Contactless cleanliness verification of optical flight hardware by portable FT-IR instrument

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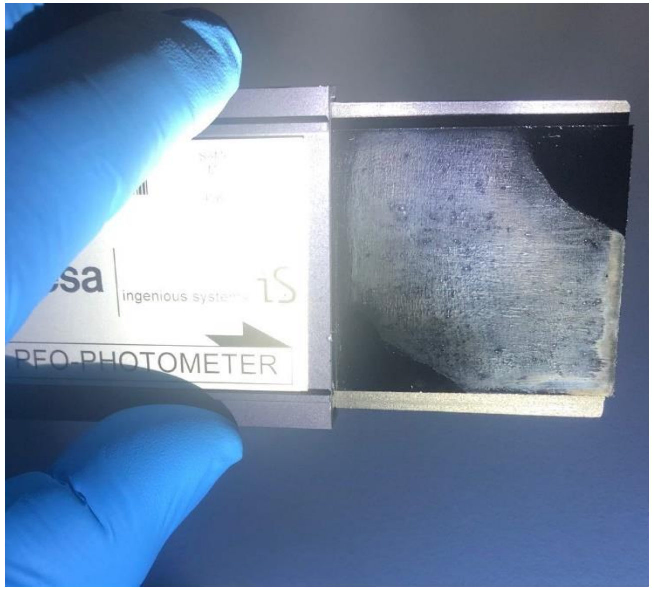
1. Introduction - Cleanliness and contamination Control

One of the most challenging aspects of CCC is the verification and validation of molecular contamination levels especially on sensitive optical equipment. Most of which are restricted in terms of handling, and direct/contact measurements are frequently not possible.

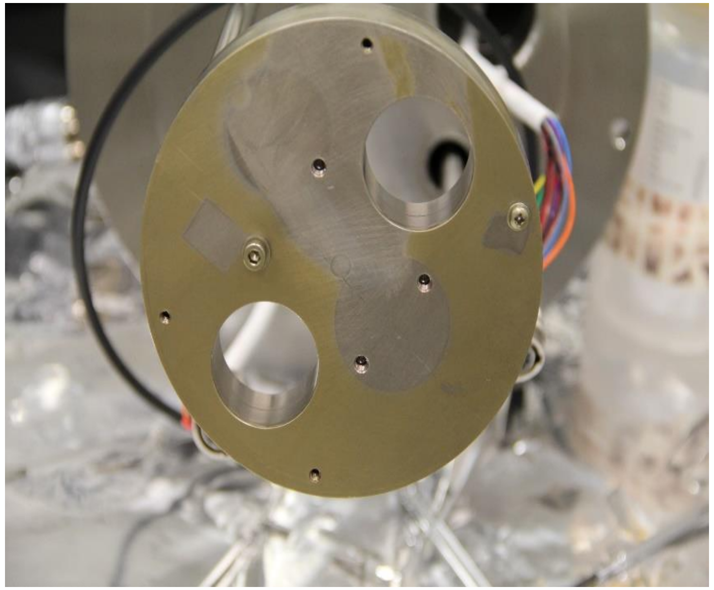
Traditionally this evaluation is performed by the measurement of **nearby** MOC witnesses. The **assumption** is to consider the same levels on the actual surface of interest. Although, nominal approach is to follow the orientation and exposure duration of the sensitive surface in an environment. The probable (positively or negative) impact of surface and material properties and the interaction with the type of molecular contamination is mostly neglected.

Measuring molecular contamination is crucial in the event of a nonconformance that cannot be captured with the witness.

Contaminant (def. in ECSS-Q-ST-70-01C)
Unwanted matter on the surface or in the environment that can affect or **degrade** the relevant **performance** or **life time**



