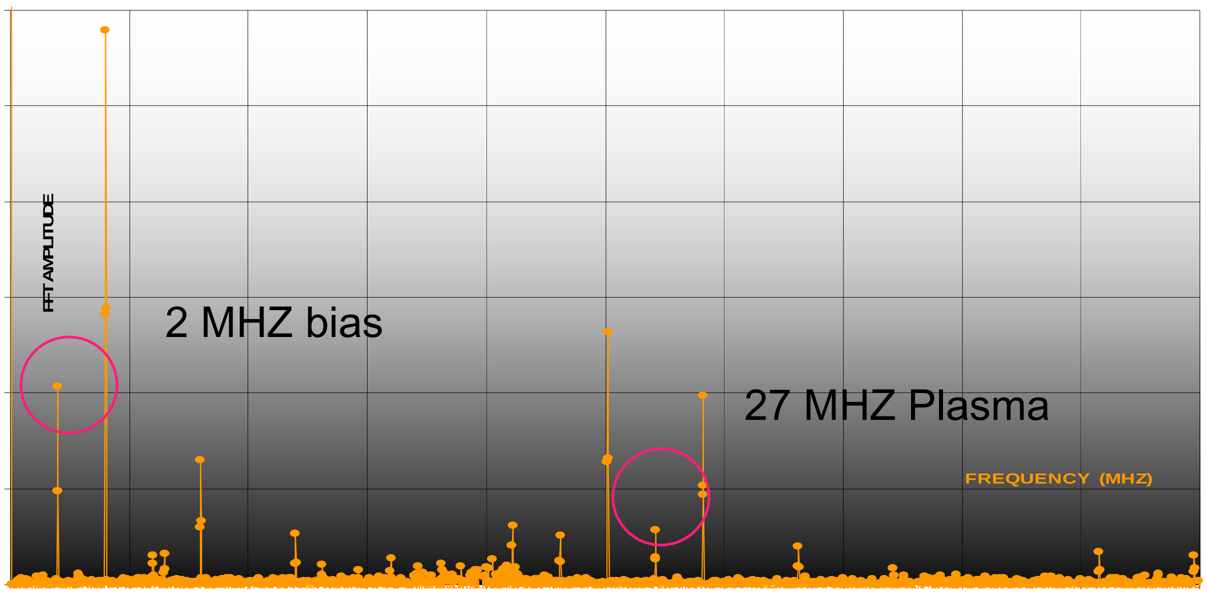
RAW vs STANDARD VIEW

RFOES R3



Raw Thru the Window
OES Signal:
The primary RF signal
can be seen with superposed
harmonics

Note: this trace is not
associated with the spectra below



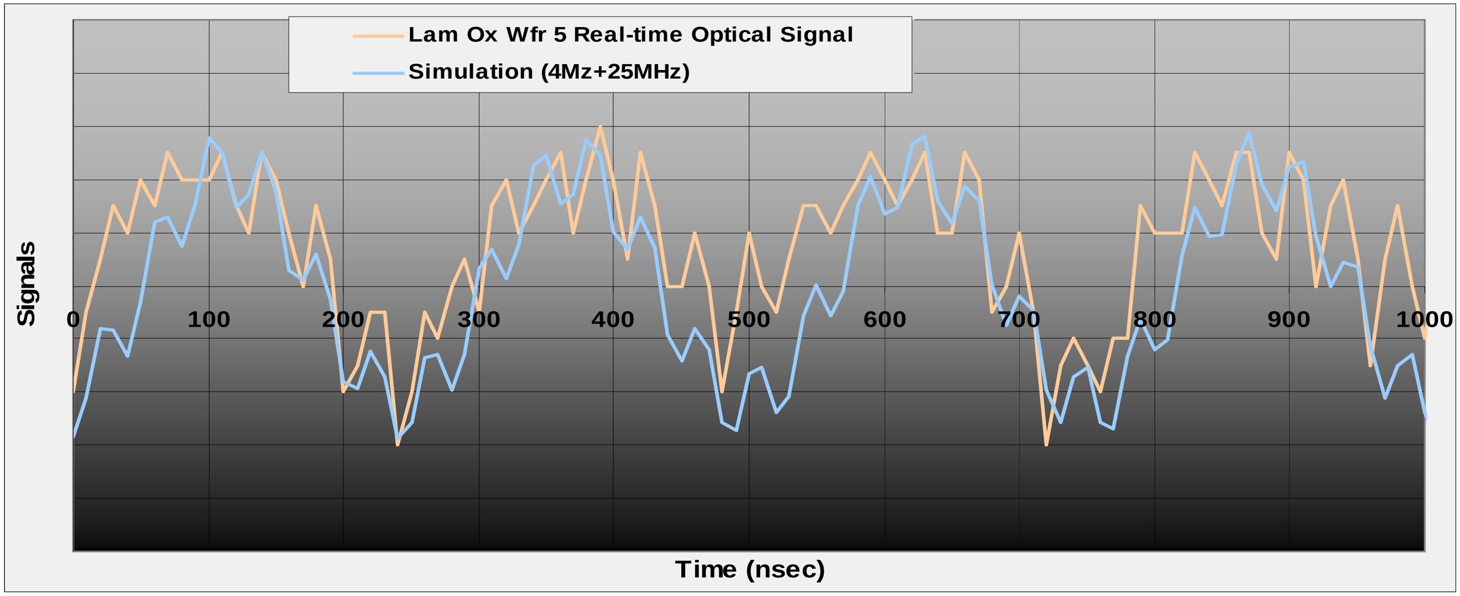
R3 Spectra for chamber with
2 RF inputs:

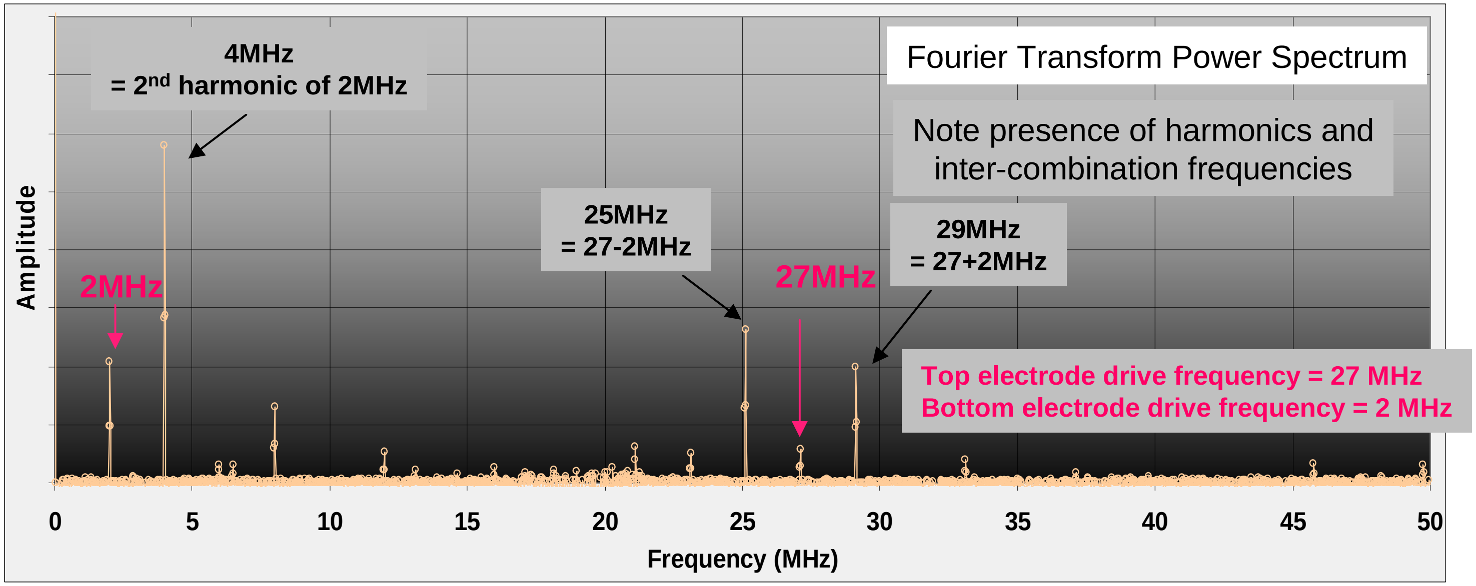
FFT of Raw Signal shows
the RF from both the Bias and
Plasma RF supplies as well
as their unique interaction
harmonics

