WHITE PAPER

MINIATURIZED HYPERSPECTRAL CAMERA FOR THE INFRARED MOLECULAR FINGERPRINT REGION

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Low-cost infrared fingerprint region imaging spectroscopy now made possible

The world of spectroscopy is currently undergoing a revolution due to the convergence of several microelectromechanical "MEMS" based technologies. The integration of MEMS microbolometer arrays with MEMS scanning Fabry-Pérot interferometers and miniaturized imaging lenses are enabling the creation of small, low-cost hyperspectral imaging instruments that can work in the infrared "fingerprint" region of the electromagnetic spectrum. Until now, this has mostly been the domain of large, expensive Fourier Transform Interferometer (FTIR) based instrumentation. These instruments are typically confined to laboratory environments and operated by trained specialists. The emergence of smaller, low-cost imaging spectrometers will greatly diminish the barrier to entry for these devices, enabling a more widespread adoption of these technologies outside the laboratory. Subsequently, the development of a host of new applications is envisioned in fields such as agriculture and food quality, advanced manufacturing, biomedical, defense and security.

Why the fingerprint region?

Currently available electromagnetic sources, spectral dispersion devices and detectors have enabled the development of low-cost portable spectrometer devices in the Visible to Near-infrared part of the electromagnetic spectrum. Although some applications have been reported, organic component identification in this region of the electromagnetic spectrum is very challenging because it corresponds to the overtone bands of molecular stretching vibration energy levels. As a result, the spectral features from organic compounds in this region are often indistinct and it is difficult to accurately discriminate the individual constituents of a complex mixture. The ideal way to accurately identify the components of a sample is rather by spectroscopy in the so-called "fingerprint" region of the electromagnetic spectrum, where the fundamental molecular energy bands are located. The fingerprint region lies between approximately 7 µm and 20 µm (500 cm^{-1} to 1450 cm^{-1}) referred to as Mid-InfraRed (MIR), and is so called because, like a human fingerprint, given compounds will have almost unique spectral lines. Figure 1 illustrates this specificity, by showing how distinct the absorption features for a typical organic compound are in the fingerprint region, as opposed to the near-infrared overtone region shown on the left of the figure.

