The Multivariate Optical Element Platform

Technology Overview

CIRTEMO™

What Does CIRTEMO™ Do?

CIRTEMO designs and manufactures patented optical filters, called Multivariate Optical Elements (MOE), which are encoded to detect/measure very complex chemical signatures/attributes.

33 Issued Patents and 9 Pending Patents

CIRTEMO™ Corporate Overview

- CIRTEMO was founded in December 2012 and is headquartered in Columbia, SC
- CIRTEMO designs and manufactures patented optical filters:
  - Called Multivariate Optical Elements (MOE)
  - Encoded to detect and measure complex chemical signatures or attributes.
- MOEs enable optical systems to
  - Detect and measure specific chemicals or attributes that cannot be achieved with traditional optical filters
  - Achieve better performances from optical components and systems
- CIRTEMO has 40+ patents around MOE technology platform
- CIRTEMO is partnering with
  - Optical Filter Manufacturers (OFMs)
  - Optical System Manufacturers (OSMs)

OMETRIC ™ → CIRTEMO™

- Patented optics platform called Multivariate Optical Computing (MOC) licensed from University of South Carolina
- OMETRIC Founded
- Successfully commercialized MOC in many markets-Chemicals, Pharma, Food, Mining, Oil and Gas
- OMETRIC sold to Halliburton in 2011 for $XXM
- CIRTEMO founded to commercialize MOC to all industries and applications outside of oil and gas
- New business model established to license technology to partners/customers
- Commercializing new markets/applications with partners /customers (eg. life science, and medical devices,)
- Establishing new Intellectual Property

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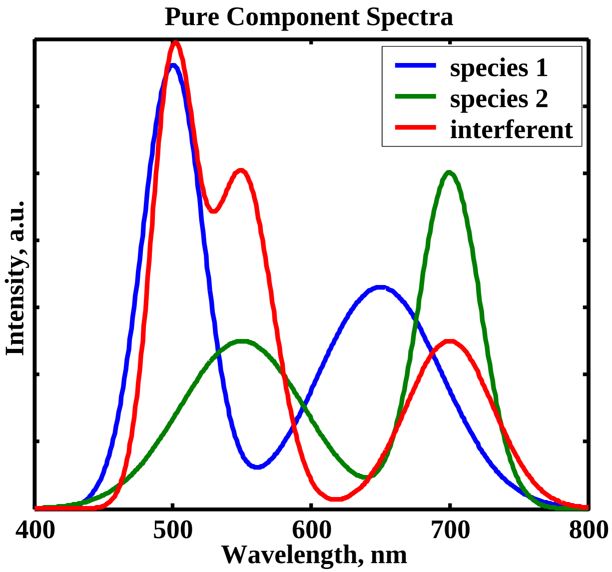
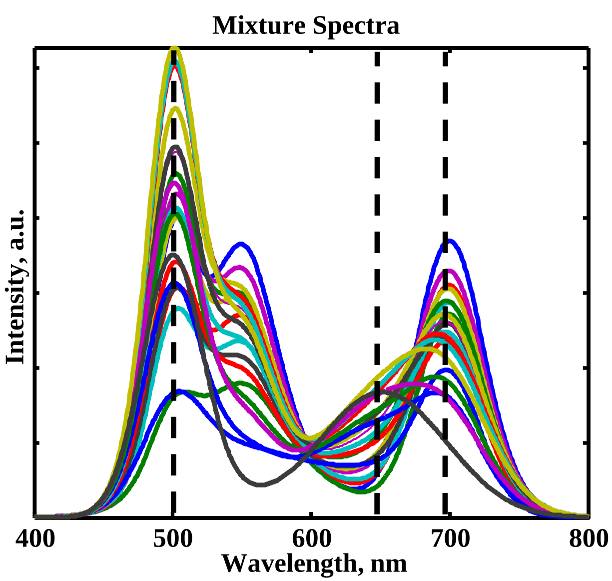
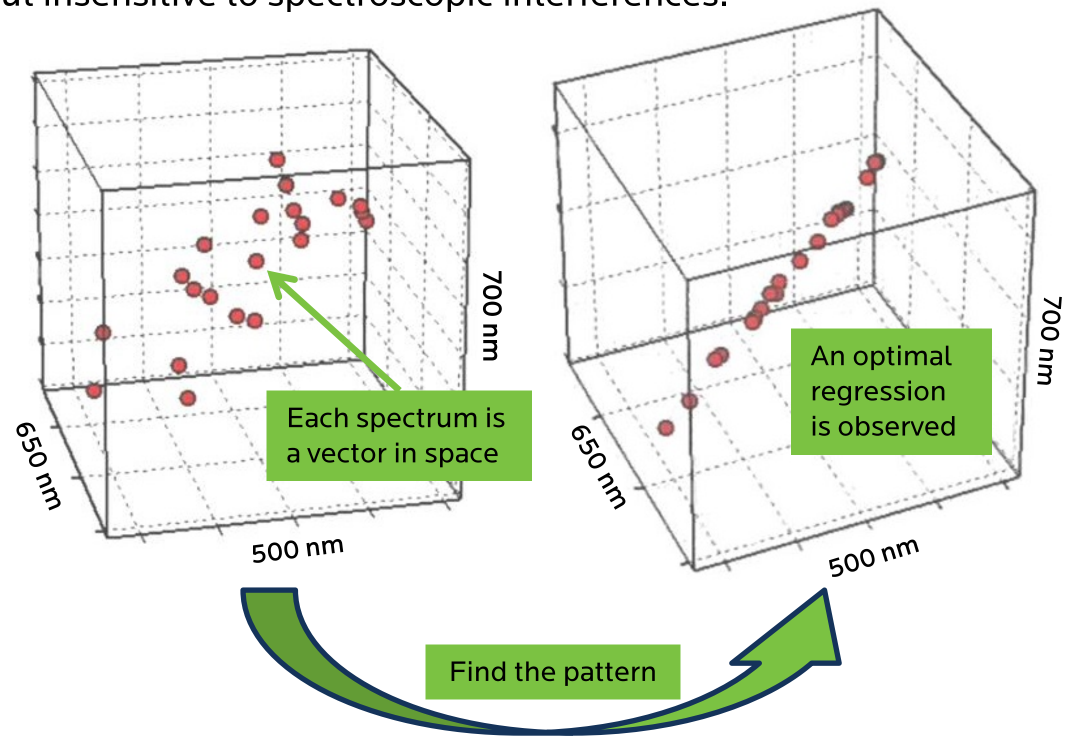
Optical Spectroscopy + Multivariate Calibration





