Photoluminescence at 8D Systems: Capability, Limitations and Solution

8D System:

8D system is a combination of FTIR spectrometer, wafer mapper, and a cryogenic system capable of going down to liquid nitrogen temperature (77 K). This tool contains an inherent and external laser source for PL spectroscopy and a lock-in amplifier for noise cancellation as well as pulsed operation.

It's a useful tool for measuring optical properties of materials through photoluminescence (PL) from the MWIR to NIR wavelength range.

Target Wavelength:

For our quantum dot project (QD) project, we are interested to measure PL at 1.55 µm and 905 nm. We often perform the PL measurement at room-temperature, as well as occasionally at cryogenic temperature. It is important to make sure bulk optics used in the setup are compatible to the NIR wavelengths we are interested in. These are:

- Excitation laser
- FTIR entrance window
- Long pass filter to block laser line
- Photodetector
- Beam splitter

Current status of the tool:

- **Excitation laser:** Two Excitation lasers emitting 980 nm (http://www.qphotonics.com/Single-mode-laser-diode-150mW-980nm.html) and 1535 nm are available. The excitation laser is placed out of the FTIR and controlled by a controller called CLD 1015 (https://www.thorlabs.com/thorproduct.cfm?partnumber=CLD1015#ad-image-0) which can

host only one laser at a time. Switching between lasers is allowed and is done manually.

- **Photodetector:** MCT-A photodetector, detection range according to the user manual is **450 - 11700 cm^{-1}** (**854 nm – 20 µm**) as shown in Fig. 1.

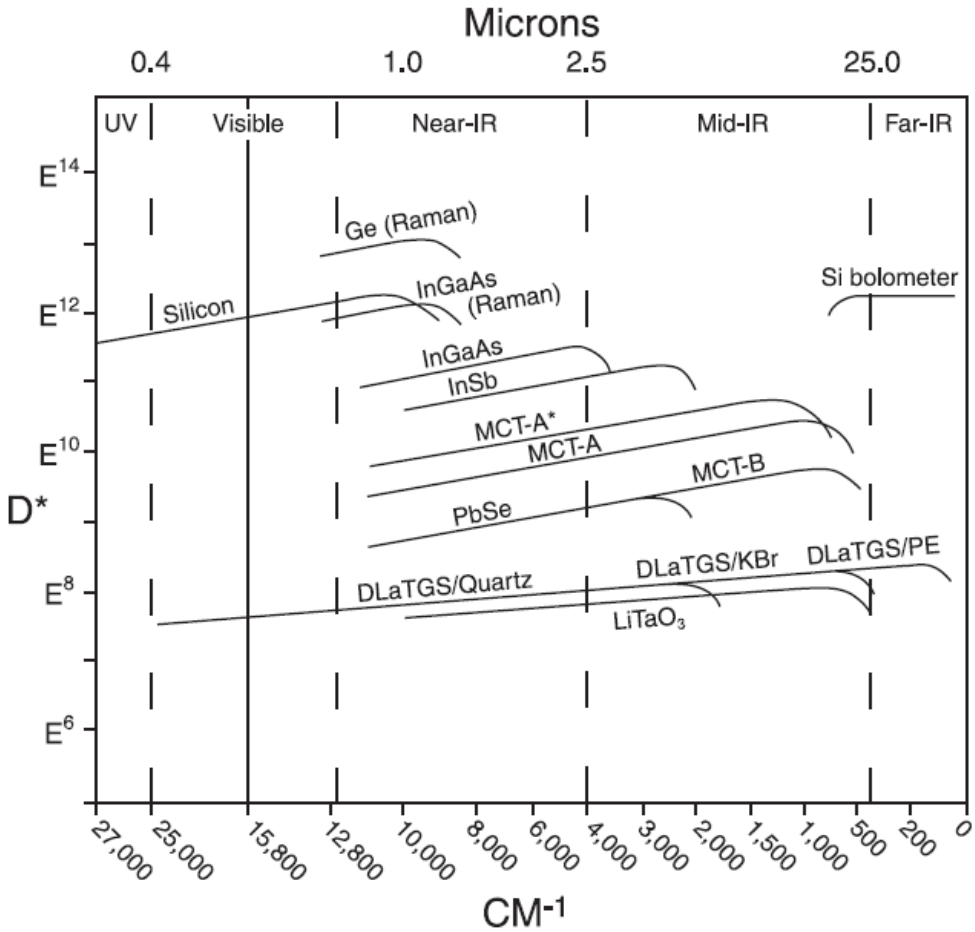

Fig. 1: Sensitivity of different photodetectors. MCT-A is used in the 8D system. The top axis plots the response as a function of wavelength (µm).

