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Micro-ElectroMechanical Systems (MEMS) Fabry-Perot (FP) spectrometer for measurement of contamination deposition

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Scope

- Background
- Standard measurement
- MEMS spectrometer development
- Some measurement results
- Conclusion

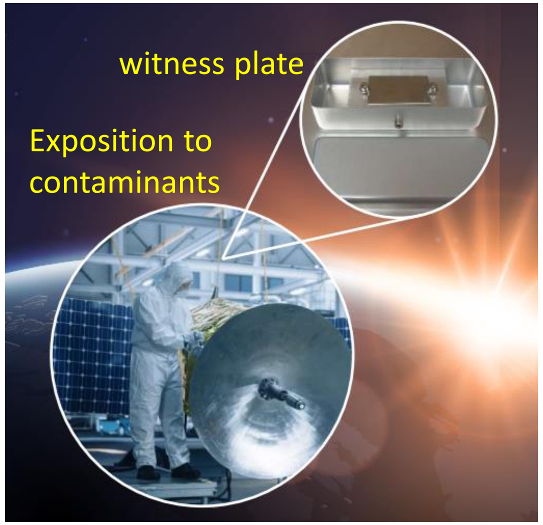
Background I

- Current monitoring methods of molecular contamination are based on witness exposure, allowing only the punctual and ex-situ estimation of the deposited levels on sensitive surfaces.
- Besides, conventional monitoring is performed usually until encapsulation, in the best case under fairing prior launch, and from launch to end of-life, only estimation by modelling is performed.
- Overall, there is currently a lack of representativeness and only a partial coverage of the molecular contamination monitoring over the whole mission.
- Having the capability to perform in-situ and real-time monitoring of the molecular contamination will improve the representativeness of the measurements and the triggering of mitigation actions to ensure optimal system performances until end-of-life (both on-ground and in-flight).

In situ monitoring of contamination

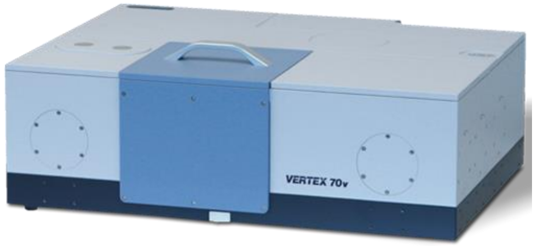
- In collaboration with European Space Agency, Tunable AS and SINTEF are aiming at developing a sensor breadboard at TRL 3 able to quantify the deposited molecular contamination (hydrocarbon, ester, and, silicones) to provide reliable in-situ and real-time data during assembly integration and testing with the possibility to be further developed for in-flight.
- The sensor is based on a piezo-MEMS Fabry-Perot Interferometer (FPI) developed and commercialized by Tunable AS for gas detection.
- The measurement system has been developed, mounted and tests on some highly concentrated reference samples initiated

Standard measurement of contamination(1)

