Stable OES System for Fault Detection and Process Monitoring

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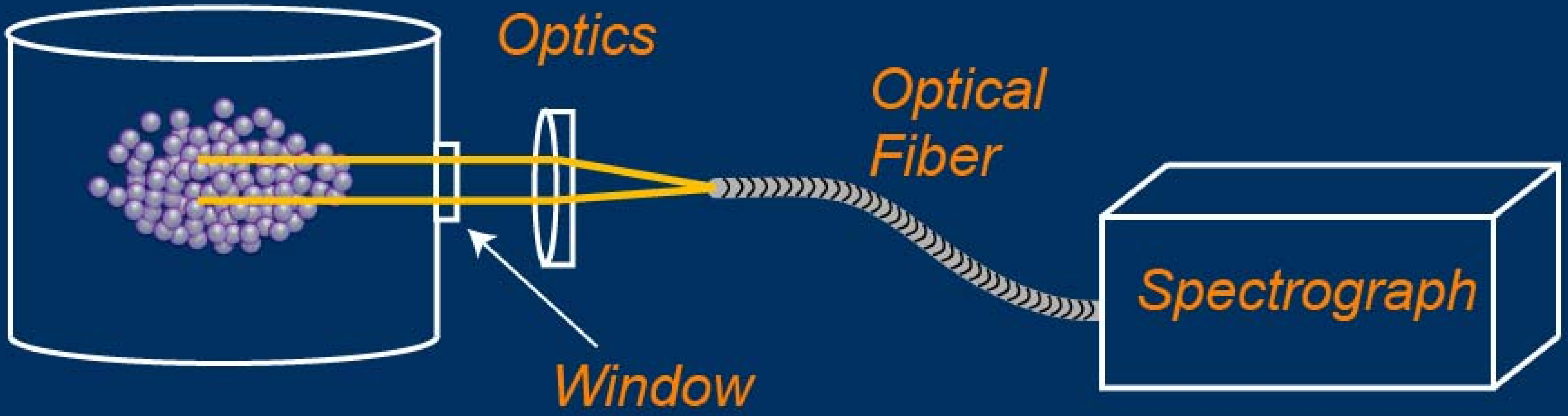
Motivation

- OES as tool for process monitoring, chamber matching[1], and fault detection[2]
- In order to detect changes in a plasma process, the entire measurement path must be stable
  - ΔSignal only arises from ΔPlasma
- Stability means
  - *Unit-to-unit* repeatability
  - Low *drift* over time

[1] – *ISMI Equipment Chamber Matching (ECM) Project*

[2] – *H. H. Yue et al., IEEE Trans. Semi. Manu., **13**, No. 3, Aug. 2000, Pg. 374-385*