- **Beamsplitter:** Currently, a Ge on KBr on-axis beam splitter is used with a broad transmission range of 1.28 µm to 28 µm.
  In Fig. 3 the transmission of a KBr window for FTIR transmission cell is plotted. Though this transmission characteristics seems well compatible for 1.55 µm PL transmission, having a coating on top of the beam splitter may worsen the transmission characteristics in the shorter wavelength side.

- **Window:** KBr window is used at the FTIR entrance. We need to make sure that the PL signal coming from the sample can go through the window and not impacted by its transmission characteristics.

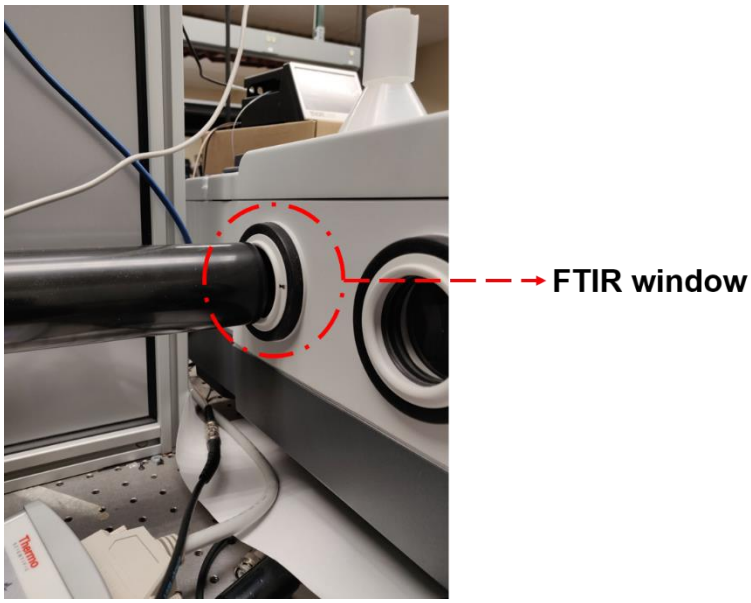

Fig. 2: Physical location of the FTIR window

The response of the window is in Fig. 3. A 90% flat transmission characteristics is observed from 40000-400 cm^{-1} (**250 nm – 25 µm**).

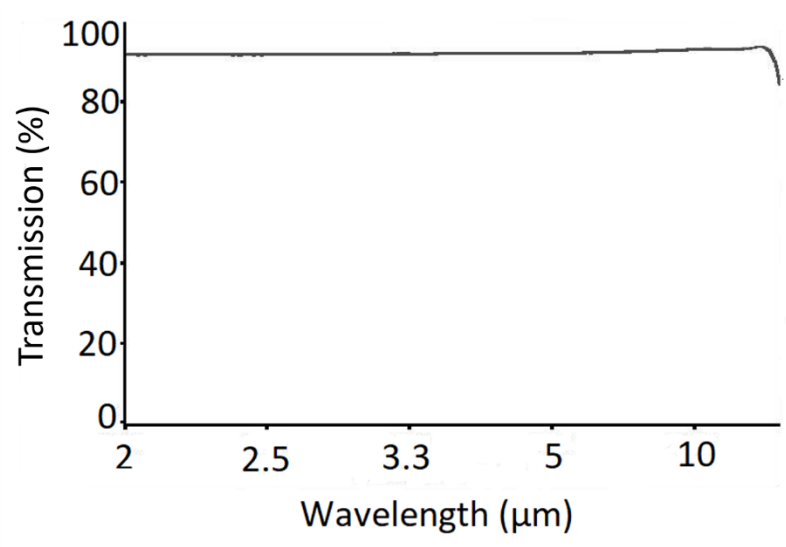

Fig. 3: Transmission spectrum of the FTIR transmission cell window which has a 90% transmission from 250 nm to 25 µm

Due to insertion of light for photodetection in the PL system may give rise to humidity and carbon-di-oxide. Having a KBr window effectively seals the FTIR and thus it cannot get exposed to the air. Another purging system is connected with the FTIR to purge all the gases inside of the FTIR.

- **Long pass filter:** A long pass filter (LPF) having a response like below is given.