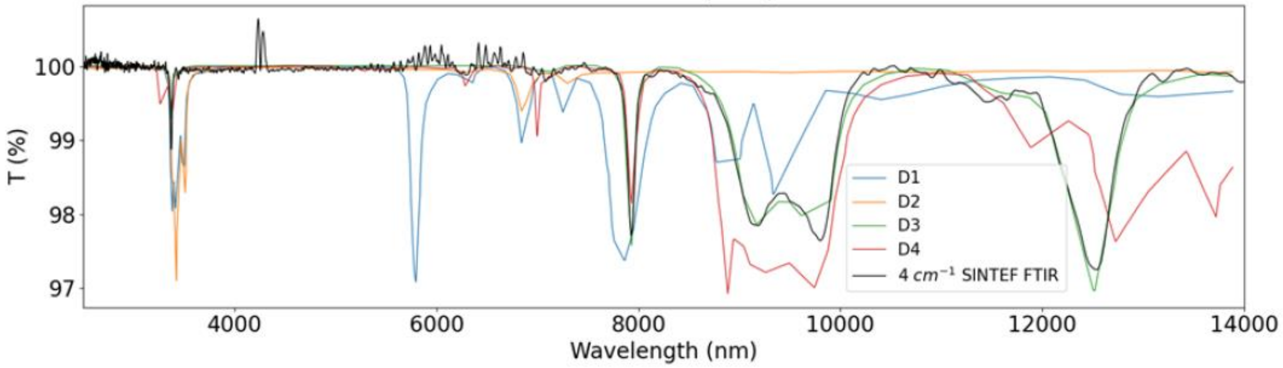


(2)

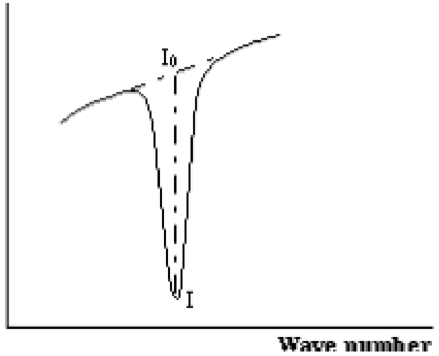
FTIR bruker V70



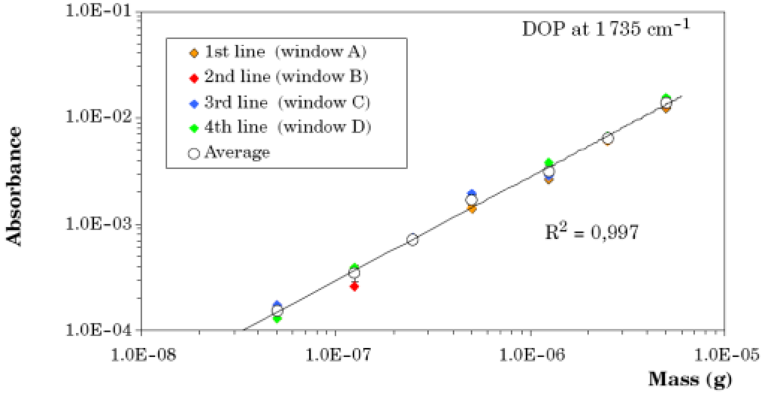
FTIR spectra of contaminants



Extraction of peak height at a few characteristic wavelengths



Quantification using Beer Lambert law



(1) Detection of organic contamination of surfaces by infrared spectroscopy, ECSS-Q-ST-70-05C Rev.1 15 October 2019
(2) Picture: courtesy of Lucideon https://cdn.lucideon.com/v2/downloads/MOC-Technical-Poster.pdf

