Detectors for Fourier Transform Spectroscopy

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KEY WORDS

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Thermo Nicolet spectrometers are designed to produce the highest performance spectral data for a wide variety of Fourier transform spectroscopic applications. Optimization for each application requires selection of specific system components – source, optics, electronics, interferometer, beamsplitter and detector – to produce the best quality spectrum. Of these components, the detector is key as it can be matched uniquely to specific applications. The choice of the ideal detector for spectral measurement is dependent upon many factors, including:

- Optical throughput (percent of beam reaching the detector)
- Spectral range of the measurement
- Sampling beam geometry
- Temporal resolution of the data collection
- Spectral resolution
- Response time

This note will describe the unique features of Thermo Nicolet's detectors, focusing primarily on Fourier transform infrared (FT-IR). It will help guide your choice of the ideal detector for your application.

High throughput (greater than 20% of IR beam reaching the IR detector) and static experiments are generally run utilizing a thermal detector, such as deuterated, L-alanine doped triglycine sulfate (DLaTGS), because it gives full, specific detectivity (D*) in high-flux environments. From an applications perspective, this means the DLaTGS detector provides linear response over a very wide range of FT-IR throughput, which is beneficial in qualitative and quantitative FT-IR sampling. Thermal detectors are generally less effective for kinetic measurements because their signal is inversely proportional to data collection speed. Low-throughput experiments (less than 20% of IR beam reaching the IR detector) benefit from the use of a quantum detector, such as the mercuric cadmium telluride (MCT) detector. High MCT sensitivity will produce a large signal in a low-flux measurement. Furthermore, the MCT detector demonstrates a relatively constant signal versus data-collection speed and is, therefore, ideal for kinetic measurements. A limitation of MCT detectors is that they lose responsivity and D* at high throughput. From the applications perspective, this means that in high-throughput applications, we must limit the beam energy reaching the MCT detector to prevent saturation, where the detector responds with a non-linear signal. Limiting the beam energy can be done by using neutral density filters, or optical screens.

Thermo Nicolet detector specifications are listed in Table 1, and described in terms of the element composition, along with the window material that determines spectral range. DLaTGS is a high-performance element which provides higher sensitivity than older technology based on deuterated triglycine sulfate (DTGS) detector elements.

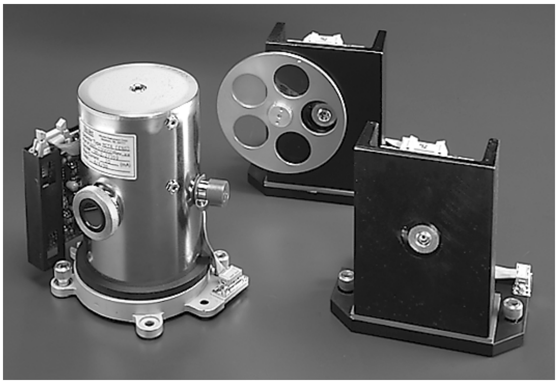

Figure 1: Thermo Nicolet detectors use a pre-aligned, pinned-in-place design and may be repositioned to other system locations with automatic recognition

Element size is reported in terms of diameter (mm) for circular detector elements, or area (mm^2), with x, y dimensions for quadrangular shaped elements. Ideally, systems are designed to match the beam diameter and detector element size – not over-filling or under-filling the detector element. A significantly, over-filled detector element will not measure the full system flux and, consequentially, the signal-to-noise ratio will be diminished. This must be balanced with the well-known fact that detector noise increases with increased detector area. To prevent saturation in high-D* detectors, reducing the beam intensity by reducing the beam diameter is not effective. Any area of the detector that is saturated will demonstrate saturation in the resulting spectrum. Figure 2 shows the Thermo Nicolet 50-micron MCT-A* detector element used for the highest sensitivity with 10-20 micron aperture sizes in the IR microscope products.