- Optical spectroscopy is the study of the interaction between light and matter where each wavelength (or color) may provide insight into an unknown material's composition
- Multivariate calibration is the utilization of many variables in order to predict a chemical/physical property of interest (i.e. analyte concentration)
- In complex chemical systems, a number of wavelengths at least equal to the number of independent chemical species is required for a calibration
- A special direction (or spectroscopic pattern) exists inside the data set that is related to the chemical measurements of interest but insensitive to spectroscopic interferences.



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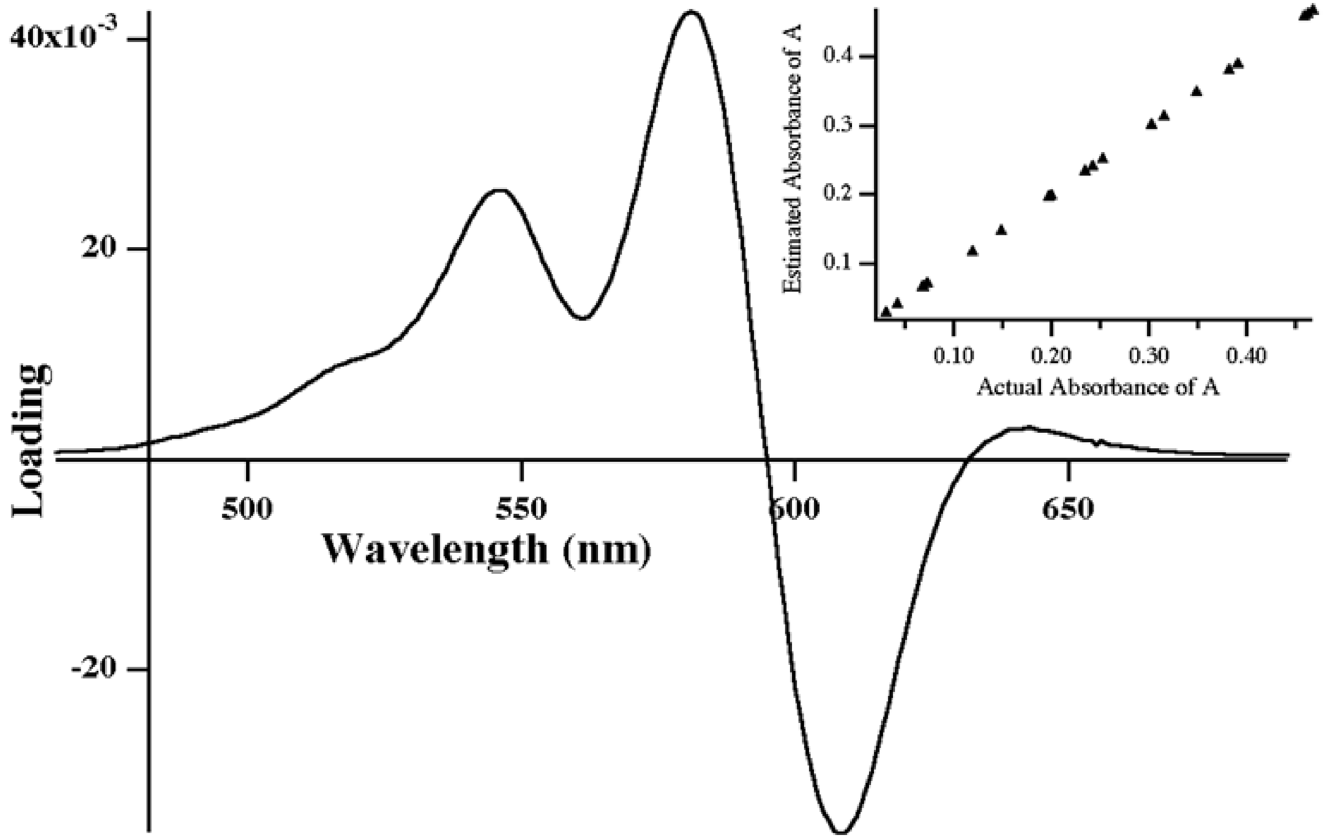
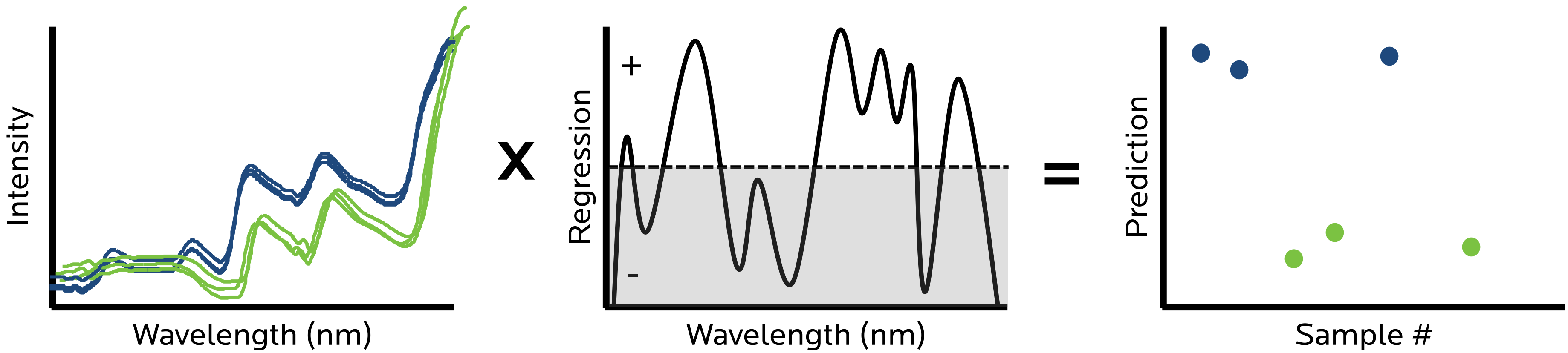
Finding the Optimal Spectral Pattern…



Recognizing spectral patterns allow us to develop weighted regression vectors thus converting optical spectra into chemical/physical properties of interest

Multivariate Optical Computing

- Chemometrics
  - is a method for modeling multivariate data (eg. optical spectra)
  - Model parameters can be applied to data from a spectrometer (or series of bandpass measurements) to estimate the composition of unknowns