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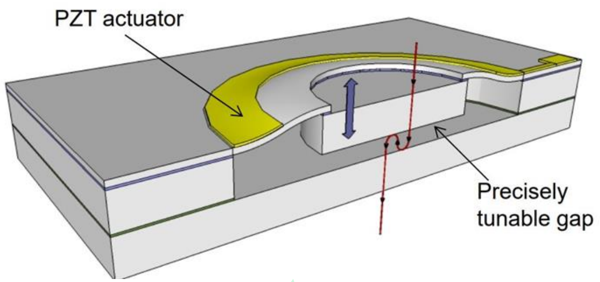
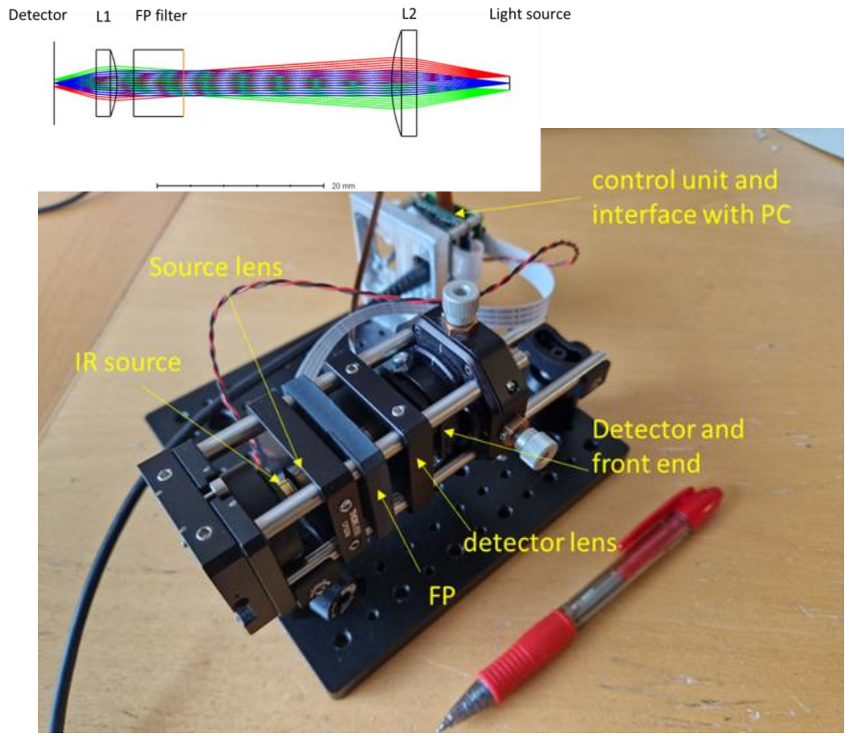
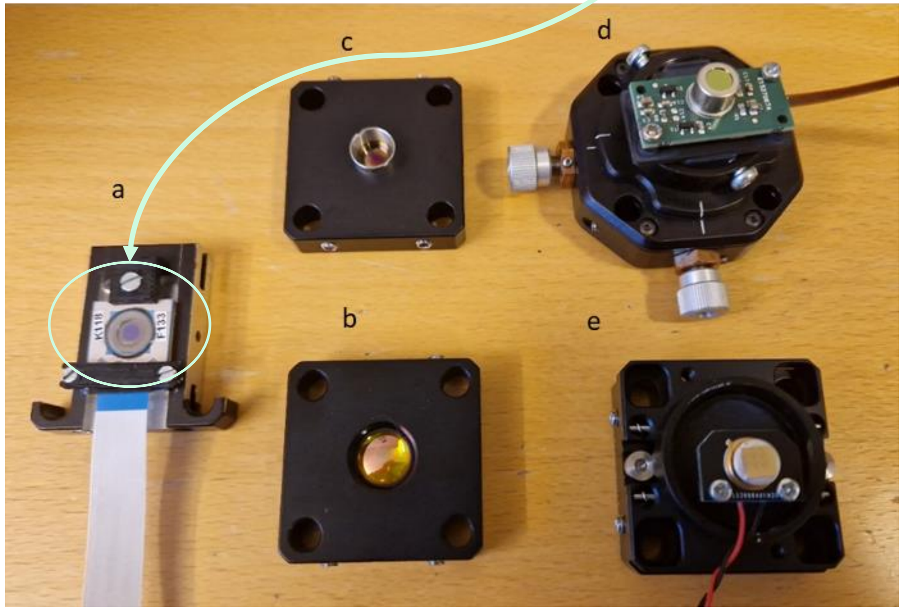
Fabry-Perot spectrometer





