Technical White Paper

# Detector Choice for FT-IR Microscopy Differences, Similarities, and Best Setup

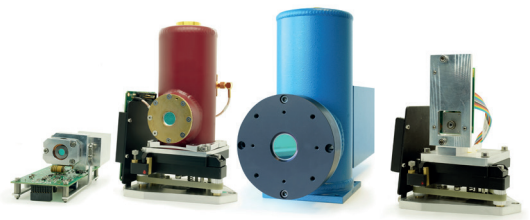

Figure 1: Typical detector elements before assembly. From left to right: TE-MCT, $LN_2$-MCT, FPA, and DTGS.

*Fourier Transform Infrared (FT-IR) microscopy is the combination of conventional light microscopy and unambiguous chemical identification by FT-IR spectroscopy.*

*Both techniques are quite powerful on their own, but together they offer the ability to study the chemistry of smallest objects by obtaining spectral information at high spatial resolution.*

*FT-IR microscopy usually deals with samples below 300 µm up to single-digit micrometers and is used to analyze and characterize smallest structures. If excellent results are demanded, highly sensitive detectors are a necessity.*

Figure 2: The LUMOS II was used to compare detectors, as it can be equipped with up to three detectors in a single system.

## About this document

In this document, we discuss the choice of detectors for microscopy, in terms of performance and suitability for different applications.

We try to answer the most common questions our customers encounter when they are faced with the choice of a detector for their new system.

- Different types of detectors in IR microscopy
- Pros and cons of different detector types
- Which application benefits from which detector
- Cryogen-free detector comparison (TE-MCT vs DTGS)
- Cryogen-free vs. with $LN_2$-cooled (TE-MCT vs $LN_2$-MCT)
- Single-element vs. imaging detector ($LN_2$-MCT vs. FPA)

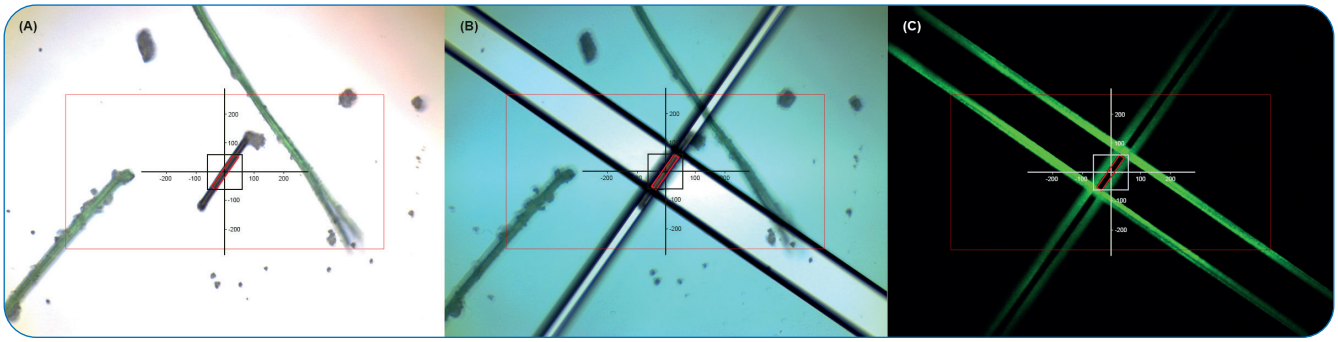


Figure 3: (A) Visual image of a polymer fiber. (B) The LUMOS II's automated knife-edge aperture limits the measuring field to the polymer fiber. (C) Knife-edge aperture illuminated by a green laser for optimal adjustment. The knife-edge aperture can take any rectangular form.

## There are challenges in IR microscopy

Typically, we analyze the transmitted or reflected IR light after interaction with our sample. For this, traditional objective lenses or parabolic mirror objective lenses with a fixed field of view are used in IR microscopy.

In this setup, the apertures are made of materials that are not transparent for IR light and thus, they are used to restrict the measurement area to the object of interest. They are placed over the structure to be investigated and ensure that only the relevant chemical information reaches the detector.

Figure 3 shows the use of automated knife-edge apertures. As said before, the aperture is used to limit the measurement window so that only the small amount of IR radiation from the ROI reaches the detector. This is why highly sensitive detectors are needed to generate interpretable IR spectra.