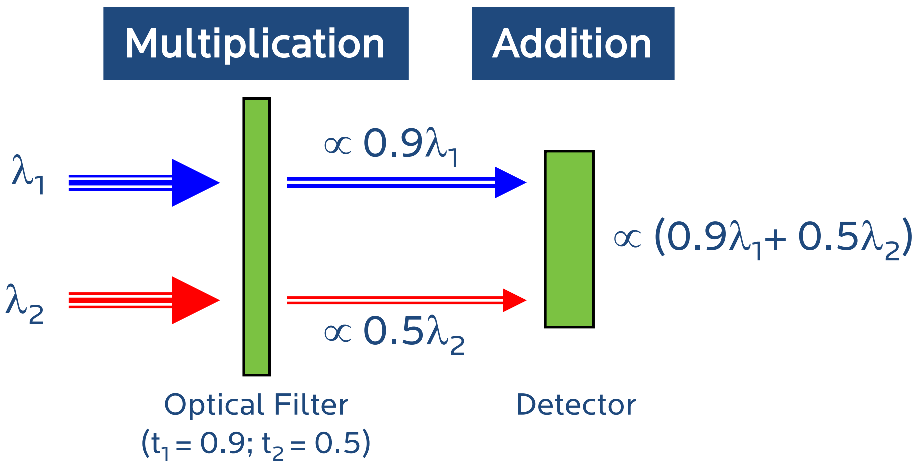


- Multivariate Optical Computing (MOC)
  - is an alternative method for modeling multivariate optical spectra
  - Is the optical equivalent of a dot product in which simple optical systems may achieve the sensitivity/specificity of a laboratory grade spectrometer.
  - is mostly achieved by refinement of optical interference filter structures that we call ***Multivariate Optical Elements (MOEs)***
  - MOEs can be installed in a photometer to estimate or predict the composition of unknowns.

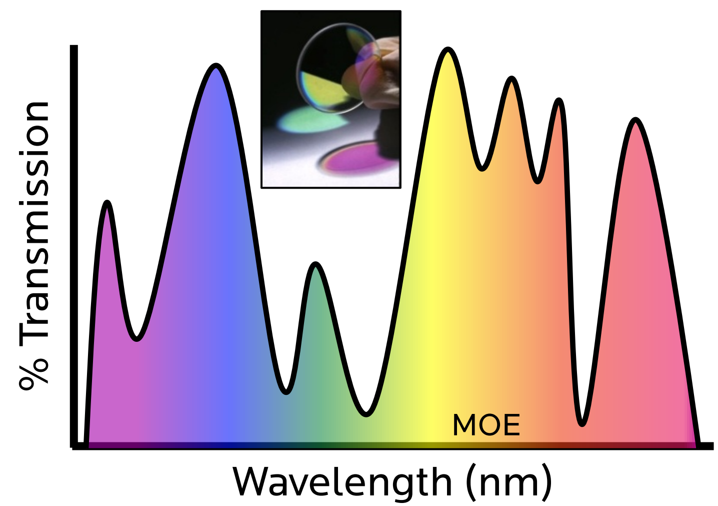
The Multivariate Optical Element (MOE) Platform

- Multivariate Optical Computing is the optical equivalent of a dot product
  - $\hat{y}$ - estimated analytical property (eg. concentration)
  - t - scaled regression vector
  - λ - analytical spectroscopic response (eg. SWIR spectrum)

$$\hat{y} = \boldsymbol{t} \cdot \lambda = \sum_{i}^{N} t_i \cdot \lambda_i$$



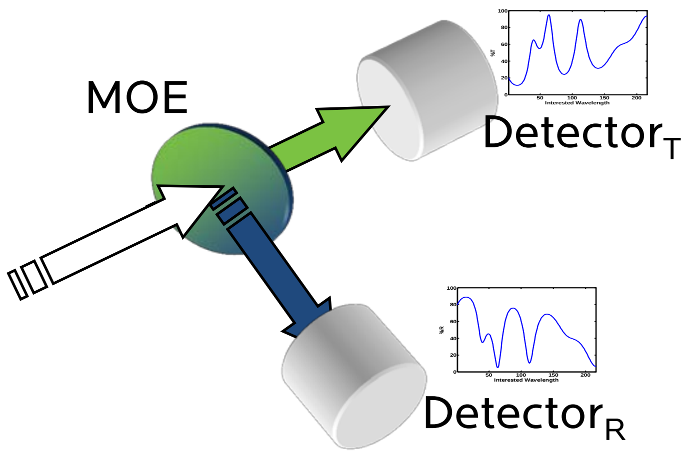
- Multivariate Optical Elements (MOEs)
  - are patented, wide-band, optical interference filters encoded with an application-specific regression (or pattern) to detect/measure complex chemical signatures.
  - realize the measurement advantages of Multivariate Optical Computing (MOC)
  - enable a filter based instrument to achieve the sensitivity/specificity of a laboratory spectrometer as well as convert a focal plane array into a real-time hyperspectral imager.



