The Multivariate Optical Element Platform

Technology Overview
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)

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OMETRIC™

OMETRIC Founded
OMETRIC sold to Halliburton in 2011 for $XXM
New business model established to license technology to partners/customers
Establishing new Intellectual Property

CIRTEMO™

Patented optics platform called Multivariate Optical Computing (MOC) licensed from University of South Carolina
Successfully commercialized MOC in many markets-Chemicals, Pharma, Food, Mining, Oil and Gas
CIRTEMO founded to commercialize MOC to all industries and applications outside of oil and gas
Commercializing new markets/applications with partners/customers (eg. life science, and medical devices,)

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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.
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 (e.g., 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
  - \( \lambda \) - analytical spectroscopic response (eg. SWIR spectrum)

\[
\hat{y} = t \cdot \lambda = \sum_{i=1}^{N} t_i \cdot \lambda_i
\]

- 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.

The Multivariate Optical Element (MOE) Platform

MOEs can be incorporated into optical systems in a variety of ways.
Example Spectral Regression Encoding with an MOE

A multivariate spectral regression may be constructed by utilizing the transmission & reflection profiles of the MOE.
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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<th>Feature</th>
<th>Benefit(s)</th>
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<td>Higher <strong>sensitivity</strong> than traditional bandpass filters</td>
<td>• Pure optical amplification of analyte signal permits lower detection limits</td>
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| 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
• 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.)
For more information:

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