## Different types of single-element detectors

In principle, two different single-element detectors are commonly used in IR spectroscopy:

**DTGS detectors** (Deuterated alanine doped Tri-Glycine Sulphate) are based on a pyroelectric effect (incoming IR radiation heats and expands the detector material).

This cryogen-free detector type is very versatile and produces high-quality IR spectra. Furthermore, they work well under room temperature conditions but require high amounts of IR radiation to produce spectra of decent quality.

**MCT detectors** (Mercury cadmium telluride) are based on an internal photoelectric effect (incoming IR radiation excites electrons into the conduction band).

Since this excitation can also be triggered by thermal processes, it is necessary to cool MCT detectors to suppress thermally induced noise. As a result, they offer highest sensitivity in IR applications, and are typically used in low-light scenarios (e.g. protein analysis in water or microscopy). They offer significantly better S/N ratios and exhibit much faster response times than DTGS detectors.

Traditionally, liquid nitrogen is used for the cooling ($LN_2$-MCT) but refilling of the nitrogen during prolonged use and cooling down takes time and creates additional costs. In recent years, cryogen-free, thermoelectrically cooled (TE-) MCTs have emerged, combining high senisitivity with low maintenance.

## Cryogen-free detector comparison: DTGS vs MCT

To shed light on the differences between DTGS and TE-MCT detectors, IR spectra of polymer particles of different sizes were acquired.

In each case, the aperture was set to the size of the particles (Figure 4) and fixed for each measurement. To create equal conditions, the spectra were recorded with a constant measurement time (1 minute) for both detectors. The results are displayed in Figure 4.

In all three examples the DTGS detector shows considerable noise. While for PMMA (50 x 50 µm) the spectral quality is still debatable, the FT-IR spectra of Rayon and calcium carbonate show problematic artefacts. This can easily lead to misinterpretation and disqualifies the DTGS from use in FT-IR microscopy below 50 µm. It should thus only be considered when an especially moderate spatial resolution is required.

The TE-MCT on the other hand outclasses the DTGS in every way. All spectral features in all three examples are precisely resolved, even at a 10 x 10 µm aperture. When it comes to cryogen-free detectors, the TE-MCT offers a decisive advantage and gives access to the single-digit micrometer range in FT-IR microscopy.

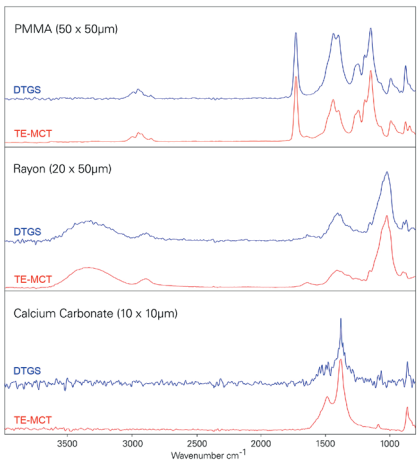


Figure 4: DTGS (blue) and TE-MCT (red) ATR spectra of different particles and fibers. Scan time: 1 minute @ 8 $cm^{-1}$ spectral resolution.

## MCT detector comparison: TE-MCT vs LN-MCT

To put the performance of the TE-MCT detector into perspective, it was also compared against a liquid nitrogen cooled MCT detector. The experimental setup was identical to the comparison between DTGS and TE-MCT detectors. The results are displayed in Figure 5.

As expected, the $LN_2$-MCT detector shows a better S/N ratio compared to the TE-MCT detector. However, the differences only get noticeable as we enter high resolution territory. For 50 x 50 µm and 20 x 50 µm apertures, the spectra of both detectors are almost indistinguishable.

The introduction of TE-MCT detectors to FT-IR microscopy achieved the long sought-after balance of high spectral quality and cryogen-free operation. Routine, high-quality FT-IR microscopy is now available without liquid nitrogen or tedious cooldown periods.

In applications requiring single-digit micrometer resolution, however, $LN_2$-MCT detectors offer a sensitivity advantage and remain the benchmark in single-point FT-IR microscopy.