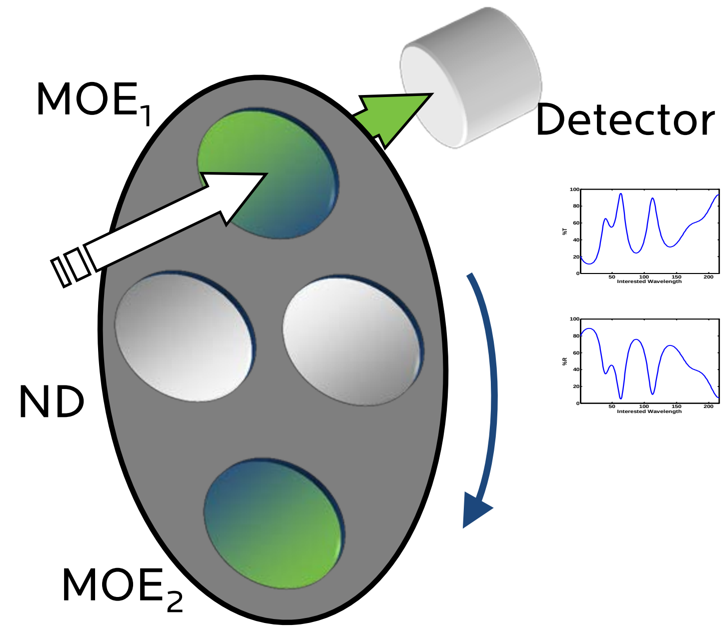
M.P. Nelson, J.F. Aust, J.A. Dobrowolski, P.G. Verly and M.L. Myrick "**Multivariate Optical Computation for Predictive Spectroscopy** " Anal. Chem. **70**, 73-82 (1998).

The Multivariate Optical Element (MOE) Platform

Beamsplitter Configuration



Filter Photometer Configuration



Snapshot Array Configuration

$A_{1,1}$	$B_{1,1}$	$C_{1,1}$	$A_{1,2}$	$B_{1,2}$	$C_{1,2}$
$D_{1,1}$	$E_{1,1}$	$F_{1,1}$	$D_{1,2}$	$E_{1,2}$	$F_{1,2}$
$G_{1,1}$	$H_{1,1}$	$I_{1,1}$	$G_{1,2}$	$H_{1,2}$	$I_{1,2}$
$A_{2,1}$	$B_{2,1}$	$C_{2,1}$	$A_{2,2}$	$B_{2,2}$	$C_{2,2}$
$D_{2,1}$	$E_{2,1}$	$F_{2,1}$	$D_{2,2}$	$E_{2,2}$	$F_{2,2}$
$G_{2,1}$	$H_{2,1}$	$I_{2,1}$	$G_{2,2}$	$H_{2,2}$	$I_{2,2}$