Optical Systems for OES

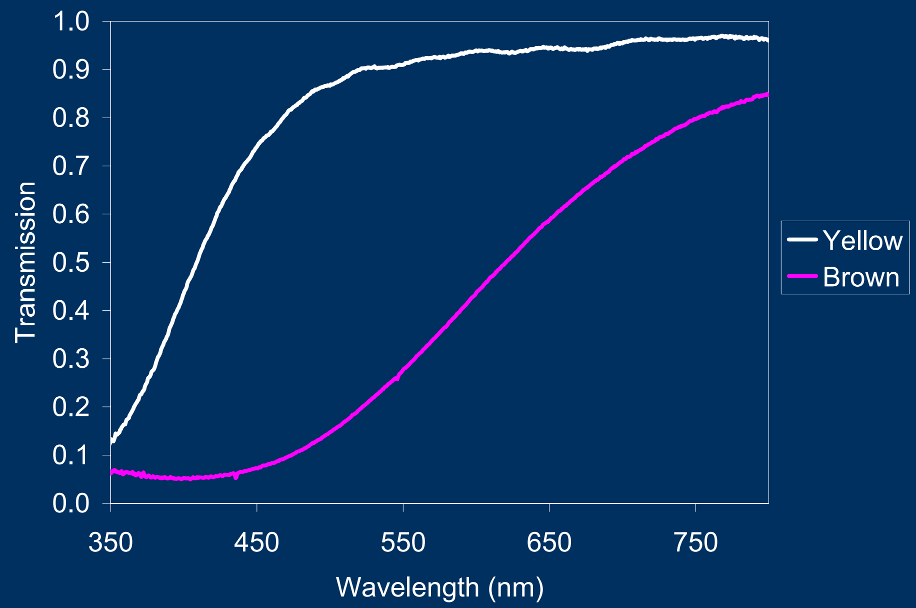


- Four primary sub-systems in OES path (window, optics, fiber, spectrograph)
- Each can impact *drift* and *unit-to-unit* variation

Chamber Coupling Optics

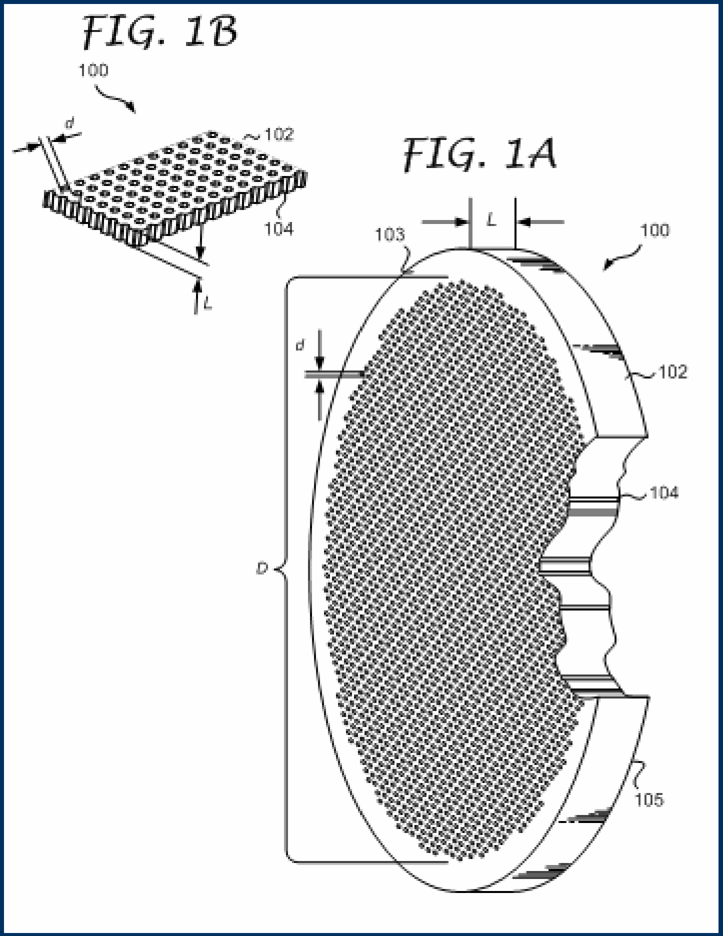
- Most common are direct (no lenses) and simple focusing lenses
- Mostly susceptible to *unit-to-unit* variations
  - Geometric alignments
  - Lens tolerances
  - Broadband AR coatings (if applicable)
- Specific to each installation