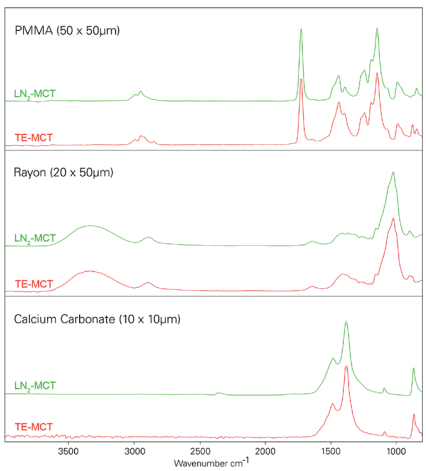


Figure 5: $LN_2$-MCT (green) and TE-MCT (blue) ATR spectra of different particles and fibers. Scan time: 1 minute @ 8 $cm^{-1}$ spectral resolution.

## Explaining the differences: mapping vs. imaging

Besides point-and-shoot operation, FT-IR microscopy applications often require evaluating the chemical distribution of a sample by creating chemical images. While single-element detectors can of course be used to create IR chemical images, there are dedicated IR imaging detectors. To evaluate their performance, we will compare the most sensitive single-element (LN2-MCT) with a true imaging detector (FPA). But first, the basic differences between the two approaches should be made clear.

**In FT-IR mapping**, the use of a single-element detector, an aperture, and a high-precision stage allows spatial resolutions down to 5 µm. A grid of several measurement points with defined distance and a fitting aperture is chosen. Then the microscope scans the sample from spot to spot. This process is very slow and can take hours or even days to complete depending on the sample and ROI.

**In FT-IR imaging**, a focal-plane array (FPA) detector is used were 32x32, 64x64 or more individual detectors elements are arranged in a rectangle, just like pixels in a digital camera. With this, the detector area of the individual elements replace the physical aperture.

This means more IR radiation can reach the detector, which results in a much better S/N ratio. Simply put, instead of needing 32x32 (1024) individual measurement points with a 5 µm aperture, the FPA in a LUMOS II can acquire the same information in a single, 2 second scan. Thus, maximum spatial resolution at minimum measurement times is achieved.

## Chemical imaging performance: MCT vs. FPA

As a test sample a barley grain microtome cut was analyzed using most sensitive single-element detector ($LN_2$-MCT) and a 32x32 FPA detector. For the FT-IR mapping, the aperture on the single-element detector was set to the FPA pixel size (5 µm) to obtain a comparable result.

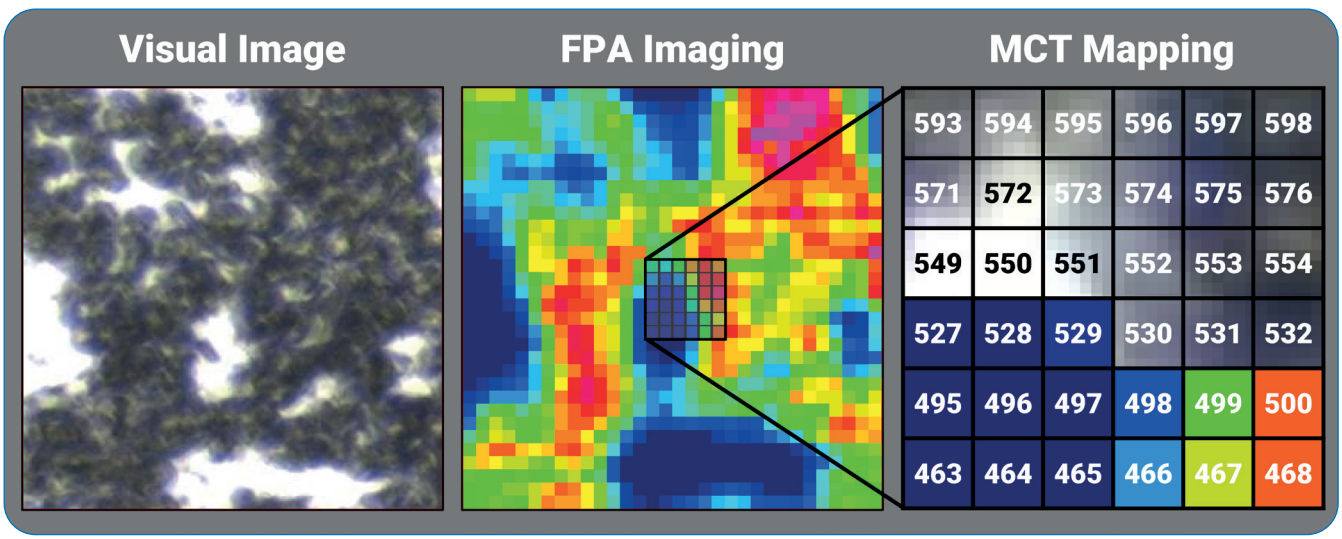


Figure 6: Principle of different IR imaging techniques. The FPA detector (mid) captures the whole area shown in the visual image (left) in a single scan. Like a digital camera, it creates 32 x 32 spatially resolved IR spectra instantly. To reach the same resolution, an MCT (right) must sequentially acquire 1024 spectra with a 5 µm aperture. It must travel from point to point during the process and thus, takes a lot of time.