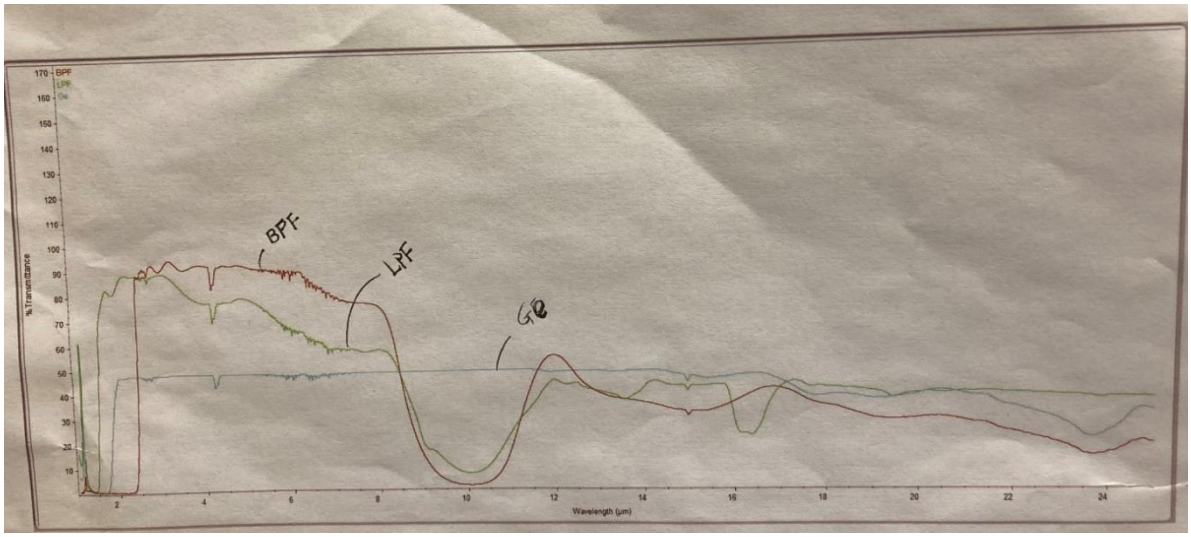

Fig.4: Filter response

To block the 980 nm excitation laser line, a new LPF is ordered which has the response shown as in Fig. 5. It can be seen that the cutoff wavelength is 1.02 µm for this LPF and it operate up to 1.6 µm.