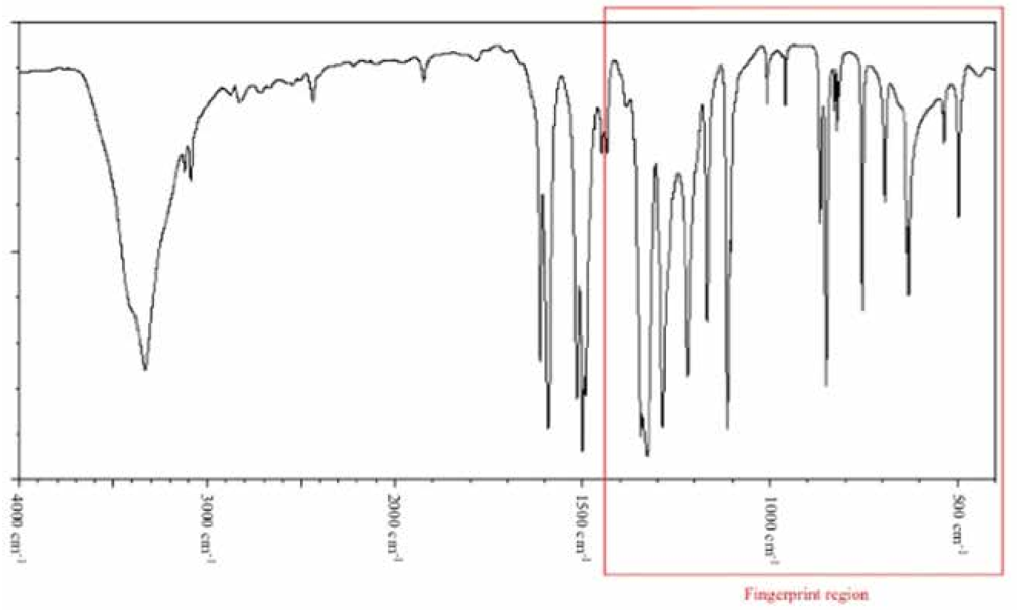


Figure 1: The fingerprint region
Source: www.chem.ucla.edu

The advantages of imaging

The accuracy of a spectral measurement is largely dependent on the performance specifications of the spectrometer instrument. Notably, a high signal-to-noise ratio and a sufficient spectral resolution and range are essential to accurately determine the composition of a sample. But that is not the whole story: often the limiting factor in performing sample compound identification by spectroscopic means is sample homogeneity. For a single point (i.e. non-imaging) spectrometer, this means that the entire area being sampled must be composed of a uniform sample, otherwise different spectra from neighbouring compounds can confuse the resulting measurement. Obtaining a spectral image over the sample area is a way of avoiding this problem. In the fingerprint region, this is currently typically performed with laboratory FTIR instruments, equipped with expensive cooled infrared detector arrays and imaging accessories. However, aside from being bulky and expensive, these imaging-enabled FTIR instruments only enable imaging over a small surface area, on the order of a square millimeter. A spectral imaging instrument capable of imaging over a larger sample area, i.e. macro imaging, could prove very attractive. For example, it would allow for a higher throughput in industrial or food quality surface inspection applications by simultaneous characterization of an array of samples.

Why INO?

Founded in 1988 and based in Quebec City, Canada, INO is a technology transfer and contract R&D organization offering a complete range of integrated services in all fields of optics and photonics. Its 200 employees constitute the largest concentration of skills in this area in Canada. INO has clients of all sizes across Canada and the world, and has a successful track record of completed R&D contracts (more than 6,000), patents (264), technology transfers (70) and spin-off companies (33) as of January, 2018.

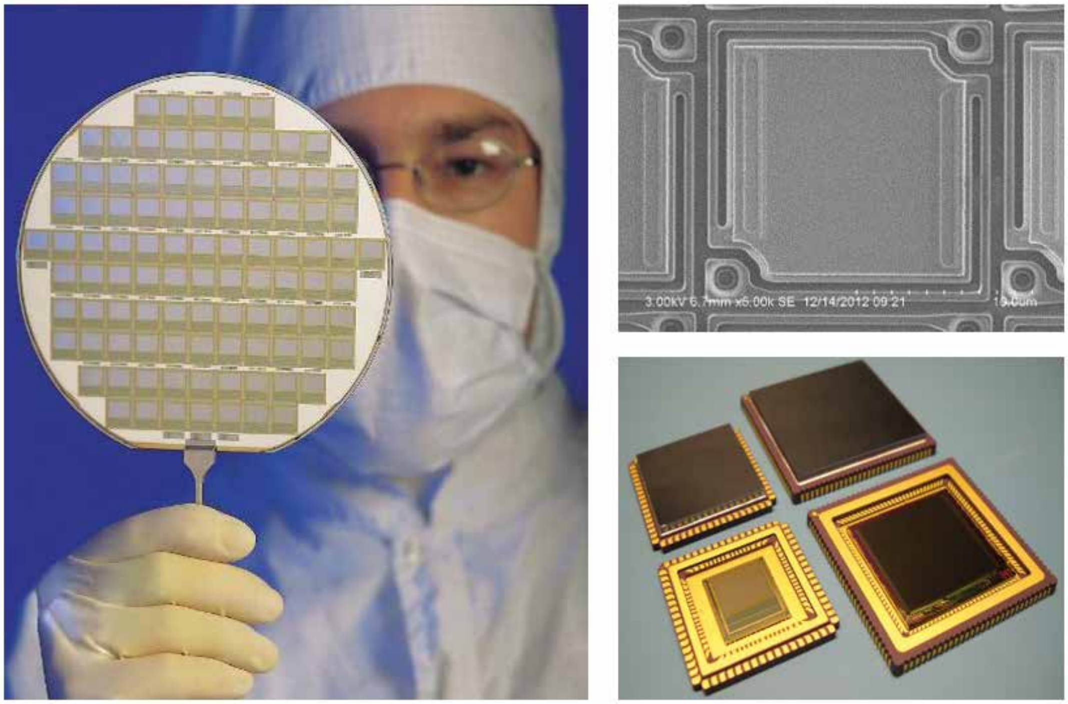


Figure 2: Microbolometer development at INO. Left: Silicon wafer containing the readout circuits that form the base of the microbolometer arrays; Upper-right: Microscope image of an INO-designed and fabricated individual bolometer pixel; Bottom-right: INO-assembled and vacuum-sealed microbolometer array detectors