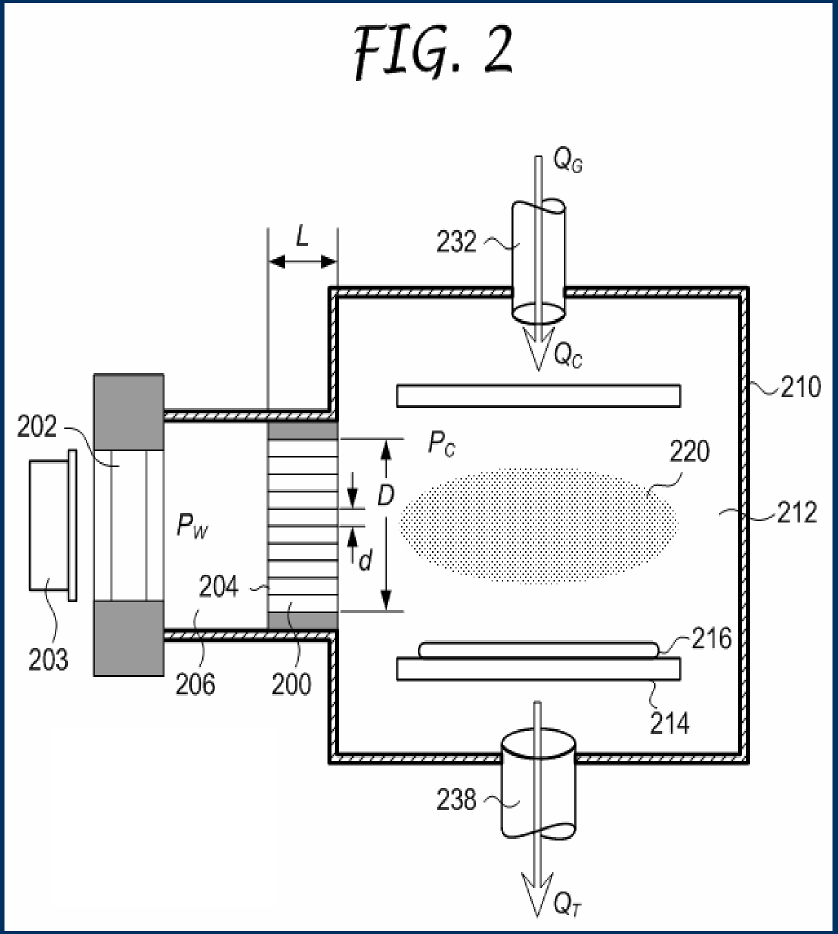
Window Transmission



- Re-deposition of particulate causes clouding → *drift*
- Depends on chamber geometry and process
- ΔTransmission/ΔTime can approach 20%/day

Robust Window Design





Robust Window Design*

- Solution is to combine
  - Multi-channel array
  - Positive pressure
- High optical transmission
- Low gas conductance means negligible gas flow into process chamber
- Utilizes existing (inert) process gases
- Virtual elimination of clouding means zero drift

** Patent pending*

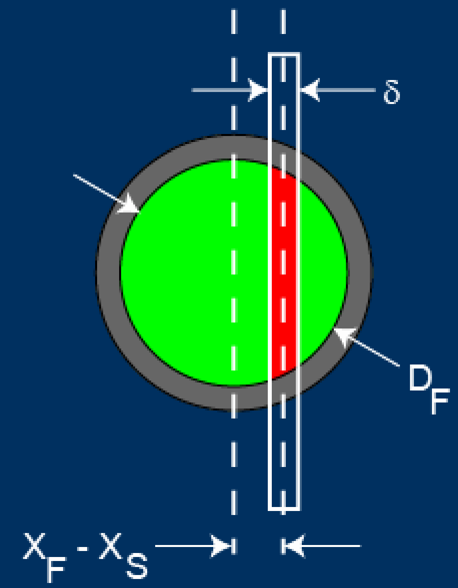
Optical Fibers

- Most convenient means to transfer signal from chamber to spectrograph
- Available with good transmission down to λ~193nm
- Subject to *drift* primarily from solarization in the UV
- And subject to *unit-to-unit* variation primarily from coupling geometry