The spectral ranges for different detectors, as shown in Table 1, are reported as the endpoints where spectral response begins and ends, and can be diminished based upon experimental throughput. Reported values are generated from the combination of detector element responsivity and window material composition. Measured response will be dependent upon the choice of beamsplitter and source.

Specific D* is a measure of the detector signal as a function of energy flux and detector noise. At low-light levels, the D* number may be directly compared from one detector type to another. For example, the MCT-A* detector with a D* of 6.4×10^{10} is approximately 237 times more sensitive than the DLaTGS detector with a D* of 2.7×10^{8}. It is important to consider that

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Detector Element/Window	Element Size	Spectral Range	Typical D* cm Hz$^{1/2}$ W^{-1}	Minimum Responsivity	Operating Temperature	Typical Preamplifier Bandwidth
Mid-infrared						
DLaTGS/KBr	1.3 mm	12500-350 cm^{-1}	2.7 E8	50 V/W	Room temp.	170 kHz
DLaTGS/KBr	1.3 mm	12500-350 cm^{-1}	2.7 E8	50 V/W	TE cooled	170 kHz
DLaTGS/CsI	1.3 mm	6400-200 cm^{-1}	2.4 E8	50 V/W	Room temp.	170 kHz
$LiTaO_3$/KBr	1.5 mm	10000-400 cm^{-1}	1.0 E8	20 V/W	Room temp.	170 kHz
MCT-A*/CdTe	1.0 x 1.0 mm^2	11700-800 cm^{-1}	6.4 E10	1,200 V/W	Liquid N_2	175 kHz
MCT-A/CdTe	1.0 x 1.0 mm^2	11700-600 cm^{-1}	4.7 E10	750 V/W	Liquid N_2	175 kHz
MCT-B/KRS-5	1.0 x 1.0 mm^2	11700-400 cm^{-1}	8.0 E9	50 V/W	Liquid N_2	175 kHz
Near-infrared						
InGaAs/glass	1.0 mm	12000-3800 cm^{-1}	4.4 E10	1.3 A/W	Room temp.	170 kHz
InGaAs/glass	1.0 mm	12000-3800 cm^{-1}	3.0 E11	1.4 A/W	TE cooled	50 kHz
PbSe/sapphire	1.0 x 1.0 mm^2	11000-2000 cm^{-1}	2.5 E9	6,000 V/W	Room temp.	100 kHz
InSb/CdTe	2.0 x 2.0 mm^2	10000-1850 cm^{-1}	2.2 E11	2.2 A/W	Liquid N_2	250 kHz
Visible						
Si/Quartz	2.5 mm	27000-8600 cm^{-1}	2.8 E12	0.4 A/W	Room temp.	170 kHz
DLaTGS/Quartz	1.3 mm	25000-2000 cm^{-1}	2.7 E8	50 V/W	Room temp.	170 kHz
Far-infrared						
DLaTGS/Poly	1.5 x 1.5 mm^2	700-50 cm^{-1}	4.8 E8	300 V/W	Room temp.	1.5 kHz
Si/Teflon®	2.5 x 2.5 mm^2	600-20 cm^{-1}	1.6 E12	170,000 V/W	Liquid He	250 Hz
IR Microscope						
MCT-A*/CdTe	0.05 x 0.05 mm^2	11700-700 cm^{-1}	6.4 E10	60,000 V/W	Liquid N_2	175 kHz
MCT-A*/CdTe	0.25 x 0.25 mm^2	11700-750 cm^{-1}	6.4 E10	7,000V/W	Liquid N_2	175 kHz
MCT-A/CdTe	0.25 x 0.25 mm^2	11700-600 cm^{-1}	4.7 E10	6,500 V/W	Liquid N_2	175 kHz
MCT-B/KRS-5	0.25 x 0.25 mm^2	11700-450 cm^{-1}	8.0 E9	400 V/W	Liquid N_2	175 kHz
InGaAs/glass	0.30 mm	12000-3800 cm^{-1}	3.0 E12	1.0 A/W	TE cooled	50 kHz
FT-Raman						
InGaAs/glass	1.0 mm	3600-100 R. shift	1.0 E12	.95 A/W	Room temp.	1 kHz
Ge/glass	3.0 mm	3600-100 R. shift	5.0 E13	.70 A/W	Liquid N_2	2 kHz
PAS						
Photoacoustic	8 mm	4000-100 cm^{-1}	2.0 E7	5 V/W	Room temp.	30 kHz
TRS						
MCT-A/CdTe	1.0 x 1.0 mm^2	11700-600 cm^{-1}	4.0 E10	6.0 A/W	Liquid N_2	20 MHz
MCT-A/CdTe	0.5 x 0.5 mm^2	11700-600 cm^{-1}	3.4 E10	4.8 A/W	Liquid N_2	50 MHz