Because of its background in MEMS development, INO is well-positioned to develop leading edge miniature imaging spectrometer instruments operating in the infrared fingerprint spectral region. This is largely due to INO's position as a world leader in the development of microbolometer sensors. In comparison with the cooled infrared imaging arrays used in FTIR instruments, microbolometer sensors are uncooled, small and inexpensive, making them an ideal choice for miniaturized, low-cost infrared spectral imaging systems. Furthermore, INO has developed a process for deposition of a gold-black broadband absorber over the microbolometer array's pixels. The gold black absorber enhances the bolometer's absorbance, and hence its sensitivity, by a factor of 2 in comparison with standard bolometer absorbance. The gold-black absorber also allows for an unprecedented large wavelength absorption range: from the visible to the terahertz region of the electromagnetic spectrum.

In addition to microbolometer sensor development, INO has also perfected heterogeneous assembly and packaging techniques, and has an experienced opto-mechanical design team capable of designing, manufacturing and assembling high precision optical systems. INO also has the capacity and expertise for small-scale production of products. This combination of expertise makes INO a "one-stop shop" for the design, manufacture, assembly and test of opto-mechanical instruments of all kinds.

Introducing INO's Imaging Spectrometer development kit

Building on its strengths in ultra-broad wavelength band microbolometer sensor technology, INO has recently developed a miniaturized spectral imaging camera specifically designed for the infrared fingerprint region (figure 3). At the heart of this system is INO's 384x288 pixel microbolometer array with gold-black absorber, enabling high sensitivity imaging of all infrared wavelengths. This sensor is plugged into an INO MICROXCAM camera core. This microbolometer sensor is coupled to a MEMS scanning Fabry-Pérot interferometer (FPI) and a miniature imaging lens to enable spectral imaging over the free spectral range of the FPI. The FPI + lens assembly is a modular system, shown as the black component attached to the front of the metallic-colored MICROXCAM camera core. The FPI + lens module can be easily swapped for another one with a different FPI, allowing for a different spectral range while keeping the camera core module the same.

The baseline configuration, designed for fingerprint region spectroscopy, has a spectral range of 8 to 11 µm, with a spectral resolution ranging from 130 nm at 8 µm to 220 nm at 11 µm. Different FPI modules operating at lower wavelengths, in the 3.8-5.0 µm range are also available. If warranted by a particular application, it is also possible to fabricate FPIs at other infrared spectral wavelengths.

Figure 3: INOs MICROXCAM-384i-HS spectral imaging camera

INO has devised a development kit for the MICROXCAM-384i-HS imaging spectrometer, to make it easy for end-users to develop and test infrared imaging applications. In addition to the spectral imaging camera, the development kit includes as an option an infrared source and a sample holder designed to allow users to perform reflectance-mode spectral imaging measurements. In the proposed development kit configuration (figure 4), a hot source provides illumination over a 1.5-inch diameter area of the sample. With the camera at a distance of 80 mm from the sample, this corresponds to a 40 pixels diameter image, with each pixel corresponding to a 0.9 mm spatial resolution at the sample. Hence, the system can measure “macro”-size spectral images, unlike the small sample imaging areas currently provided by imaging FTIR systems. This could prove very useful in applications such as impurity detection. Under typical operating conditions, a signal to noise ratio close to 1280 is achieved with this system.