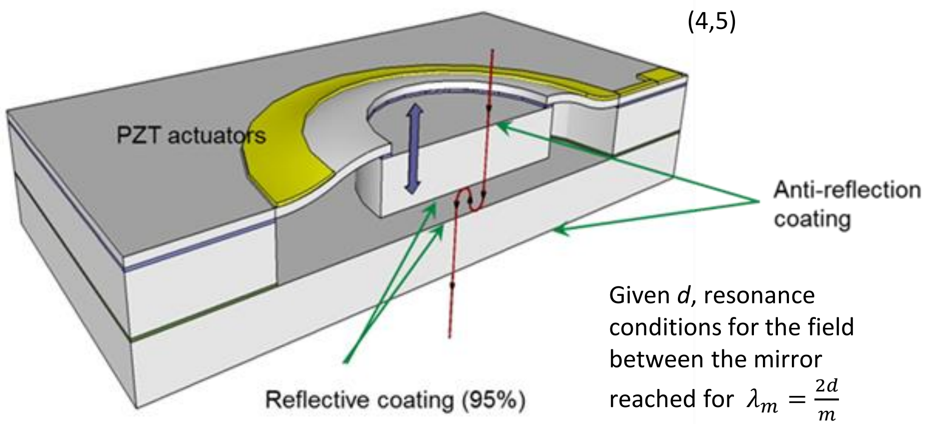


a) FP filter; b) Lens L2; c) lens L1; d) Detector and detector front end electronic; e) Light source

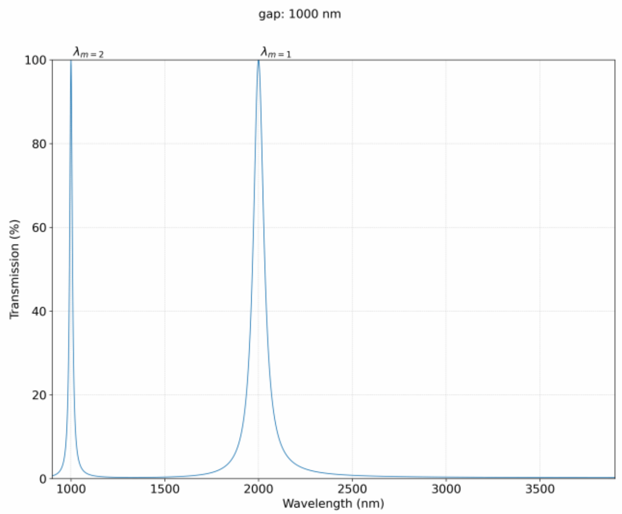
- Volume: 15 cm x 15 cm x 10 cm.
- FWHM ranging between 25 cm^{-1} and 40 cm^{-1} (3)

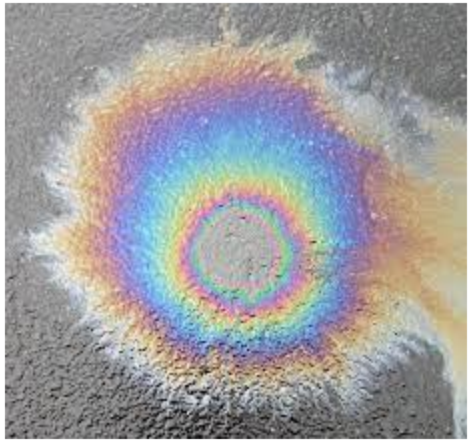
(3) FWHM α path difference between in and out beam

Piezo MEMS Tunable filter

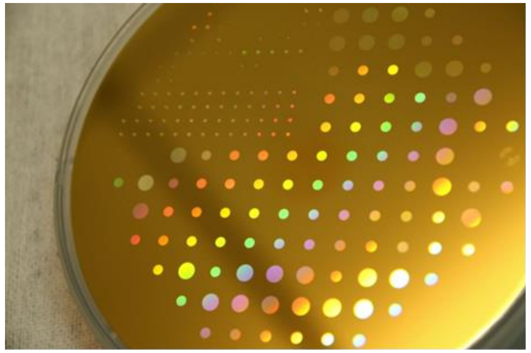


Given d, resonance conditions for the field between the mirror reached for $\lambda_m = \frac{2d}{m}$