MOEs can be incorporated into optical systems in a variety of ways

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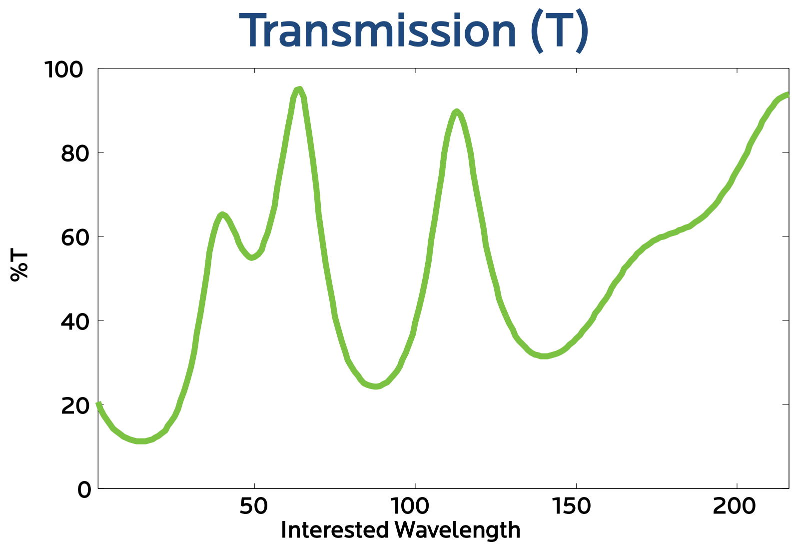
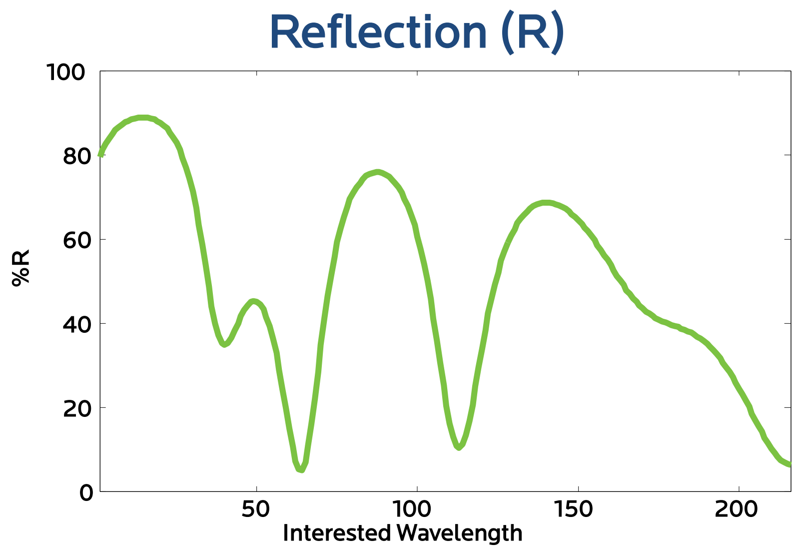
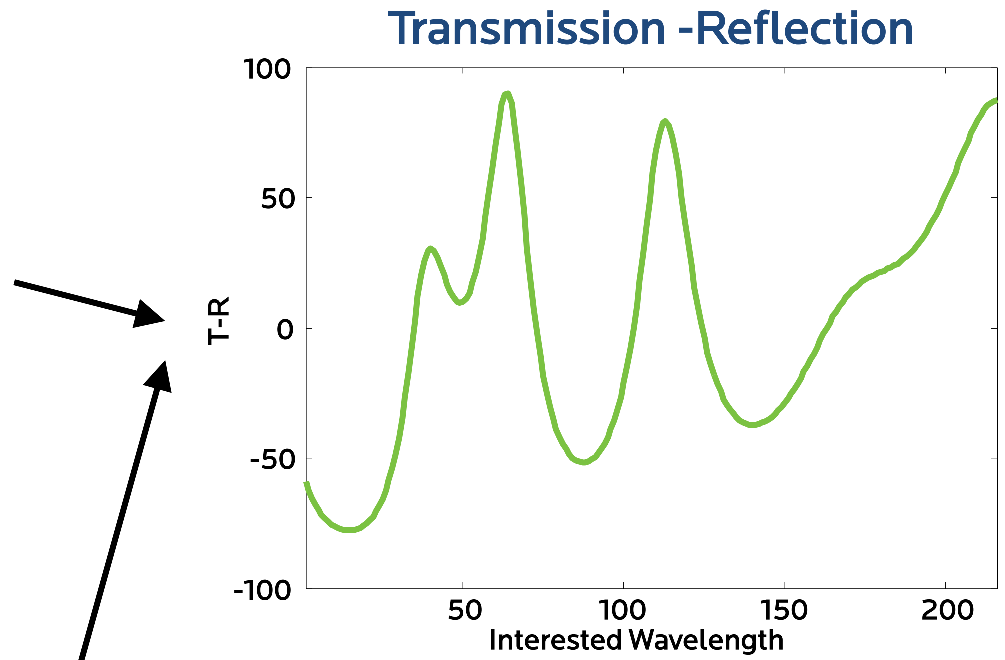
Example Spectral Regression Encoding with an MOE







A multivariate spectral regression may be constructed by utilizing the transmission & reflection profiles of the MOE