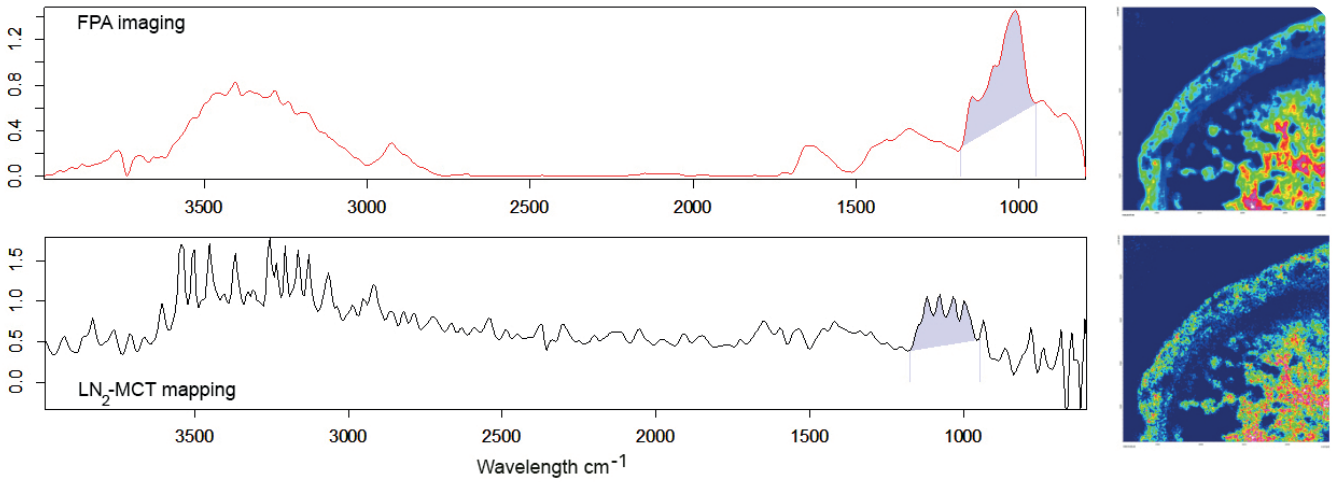


Figure 7: Transmission spectra comparison of FPA imaging (top) and $LN_2$-MCT mapping (bottom): 36.864 FT-IR spectra in total, 5 µm spatial resolution. Time required: MCT-Mapping needed 150 min @ 1 scan; FPA-Imaging needed 1 min @ 1 scan.

A sample area of about 1 mm² was chosen. All other measurement parameters, like scan time, were set identically for both measurements.

A total of 36.864 FT-IR spectra was collected (Fig. 7). While the FPA finished the measurement in ~1 minute, the $LN_2$-MCT detector needed 150 minutes. More importantly, that tremendous speed increase had no negative effect on the spectral data quality - quite the opposite actually.

In fact, Figure 6 clearly shows that the FT-IR spectra obtained with the FPA are far superior to those from the $LN_2$-MCT. They are ideal for identification by reference library search and the resulting chemical image is significantly richer in contrast.

It should be emphasized, that the data presented here has not been post-processed or altered in any way.

## Conclusions and a clear winner

- DTGS performance is inadequate for micro IR applications.
- TE-MCTs are vastly superior to DTGS detectors in FT-IR microscopy.
- An $LN_2$-MCT offers max. single-point sensitivity, if required (<10 µm).
- FPA detector is the IR imaging performance benchmark.

For most scenarios, a TE-MCT for routine single-point measurements paired with an FPA for brilliant FT-IR imaging at high-resolution is the optimal detector configuration for an FT-IR microscope.

As an all-in-one device, the LUMOS II offers up to three detector positions: 2x single-element detector (e.g. TE-MCT + $LN_2$-MCT) and 1x FPA detector.

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