Film on a witness material

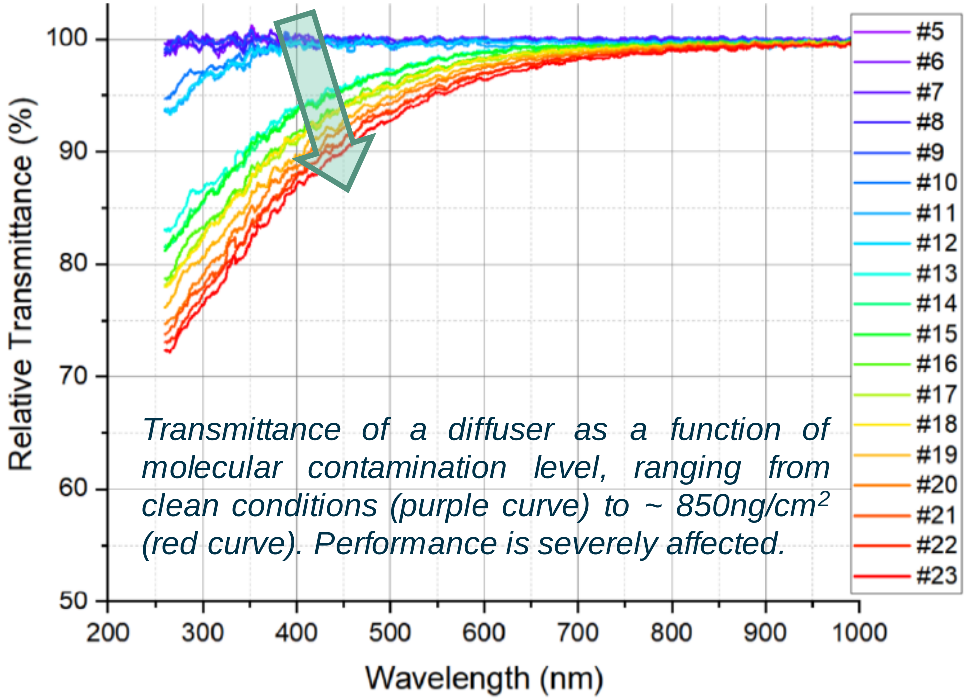


Example of a contaminated cold plate (after bake-out).