Table 1: Thermo Nicolet detector specifications. These specifications are subject to change based upon technological advancement. Please contact your local Thermo Nicolet representative for more information

detectors with high D* values tend to demonstrate saturation effects in high-throughput experiments. In this case, a neutral-density screen may be used to reduce energy flux at the detector.

Mathematically, D* is expressed using the following equation and terms:

$$D^* = \frac{\Delta f^{1/2} \bullet V_s}{V_n \bullet E_s \bullet A^{1/2}}$$

Where Δf is bandwidth, A is detector area, V_s is detector signal, V_n is the root mean square (rms) detector noise and E_s is energy flux at the detector.

Therefore D* is proportional to the signal from the detector relative to the energy flux reaching the detector. This means that a higher D* detector can provide higher response in a low energy flux environment. This equation also shows that D* accounts for detector noise and that selecting a high D* detector can provide a higher signal and lower noise.

Figure 2 in this document shows a graphical representation of D* and the spectral range for Thermo Nicolet detectors. This figure can be used to graphically compare detector D* and spectral range for most of the detector products.

Another measure of detector performance is responsivity (R_y), which is a measure of the detector signal per energy flux and detector area. It is expressed in the following equation.

$$R_y = \frac{V_s}{E_s \bullet A}$$

A higher value of R_y indicates a higher detector response for a given energy flux and is corrected for a detector area. Note that R_y does not consider detector noise. However, responsivity is a good measure of detector response where signal is sufficient such that noise is not observed.