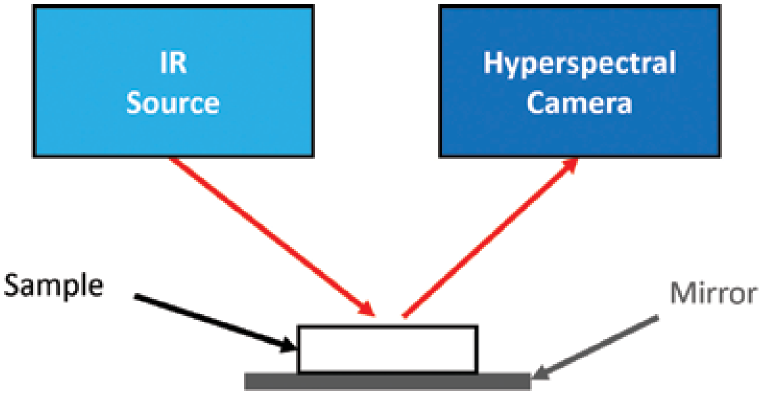
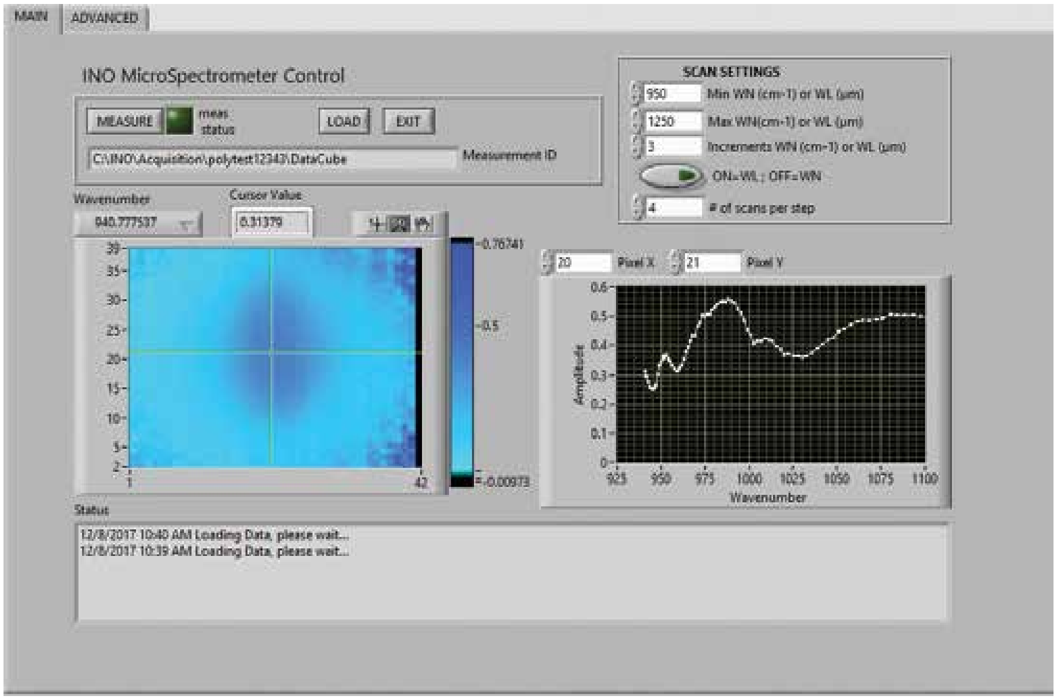


Figure 4: Development kit camera-source-sample configuration for reflectance mode spectral imaging measurements

The LabVIEW-based, user friendly software allows to visualize IR images and spectra at selected locations (figure 5). Spectral measurement datacubes are saved in a user-friendly text file format, allowing them to be easily imported by spectral analysis software.



INO MicroSpectrometer Control

Measurement ID: C:\INO\Acquisition\polytest12343\DataCube

Wavenumber: 940.777537

Cursor Value: 0.31379

SCAN SETTINGS

950 Min WN (cm-1) or WL (µm)
1250 Max WN(cm-1) or WL (µm)
3 Increments WN (cm-1) or WL (µm)
ON=WL ; OFF=WN
4 # of scans per step

20 Pixel X
21 Pixel Y

Status

```
12/8/2017 10:40 AM Loading Data, please wait...
12/8/2017 10:39 AM Loading Data, please wait...
```

Figure 5: Screenshot of the software

To perform a measurement, a reference spectral image of a mirror is first obtained, then the sample to test is placed over the mirror and a second spectral image is obtained. The sample's spectral reflectance is then obtained by dividing the two spectral images. The total time to perform a measurement depends on the number of spectral points to scan and how much averaging to perform, but typically does not exceed 3 minutes.

Key Advantages

The MIR hyperspectral camera platform developed by INO is offered as an application development kit and intended for customers who wish to develop their own specific applications. To that end, key features have been implemented. First, it includes an interchangeable optical module in which different Fabry-Pérot interferometers covering the range from 3-11 µm can be inserted. Second, spectral measurement datacubes are saved in a user-friendly text file format, allowing them to be easily imported by spectral analysis software. Third, source modules can be optionally included to provide a complete turn-key system for application development. Finally, INO's vision is to maintain strong ties with the developer community and eventually support custom product development based on its platform.

Applications

MIR hyperspectral imaging will find a wealth of applications in markets such as defense and security, advanced manufacturing, biomedical or environment and natural resources. The figure below (Figure 6) illustrates a potential application in food counterfeiting namely the discrimination between pure maple syrup, corn syrup and molasses. Images and IR spectra (transflectance) were recorded from thin layers of these liquid sugars deposited onto a gold-coated glass slide.