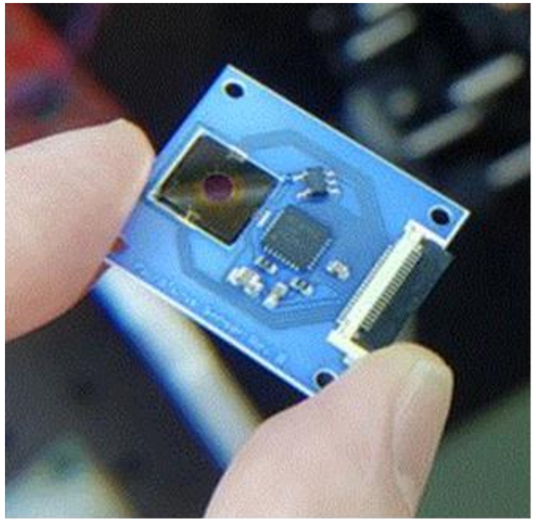




interference on thin oil film on water



micromirrors on wafer Photo: Karolina Milenko / SINTEF



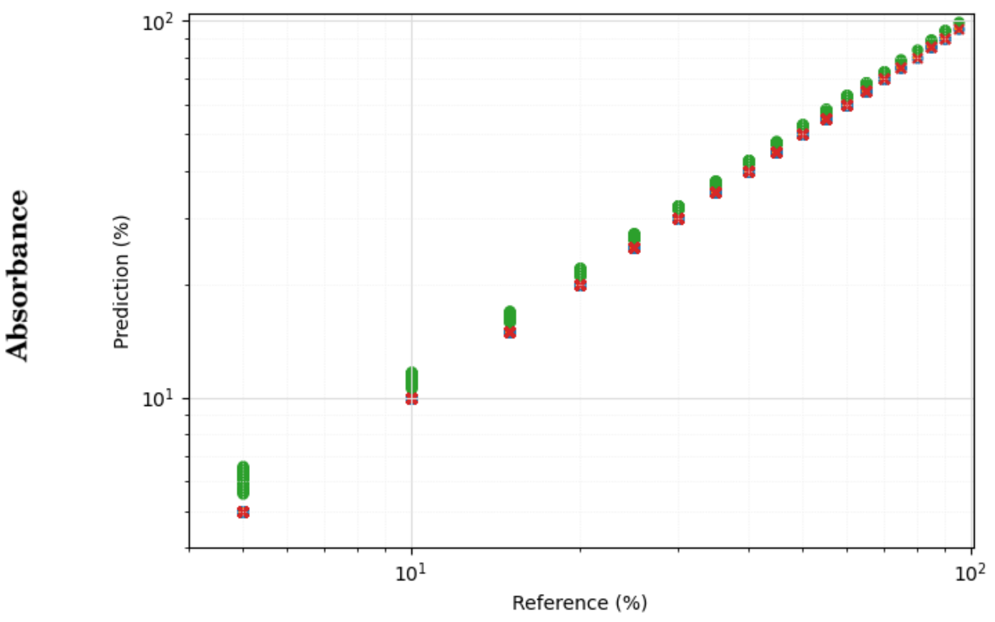
Picture: courtesy of Tunable AS

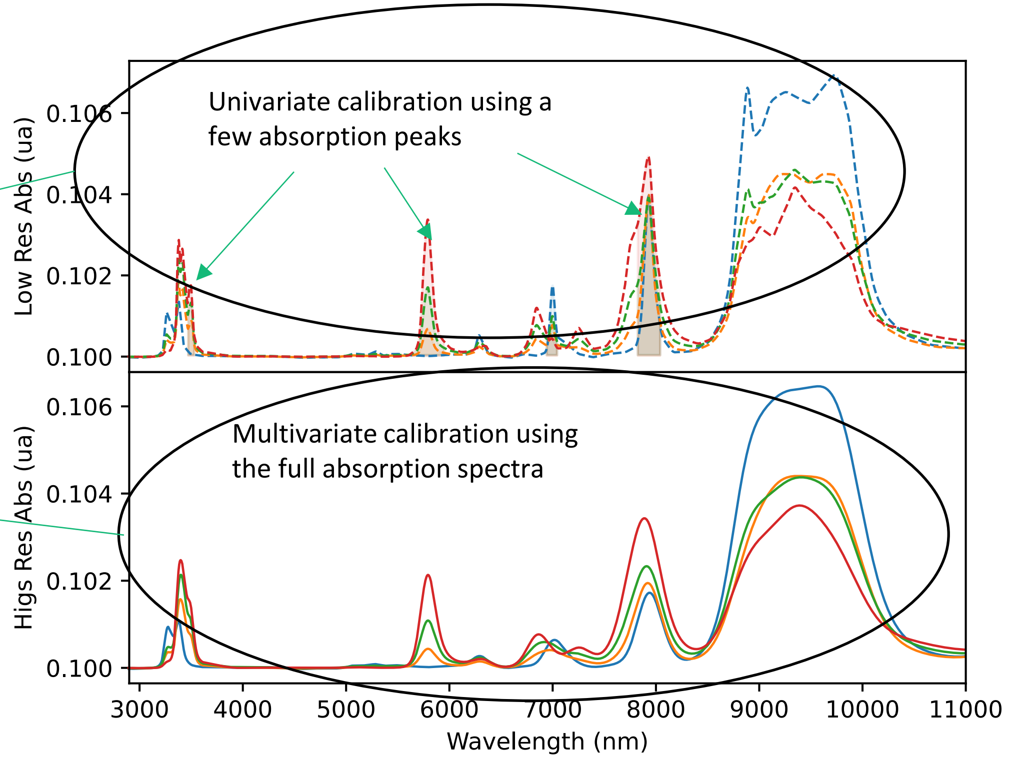
[4] https://www.sintef.no/en/expertise/digital/microsystems-and-nanotechnology/piezomems/
[5] T. Bakke, A. Vogl, O. Żero, F. Tyholdt, I.-R Johansen and D. Wang, 2010 *J. Micromech. Microeng.* **20** 064010

FTIR versus Micro MEMS spectrometer