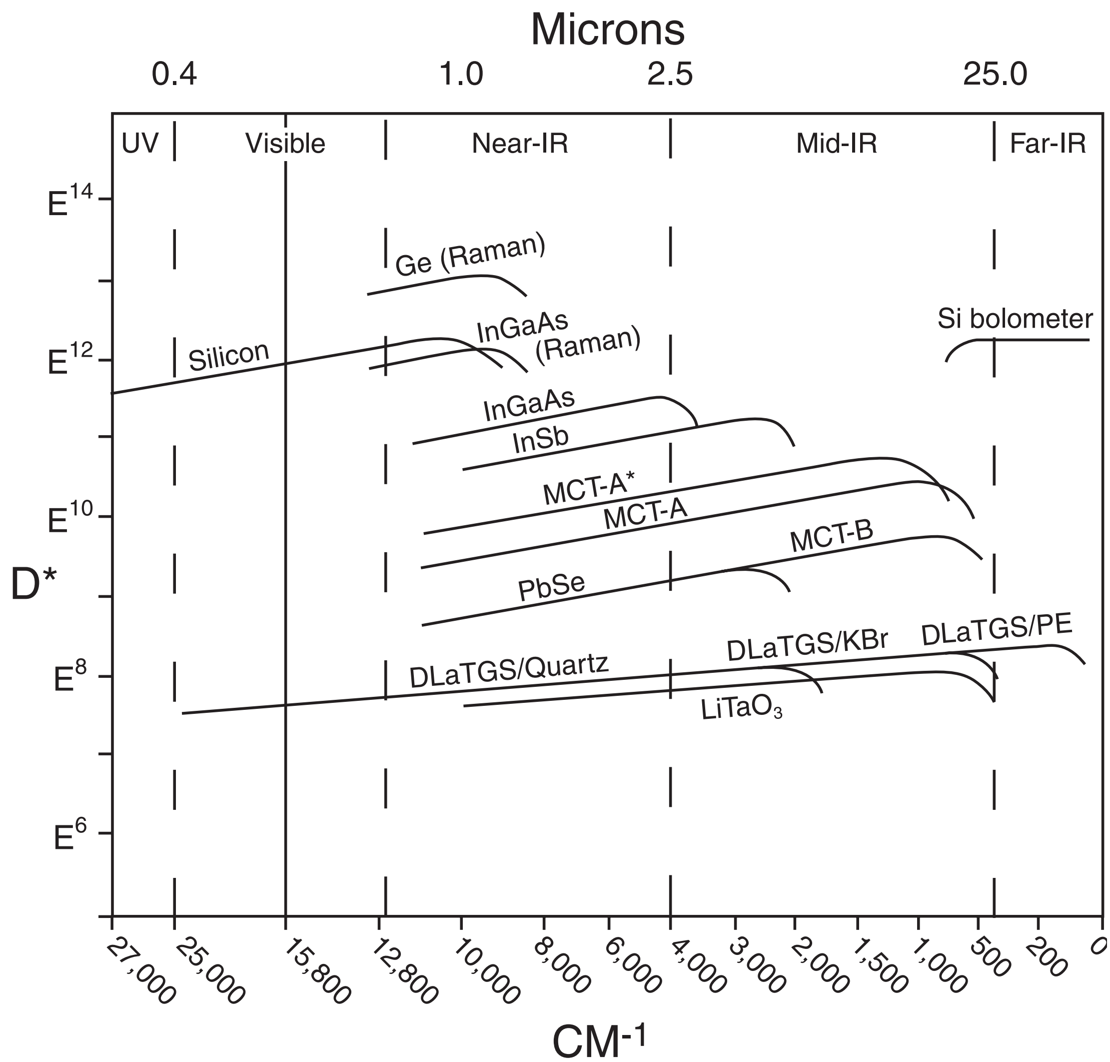
Many FT-IR detectors operate at room temperature while others require cooling, with liquid nitrogen (77 K) for example. Thermo electric cooling (TE or Peltier cooling) provides enhanced, 100% line stability for the DLaTGS detector, minimizing response changes due to changes in room temperature. For indium gallium arsenide (InGaAs) detectors, cooling can provide increased performance at very low-light levels.

Thermo Nicolet detectors, cooled by liquid nitrogen, utilize a patented, stainless steel dewar which provides a liquid nitrogen hold time of 18 hours (U.S. Patent 4,740,702). This extended hold time is useful for long experiments such as microscope mapping and extended kinetic measurements. This proprietary detector design also eliminates the formation of ice on the MCT element, thereby preventing spectral artifacts due to water absorption.

Preamplifier bandwidth applies to the maximum sampling frequency available for the detector and its preamplifier before significant signal loss has occurred. Generally, higher bandwidths are required for fast, data-collection applications, such as rapid-scan analysis and time-resolved spectroscopy (TRS).

Thermo Nicolet offers a wide variety of detectors to optimize each FT-IR experiment and sampling condition. This document provides a reference of general sensitivity, responsivity and spectral range information for most of the detectors. It is intended as a general reference for standard versions of the detector products. If you have questions or comments about a detector not shown here, or a special requirement, please contact your local Thermo Nicolet representative.

Figure 2: Graphical representation of detector D* versus spectral range for Thermo Nicolet FT-IR detectors. The vertical line at 15798 cm^{-1} represents the helium neon (HeNe) laser emission band which is utilized for internal registration of Thermo Nicolet FT-IR spectral data



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