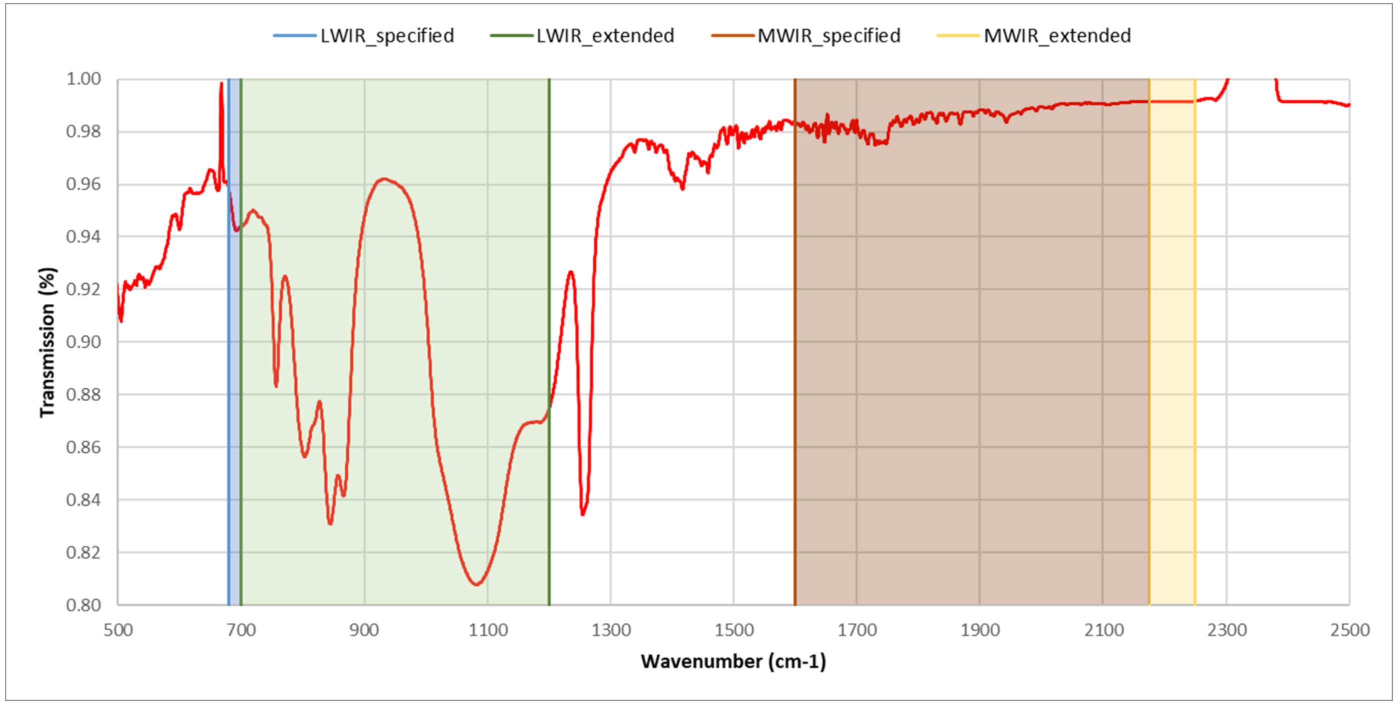
Molecular witness

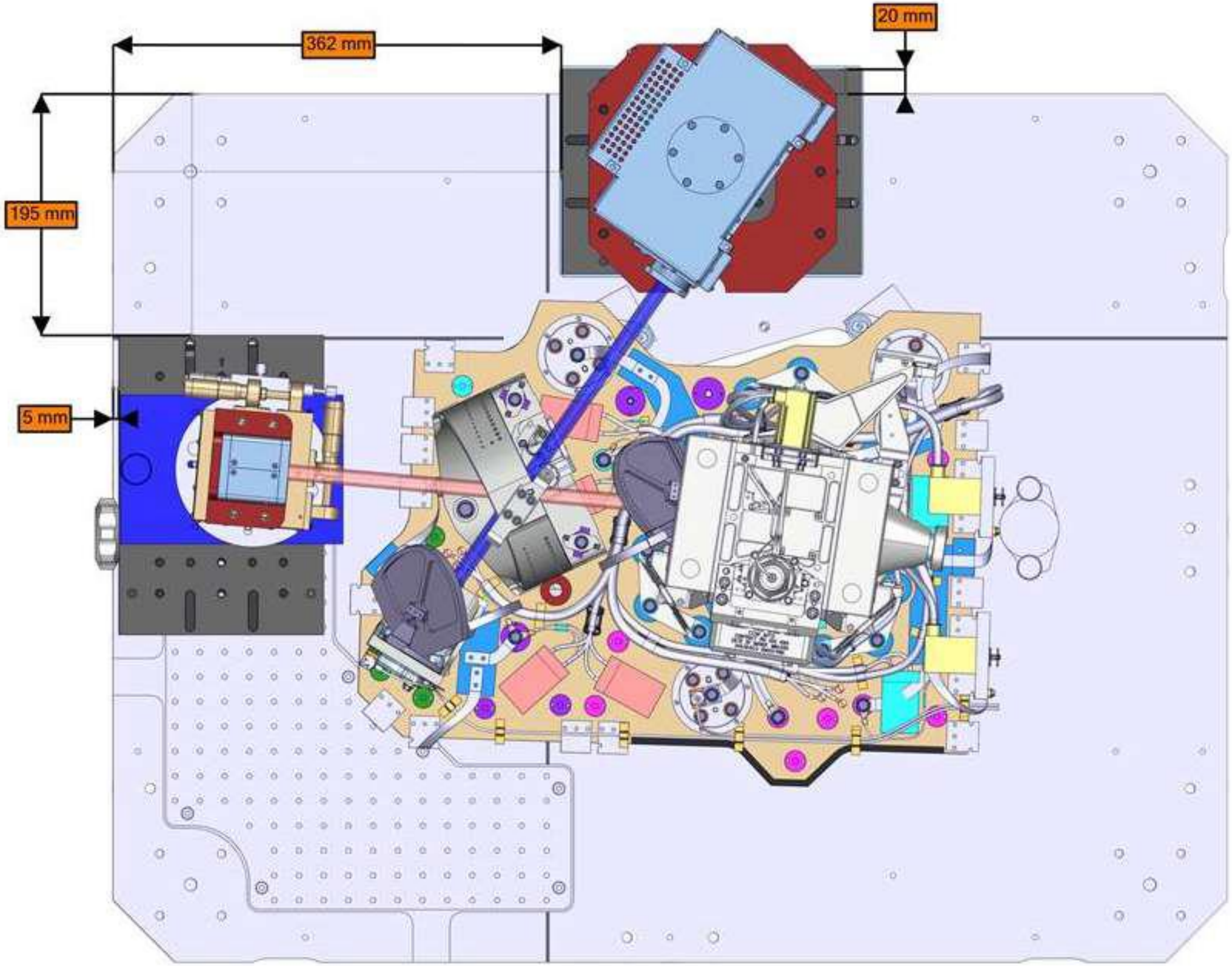
1. Molecular contamination impact

- Thermo-optical properties degradation (e.g. overheating)
- Degraded optical properties
  - Performance loss (throughput, increased noise, …)
  - Effects depend on **wavelength of interest**.



*Transmittance of a diffuser as a function of molecular contamination level, ranging from clean conditions (purple curve) to ~ 850ng/cm²
(red curve). Performance is severely affected.*





erification

ɔact) on the optical surfaces and systems.

-as-is, rework, scrap, …).

ntify contaminant groups (e.g. hydrocarbons,

pass/fail criteria, …

.).

2. Methodology

- Creating (contaminated) reference samples:
  - Transmitting surfaces
  - Reflective surfaces
- Optimization of the setup in multiple configurations:
  - Transmission
  - Reflectance
- Optimization of the setup in various distances (5-60cm) between interferometer module and detector.
- Correlation of the results with the calibrated lab-equipment and in accordance with ECSS-Q-ST-70-05.
- Preliminary analysis of the limitations of the technique.
  - Beam diameter, focusing, intensity, noise, environment influence, ...
- Creation of lessons learned document.

2.1 Creating reference samples

IR transparent materials for transmission measurements:

CaF2 windows

- Clean windows
- Contaminated with silicones
  - In-vacuum contaminated (methyl silicone) samples: #322, #203, #217
  - Directly contaminated samples: #328, #715
    (with standard compound for IR analysis – poly(dimethylsiloxane), according to ECSS-Q-ST-70-05)

IR reflective materials for reflection measurements:

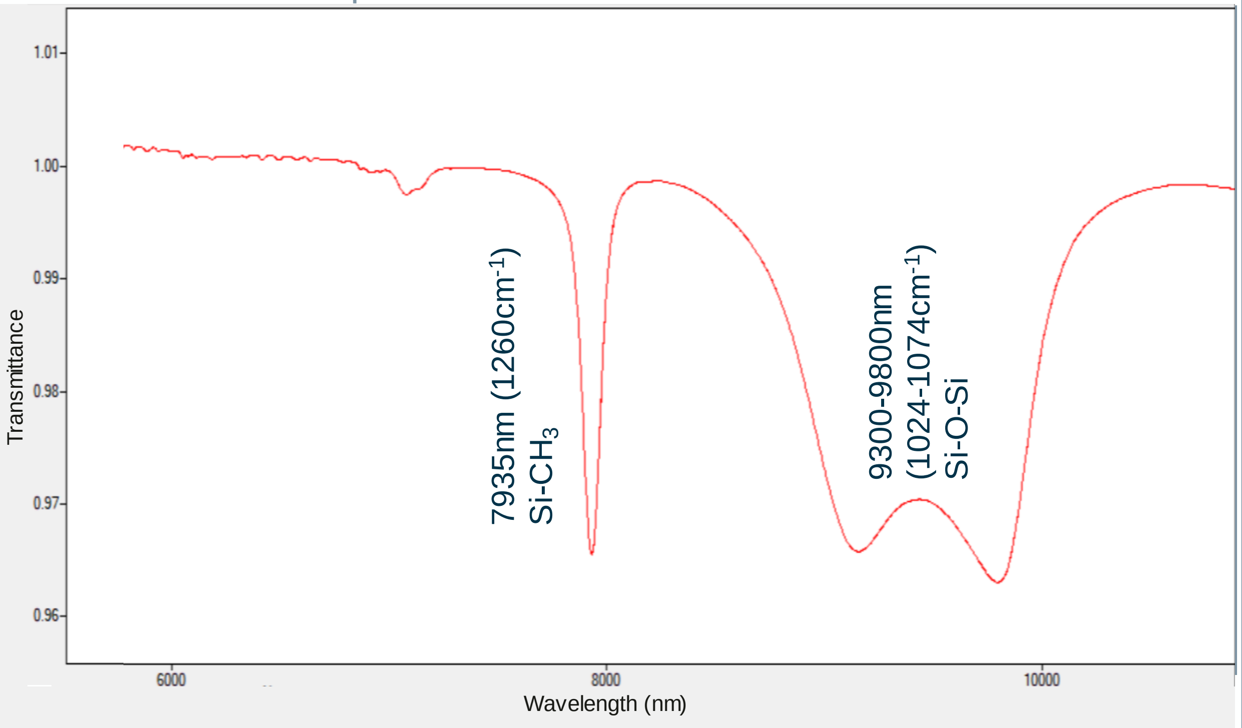
First surface gold mirrors

- Clean mirrors
- Directly contaminated mirrors (with standard material for IR analysis – poly(dimethylsiloxane))

2.1 Creating reference samples

IR fingerprint of the standard compound

IR fingerprint of the standard compound -The absorptions of particular interest to detect the presence of silicone contamination.



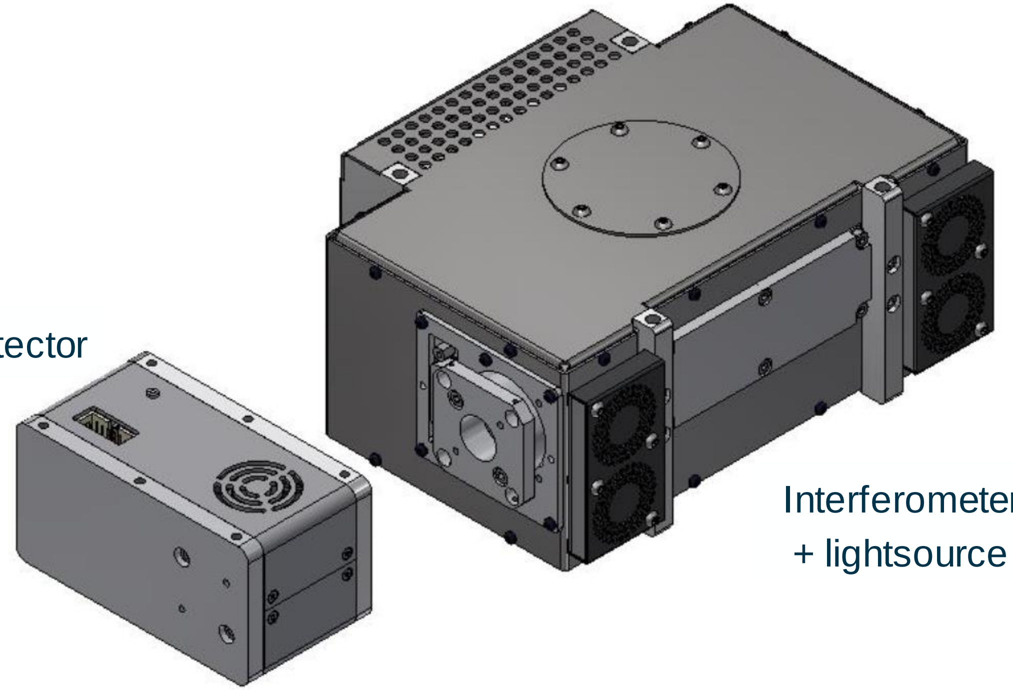
(Spectrum acquired with benchtop Bruker spectrometer)