Fiber-to-Spectrograph Coupling

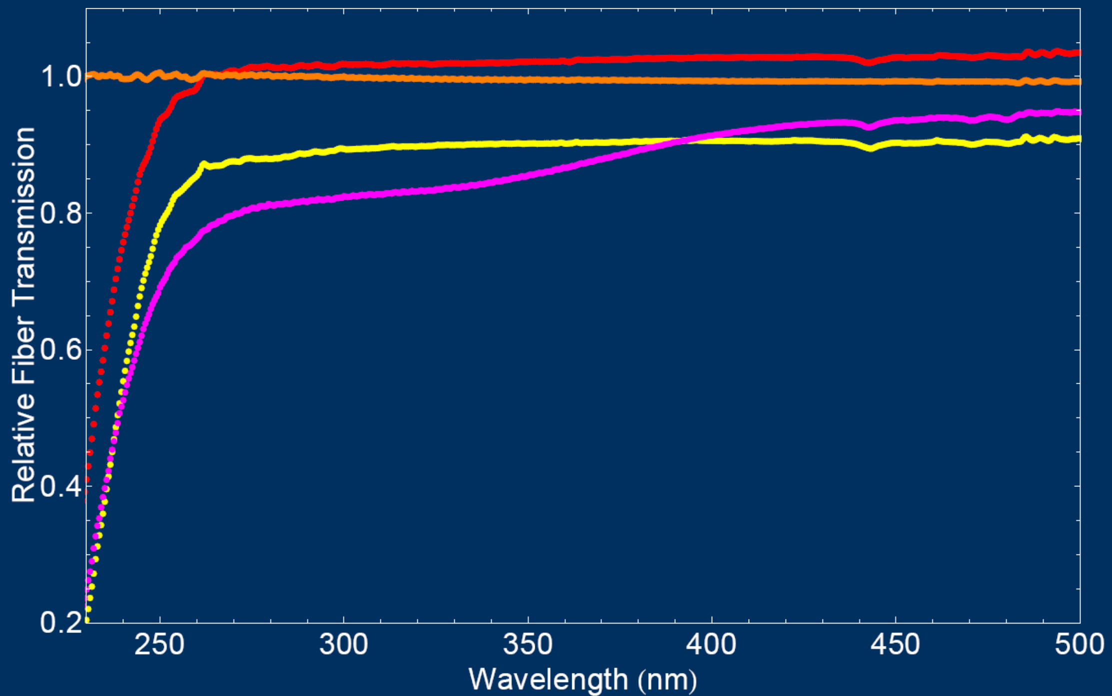
$$\text{Coupling} \approx I_0 \cdot \delta \cdot D_F \left[1 - \frac{2(X_F - X_S)^2}{D_F^2}\right] \cdot T(\lambda)$$

$$\begin{aligned} I_0 &= \text{Irradiance entering fiber in W/cm}^2 \\ \delta &= \text{Slit width} \\ D_F &= \text{Fiber core diameter} \\ X_F - X_S &= \text{Transverse offset from fiber to slit} \\ T(\lambda) &= \text{Transmission of fiber} \end{aligned}$$



- Red overlap region is signal collected by spectrograph ("Coupling")
- To lowest order coupling depends on transverse errors from slit to fiber core
- Verity's products minimize coupling variations

Variation Between Fibers



- Four different fibers measured relative to a (new) fifth
- D_F = 200μm, X_F - X_S = ±0.002" → ≈13% variation *unit-to-unit*
- Solarization gives rise to up to 80% *drift* variation in deep UV