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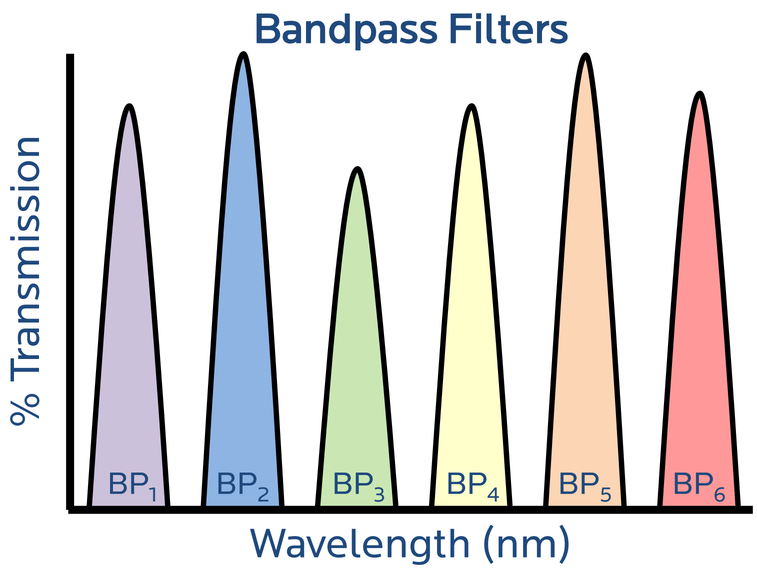
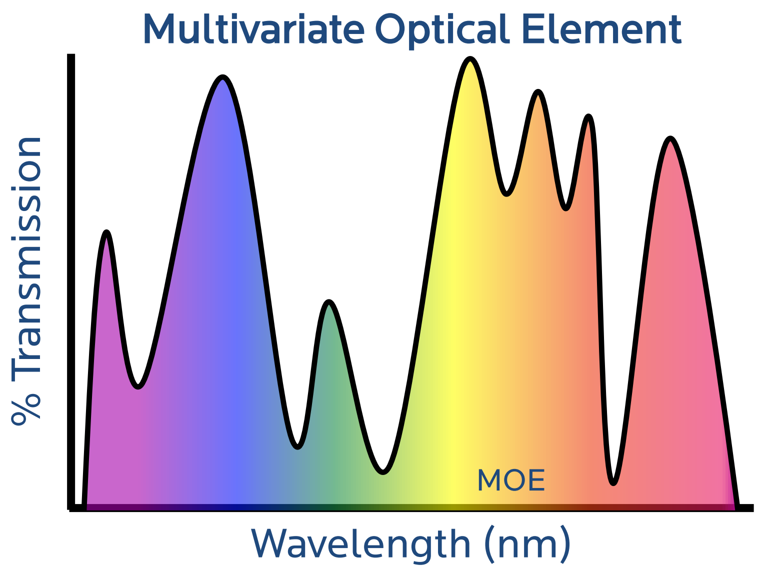
Multivariate Optical Elements vs. Bandpass Filters

- Multivariate Optical Elements (MOE) are not bandpass (BP) filters
  - MOEs possess a higher overall throughput than individual BP filters yielding a higher analyte sensitivity based on superior SNR
  - MOEs sample more spectral wavelengths than discrete BP filters yielding a higher analyte specificity
  - MOEs are physically less complex than BP filters
- MOEs tend to exhibit fewer layers and overall filter thicknesses less than traditional band pass filters.
  - Unlike well defined quarter wave optical thickness (QWOT) deposition recipes used for BP filter fabrication, there are multiple MOE solutions possible for any application
  - Optimal MOE designs are selected based on a set of performance criteria inclusive of overall physical thickness and number of layers
- MOEs are fabricated via the same methods as traditional BP filters





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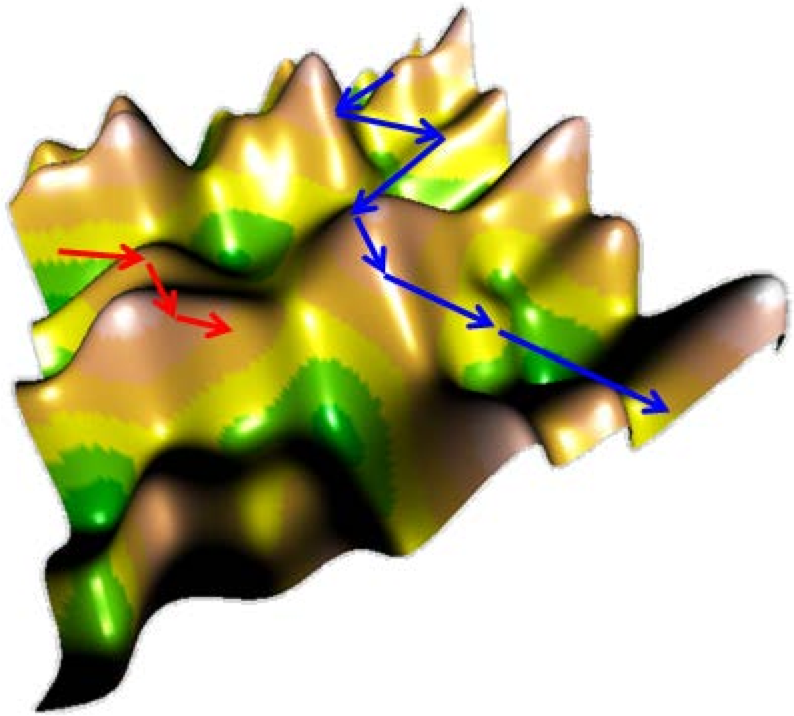
Multivariate Optical Element Features & Benefits

Feature	Benefit(s)
• Higher **sensitivity** than traditional bandpass filters	• Pure optical amplification of analyte signal permits lower detection limits
• Higher **specificity** than traditional bandpass filters	• Reduced crosstalk • Multiplexing opportunities (more analytes can be detected simultaneously) in complex mixtures
• Higher **signal-to-noise** ratio measurement than traditional narrow bandpass filters	• Less sample material (smaller volume) can be used • Less expensive/powerful subcomponents may be used
• Measurement **flexibility**	• Environmental interference compensation may be rolled up into the MOE design

Multivariate Optical Elements can increase the sensitivity and specificity of analyte detection compared to bandpass filters.