2.2 Commercially available equipment

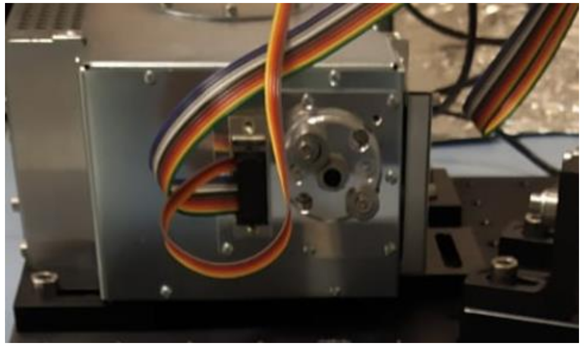
- Portable FTIR (*Arcoptix OEM* series was used in this study; other commercial hardware is available)
    - Interferometer module with integrated IR source
    - Detector module
- Optics (fibre optics, collimators, iris, …)

Measurement sensitivity
Spectral range
Portability
Easiness of use (LN2)
Limit of detection

Detector



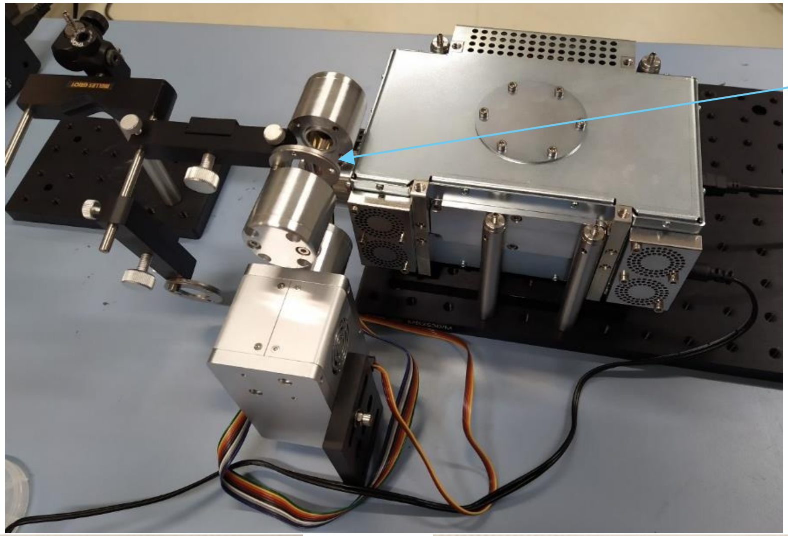
Interferometer
+ lightsource

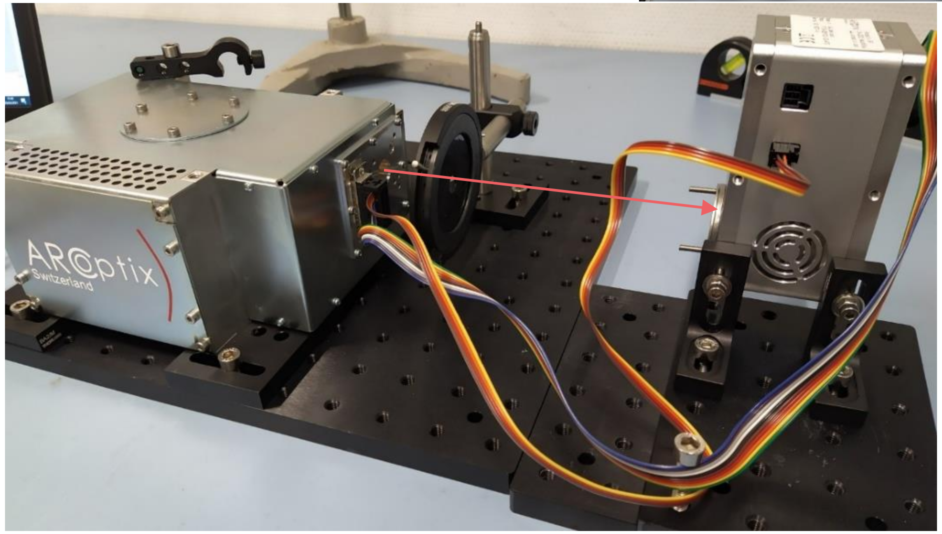


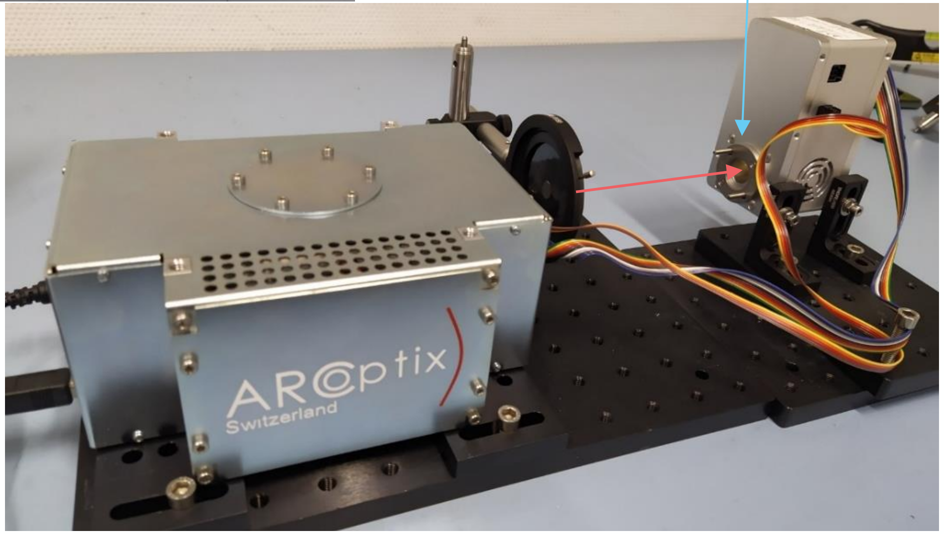
2.3.Set-up

Transmittance configuration

Contaminated surface



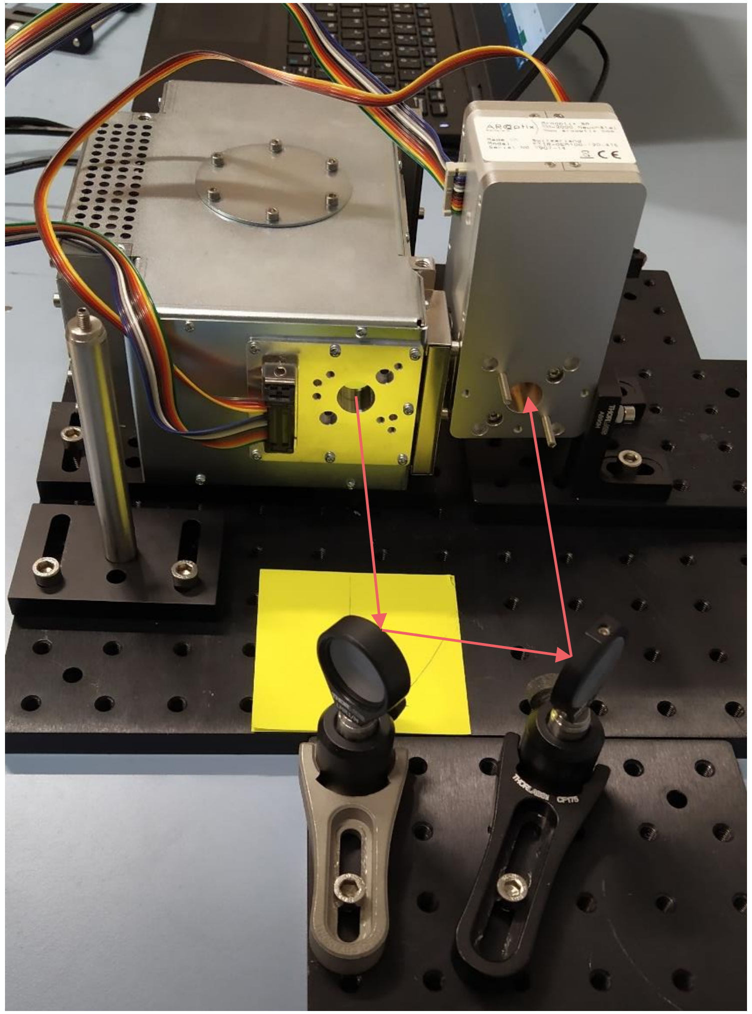




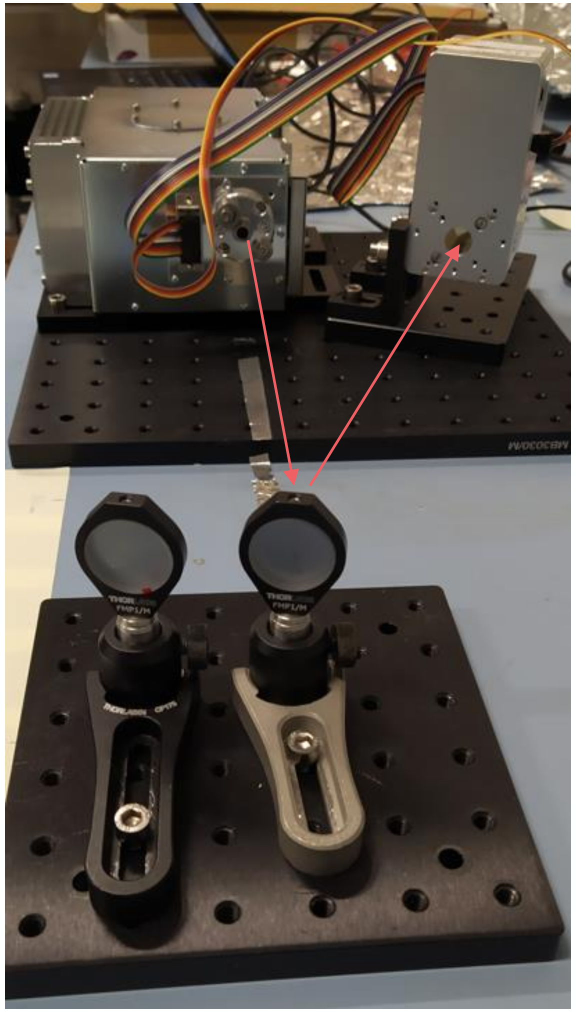
2.3 Set-up

Reflectance configuration: Some examples

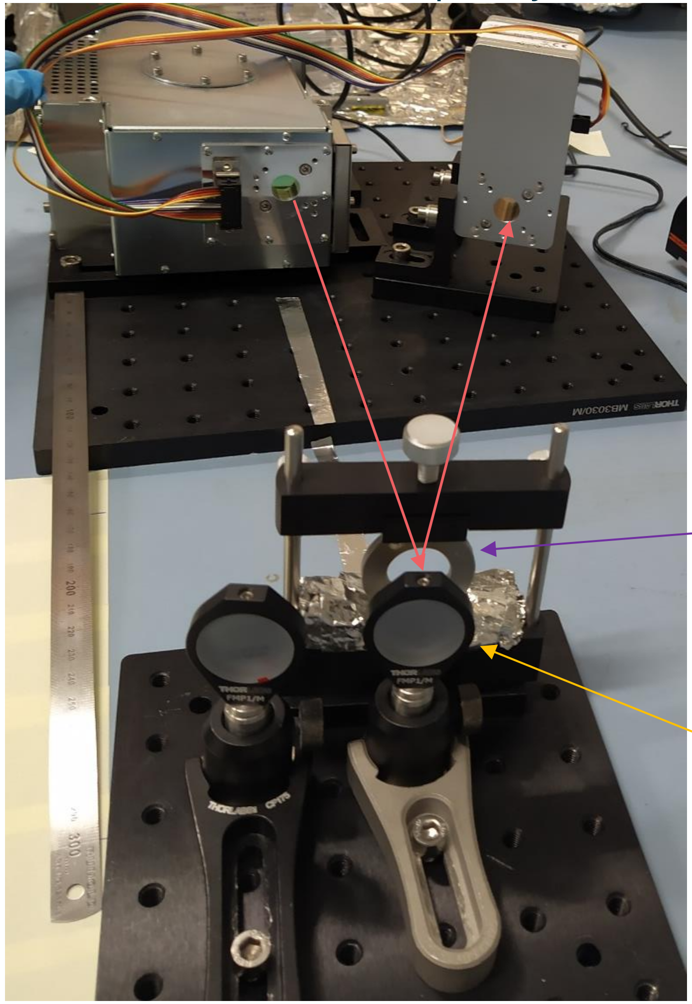
Double reflection



Single reflection