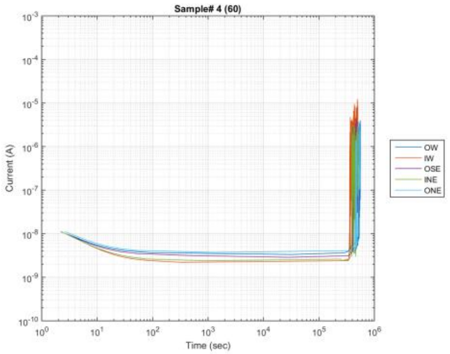
- **A MEMS spectrometer would outperform FTIR in terms of volume, weight and cost, but with a trade off in term of spectral resolution and Signal to Noise Ratio =>no free lunch**

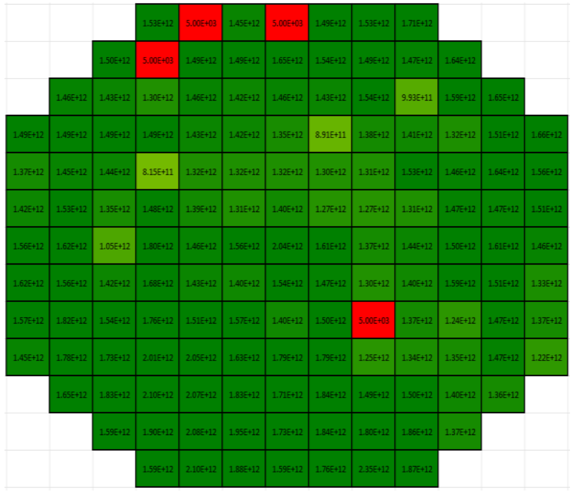
- **Using more points from a low-resolution spectra will enable good enough quantification, by using machine learning algorithm (e.g Partial Least Square) to handle collinearity between spectral channels**