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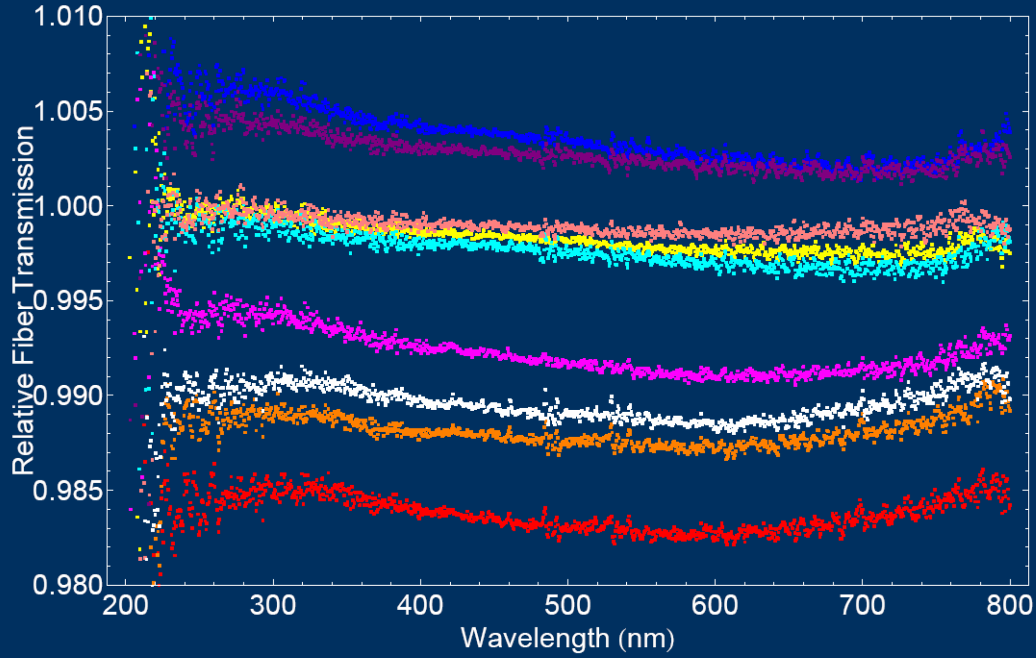
Repeatability of Single Fiber



- Take one fiber and measure multiple repeat installations
- Mechanical connection variations and bend losses create *unit-to-unit* variation
- "Worst" case is ~5% (primarily due to bend losses), and careful control limits this to under 2% (as shown)

Spectrographs

- *Unit-to-unit* variations
  - Calibration of λ
  - Sensitivity calibration
- *Drift* sources
  - Temperature
  - Vibrations
  - Component creep
- Verity spectrographs address each of these issues

Verity Spectrographs

- Product Design
  - Vibration isolation (SD1024F™ series)
  - Thermoelectric cooled CCD for low noise
  - Design refined through HALT testing iterations
  - Over 8 years installed base of OES solutions in fabs worldwide
- Precision calibration processes
  - NIST traceable sensitivity calibration
  - Wavelength accuracy <0.2nm
- Manufacturing processes
  - HASS testing to insure outgoing quality

Example: Gas Flow FDC

- Use model based control
- Partial Least Squares

$$
\begin{aligned}
\bar{Y} &= \bar{\bar{X}} \cdot \bar{b} \\
\bar{Y} &= \text{Vector of predictor variables} \\
\bar{\bar{X}} &= \text{Matrix of spectra} \\
\bar{b} &= \text{Vector with calibrated ``slopes''}
\end{aligned}
$$

- Compare sensitivity in stable OES link vs. one with *unit-to-unit* variations and *drift*

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O_2 Flow Simulation

Hardware	Actual O_2 Flow Rate (arb. units)	Predicted O_2 Flow Rate	Error	Average Error
Baseline	0.95	0.95	0%	
Baseline	1.00	1.01	1%	0%
Baseline	1.05	1.04	-1%	
New Fiber	0.95	0.98	3%	
New Fiber	1.00	1.03	3%	2%
New Fiber	1.05	1.05	0%	
Solarized Fiber	0.95	1.00	5%	
Solarized Fiber	1.00	1.06	6%	5%
Solarized Fiber	1.05	1.08	3%	
Yellow Window	0.95	1.97	107%	
Yellow Window	1.00	1.99	99%	99%
Yellow Window	1.05	1.99	90%	

- Accuracy of PLS model predictions of flow rate are impacted by unit-to-unit variation and drift

Conclusions

- The utility of an OES optical path can be increased by careful optical and mechanical design
- We have analyzed the sources of variation and shown how they can be controlled
- In critical OES applications, orders of magnitude sensitivity improvements can be made over “typical” installations