Designing a Multivariate Optical Element (MOE)

- Traditional chemometric modeling identifies and exploits the variance within spectral (and reference) data to correlate with a feature/analyte of interest
- A definitive model is achieved most often by deconvolving the spectroscopic data into a projection in N-dimensional space (i.e. score)
- An MOE is designed through an iterative, non-linear optimization routine.
  - A local minimum response is achieved based upon a random starting point
  - a Newton-Raphson nonlinear optimization method is typically employed



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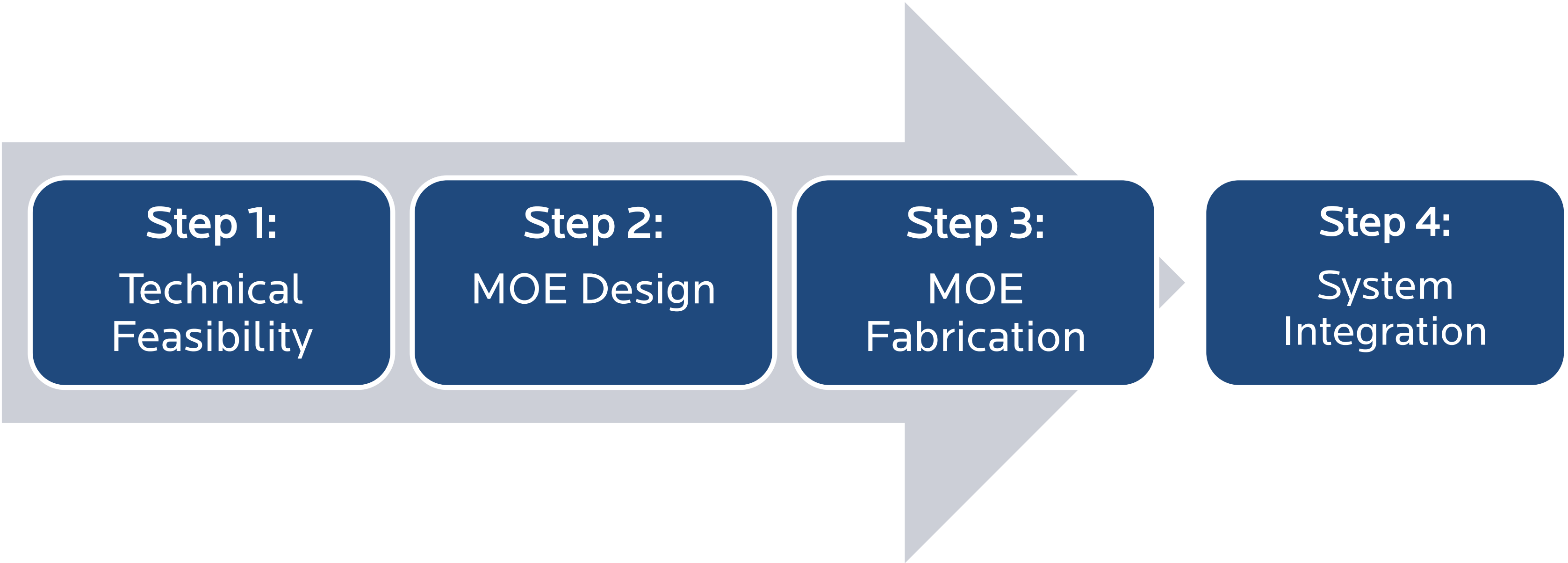
Working with CIRTEMO



- CIRTEMO can determine via modeling whether or not an MOE can provide value before fabricating actual filters
- Although we have had commercial success in a range of industries, each application is unique

- Step 1: Technical Feasibility
  - Collection of spectroscopic calibration data
  - Convolution of radiometric data
- Step 2: MOE Design
  - Determination of spectral shapes
  - Optimize optical filter recipe
- Step 3: MOE Fabrication
  - Traditional hard coating deposition (eg. RMS, IBD, etc.)

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For more information:

Visit us at www.cirtemo.com
Drop us a line at info@cirtemo.com

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