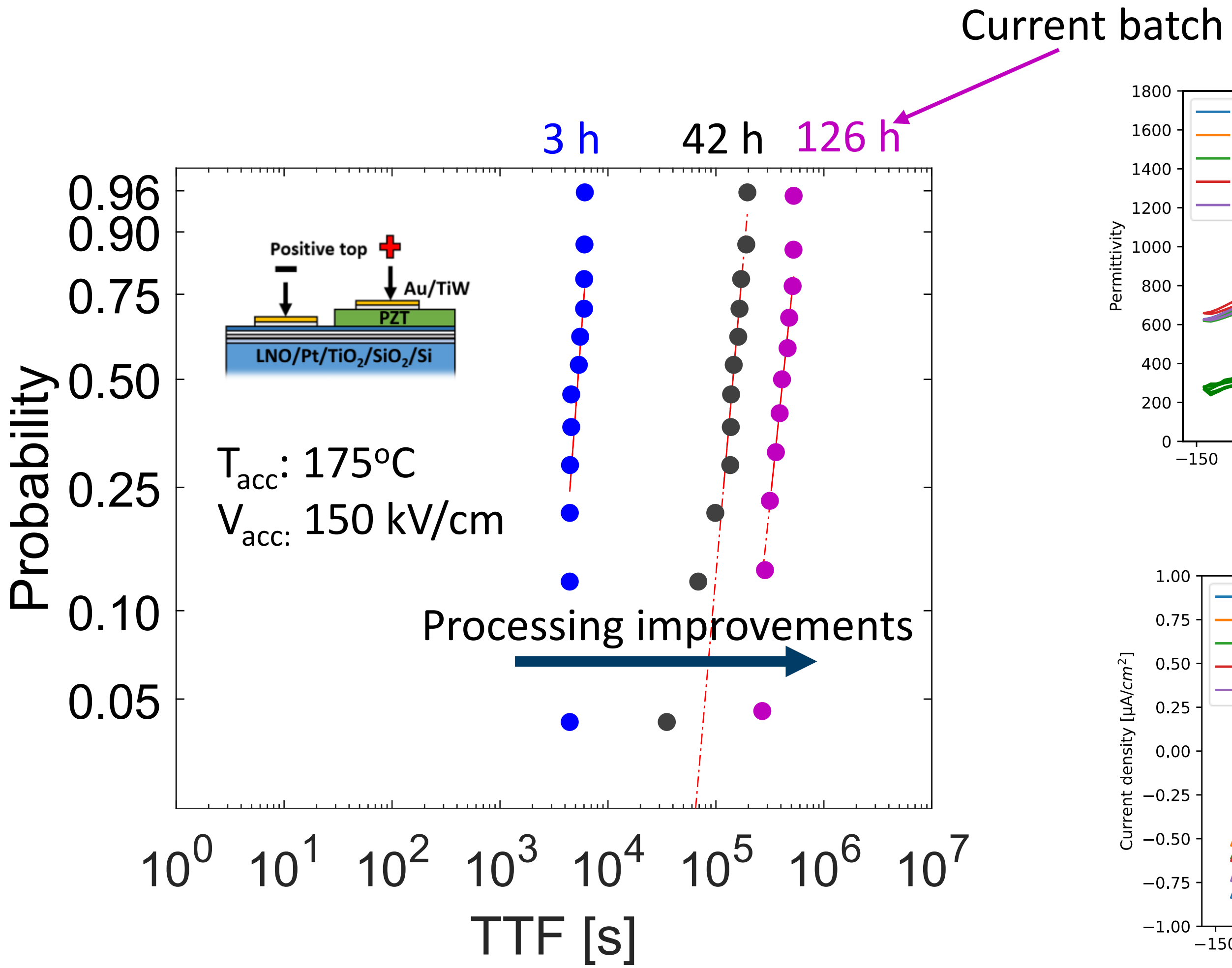


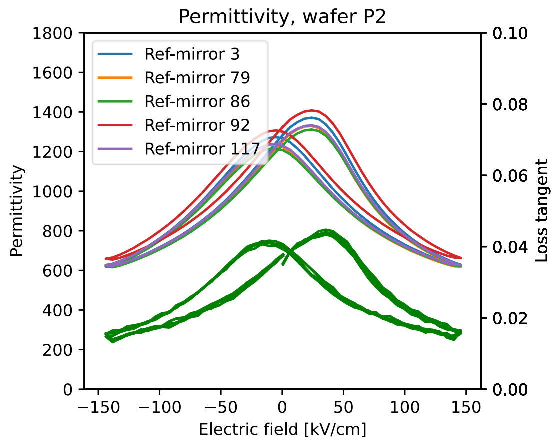


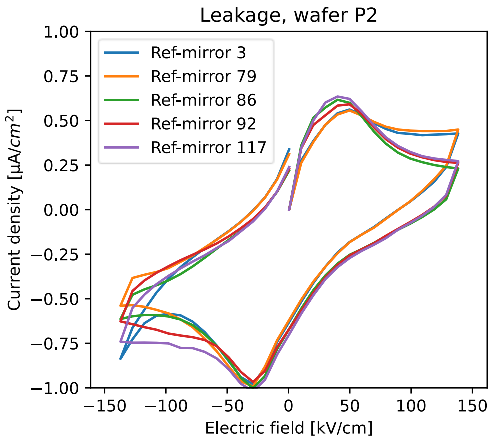