a somewhat more complex system:



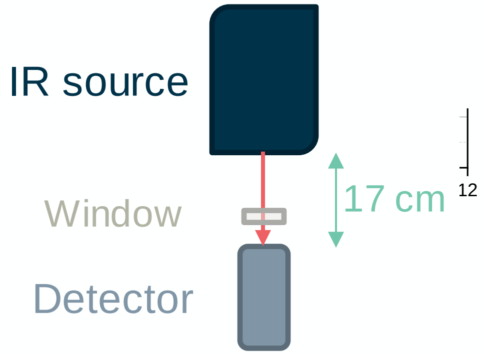
Contaminated window

measured through

Specular back reflection

3. Results

Transmittance:

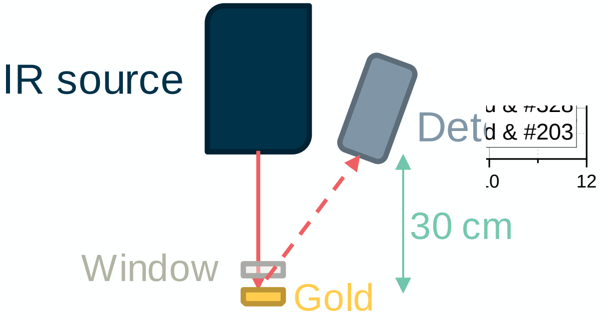


Level of silicone contamination:

#203: 1E-05 g/cm²
#217: 1E-05 g/cm²
#328: 1E-06 g/cm²
#322: 5E-07 g/cm²

3. Results

Reflectance:

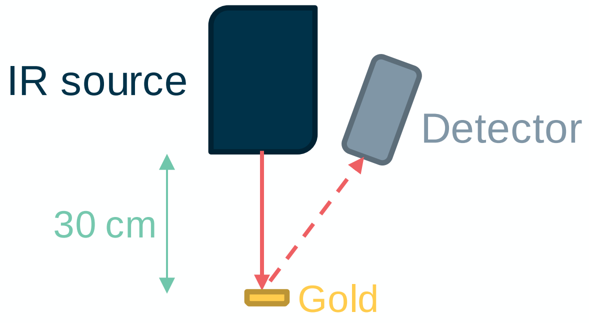


Level of silicone contamination:

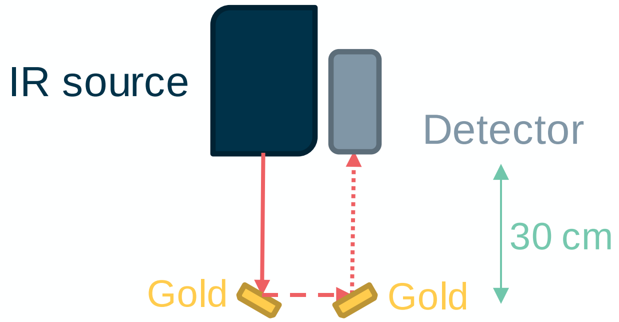
#203: 1E-05 g/cm^2
#328: 1E-06 g/cm^2
#715: 7E-08 g/cm^2

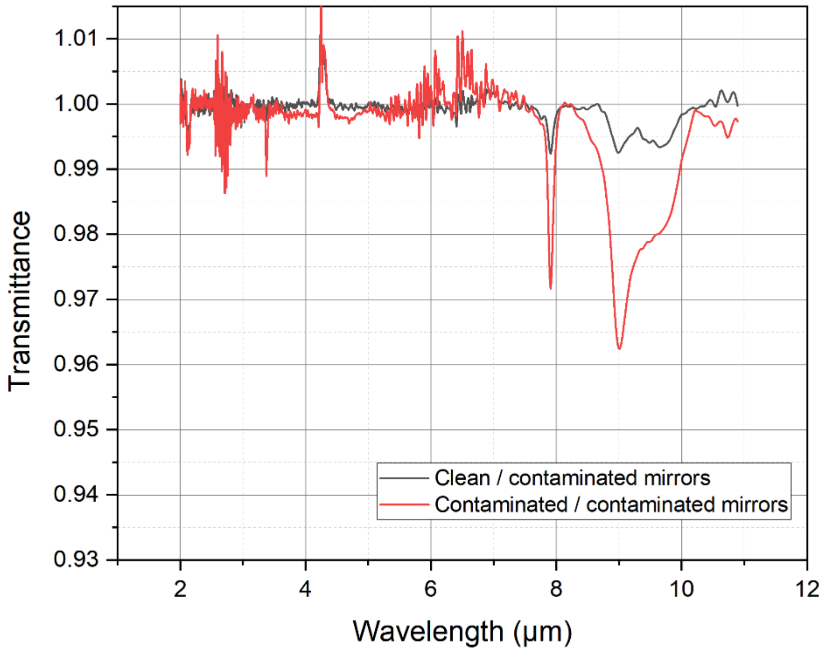
3. Results

Single reflection:



Double reflection:





Level of silicone contamination (dark grey curve):

Contaminated mirror : ~ 1E-06 g/cm^2

4. Key variables for future work

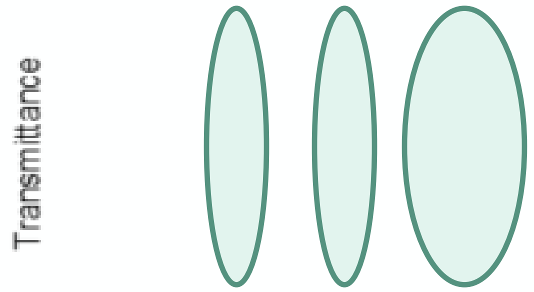
Some aspects to consider:

- **Alignment is key**
  - Reproducibility / repeatability / probed area
  - Homogeneity of contaminant

- **Environmental effects**
  - CO_2, H_2O compensation
  - Inert atmosphere (?)

- **System**
  - Set-up (distance, accessibility of hardware)
  - Instrument settings (apodization, gain, …)
  - Sensitivity / Limit of detection
  - Wavelength of interest (e.g. silicones vs hydrocarbons detection)
  - Optical guides (?)
  - Calibration (absorbance curve)

- Artificially contaminated references can be difficult to produce



5. Conclusions

The study confirms the **feasibility** of the new method to allow *contactless molecular contamination measurements*.

It can be used to verify molecular contamination requirements **directly on sensitive surfaces** during ground life (e.g. acceptance of hardware), post TVac, etc.

It can also be used as an inspection tool to **evaluate non-conformances**, allowing a correct assessment of the risk and helping define a way forward (cleaning method, use-as-is, rework, scrap, …).

- **Calibration** is possible through absorbance curves
- Based on **well established FT-IR** measurement procedures used to quantify MOC levels (e.g. hydrocarbons, esters, silicones)
- Wide range of **surfaces** can be measured (IR mirrors, transparent optics, …)

The wide spread application as a **verification tool** can be reached after some optimizations and trade-offs (future work).

Acknowledgement

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