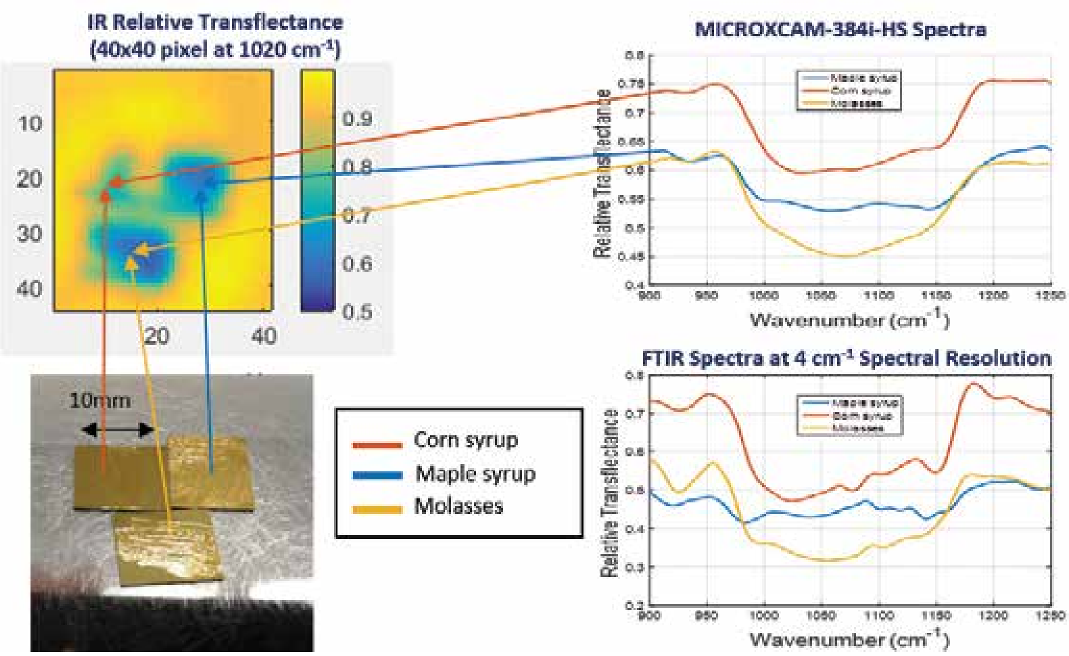


Figure 6: Simultaneous IR spectral transflectance imaging of maple syrup, corn syrup and molasses

Microxcam-384i-HS

MIR Hyperspectral Camera

Preliminary Technical Specifications[1]			
Spectral range	8 – 11 µm	5.5– 8 µm	(a) 3.8 – 5 µm (b) 3.1-4.4 µm
Spectral resolution	Typ: 130-220 nm	Typ. 100 nm-130 nm	(a) Typ. 60 nm-75 nm (b) Typ. 55 nm- 70 nm
Field of View	±41° (100 pixel diameter image) [2]		
Focal length	3 mm		
Aperture	2 mm x 2 mm		
Detector	• 384 x 288 pixels blackened VOx uncooled microbolometer FPA • 35 µm pixel pitch • 2 to 14 µm uniform responsivity • NEP = 20 pW • NETD = 25mK, 8 - 12 µm, 300K, F/1, 50 fps		
NESR (mW/ m² sr µm)	• 800 at 8 µm • 830 at 9 µm • 690 at 10 µm	In development	In development
SNR	1 280 (Blackbody source at 1 000 °C)	In development	In development
Camera frame rate	50 fps		
Acquisition time	• 0.18 s per wavelength sample (SNR = 1000) • <3 min (full spectral range, 25 nm sampling, SNR = 1000)	In development	In development
Video outpout	Gigabit Ethernet, RJ-45 connector		
Supply	24 Vdc Nominal		
Temperature	15 °C to 35 °C		
Power	< 7 W typical		
Mechanical Characteristics			
Dimensions	61 mm (H) x 78.5 mm (W) x 101 mm (L) 2.4 in. (H) x 3.1 in. (W) x 3.98 in. (L)		
Weight	420 g / 0.93 lb		

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[1] Specifications subject to change without notice.

[2] Determined by the Fabry-Pérot interferometer.

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