LIGHTWIND

RAW AND SIMULATION vs STANDARD VIEW

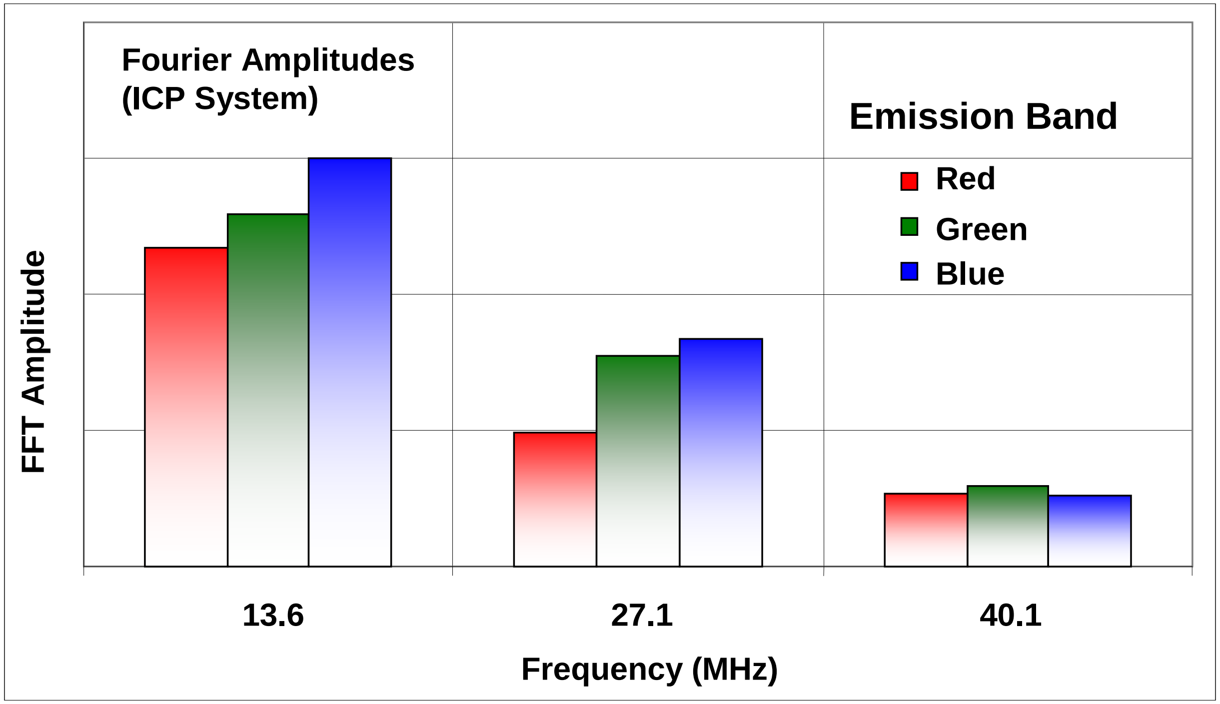
RFOES





LIGHTWIND

COMBINATION OF WAVELENGTH AND FREQUENCY

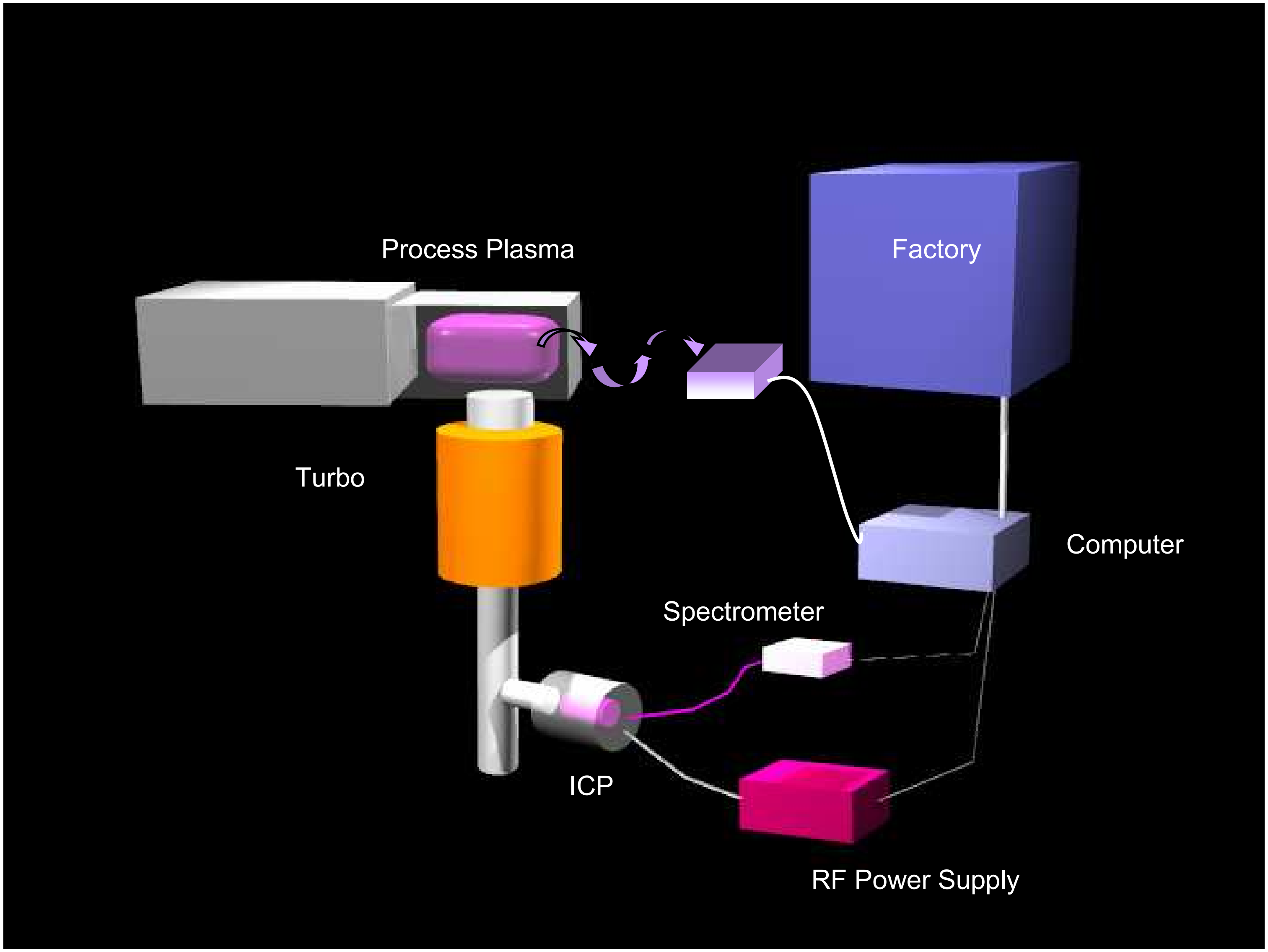


DETAILED COMPARISON WITH VI PROBE

RFOES R3

CHARACTERISTICS	RF OES	VI Probe
Detects Primary Frequency and Harmonics	Yes	Yes
Measures Applied Voltage	No	Yes
Violates RF path from Supply to Chamber	No	Yes
Monitors all rf supplies on chamber at same time or individually	Yes	No
Walk up sampling	Yes	No

LIGHTWIND


Process Plasma
Factory
Turbo
Computer
Spectrometer
ICP
RF Power Supply

PROCESS DIAGNOSTICS AND TROUBLESHOOTING

Module 1 Process Chemistry Only	ICPOES
Module 2 RF Separate from the Process Chemistry	RFOES
Module 3 Interactions of Tool RF and Chemistry	OES

BENEFIT:
COMBINATION OF RF AND OES PROVIDES COMPLETE PROCESS MAP
SUPPORTS INDEPENDENT TESTS OF PROCESS CHEMISTRY AND RF

APPLICATIONS:
PROCESS BASELINE/CHARACTERIZATION
CHAMBER MATCHING
TROUBLESHOOTING
PROCESS TRANSFER

LIGHTWIND

VARIATION IN ETCH

TEST VARIABLE	Parameter Change	ICP OES Sensitivity
Electrode Spacing Variation	Electrode gap	5 – 10 % change in gap
Process Chemistry	Pure gases no plasma required in process chamber	1% (1 sccm)
Pressure		4 to 5%
RF Power		4 to 5%

* *Oct 2-4, 2006 AEC/APC XVIII Symposium: David Dotan, Intel*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We would like to thank all the atoms and molecules that share their light with us

LIGHTWIND