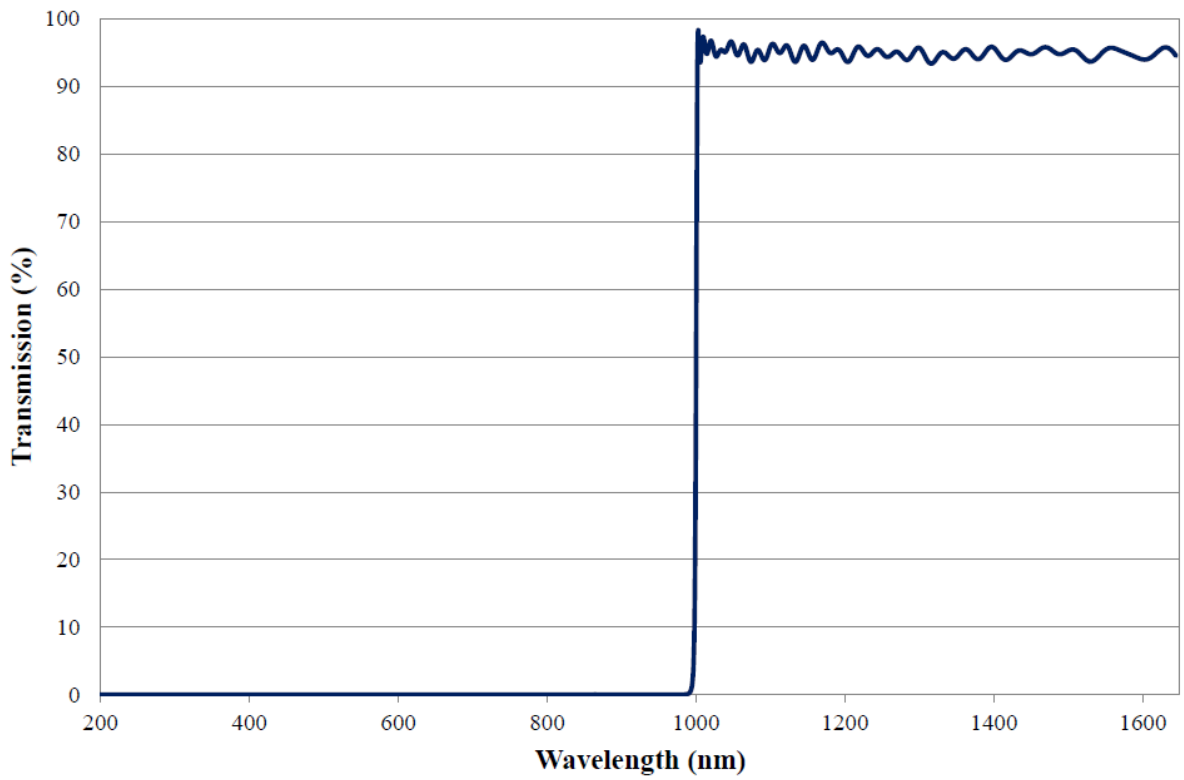

Fig. 5: Filter response for new LPF. Cutoff at 1.02 µm.

Limitations and solution for 1.55 µm:

- **Laser:** For 1.55 µm PL, 980 nm excitation is good.
- **Photodetector:** MCT loses its sensitivity at NIR. But for 1.55 µm, this MCT-A photodetector is capable.
- **Long pass filter:** Drops at 1.1 µm shown in Fig. 3. A new one is already ordered as mentioned earlier (https://www.edmundoptics.com/p/1000nm-50mm-dia-high-performance-longpass-filter/27835/). The new filter is a longpass filter with a cut-off at 1.02 µm.
- **Beamsplitter:** The KBr beam splitter has a good response in the 1.55 µm and cut-off at 1.28 µm as discussed earlier. So ideally it does not require a replacement.
- **Window:** The KBr window installed in the FTIR is capable to handle PL at 1.55 µm as it has a cut-off at 250 nm (250 nm- 2.5 µm).

Limitations and Solutions for 905 nm:

- **Laser:** To see PL at 905 nm peak wavelength, none of the stored lasers are compatible. A laser of wavelength around 700 nm can be perfect. Below link is the one of a diode laser for 735 nm emission suggested by Prof. Arafin.
  https://www.thorlabs.com/thorproduct.cfm?partnumber=FPL785S-250
- **Photodetector:** MCT-A PD loses its sensitivity at NIR (cut-off at 854 nm). So, for 905 might not be okay. Two possible solution is Si (0.74 to 8.3 µm) and InGaAs (0.83 to 2.6 µm) photodetector.
- **Window:** The KBr window has 90% transmission from 250 nm to 25 µm. So according to the manual, it should be okay for 905 nm PL. However, there is a suggestion from the manufacturer to use a CaF_2 window.
- **Beam Splitter:** As the current KBr beam splitter has a cutoff at 1.28 µm, this is not the choice for 905 nm PL.
  According to the manufacturer there is a suggestion to replace the KBr beam splitter by a CaF_2 beam splitter. One such option suggested is Silicon on CaF2 Substrate On-Axis Beamsplitter (740 nm – 8.3 µm). (Price: $9400)

Summing up all these, one available solution for NIR spectroscopy given by the manufacturer (Spectratech) is as follows:

Product id	Name	Cost
840-129500	Silicon on CaF_2 Substrate On-Axis Beamsplitter (13,500-1,200 cm^{-1})	$ 9,400.00
840-231100	TE Cooled InGaAs Detector for NIR (12,000-3,800 cm^{-1})	$ 9,100.00
470-466800	Desiccated CaF_2 Window Kit	$ 553.00

- **Filter:** The current filter is not supported by 905 nm. So a new filter is desired to pass 905 nm and block the excitation wavelength.

Summary:

Equipment	Current Status	Desired optimization for 1.55 µm	Desired optimization for 905 nm
Laser	980 nm	OK	735 nm
PD	MCT-A	OK	Si/InGaAs
Filter	LPF at 1.1 µm cut-off	LPF (1.02 µm cut-off)	Any filter to pass 905 properly and block 735 nm
Beamsplitter	KBr	OK	CaF_2
Window	KBr	OK	CaF_2 window

Conclusion:

In conclusion, the system is well capable to measure PL at 1.55 µm. Only bottleneck was the filter issue, which is going to be replaced by a new longpass filter of 1–1.6 µm transmission range. The cut-off of MCT detector is at 854 nm. But it can handle the target wavelength of 1.55 µm.

On the other hand, for PL at 905 nm, there is some addition required for excitation laser, photodetector, filter, beam splitter and preferably window.