MEMS manufacturing and reliability







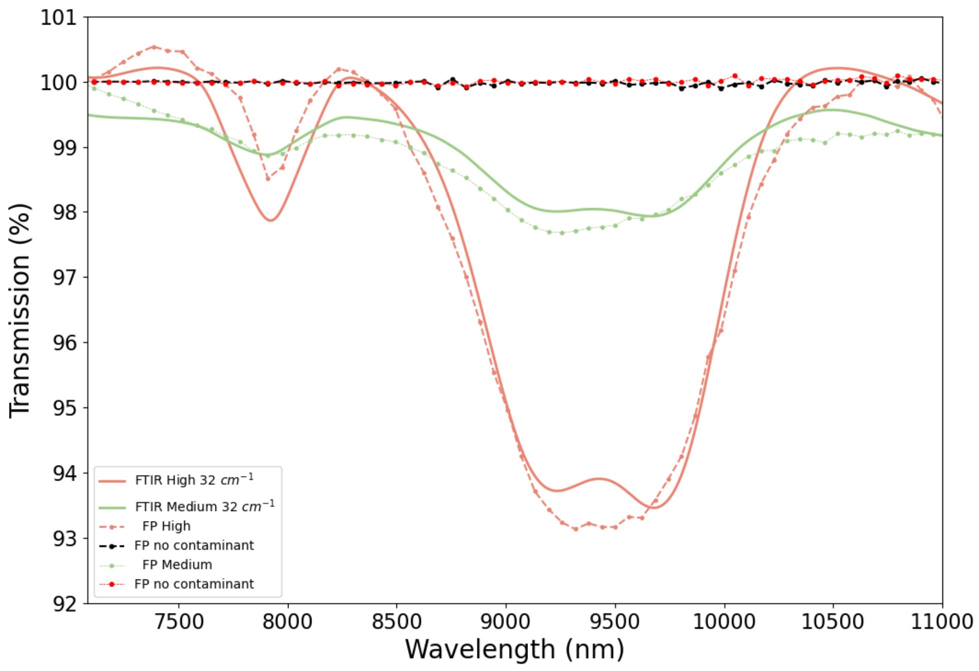




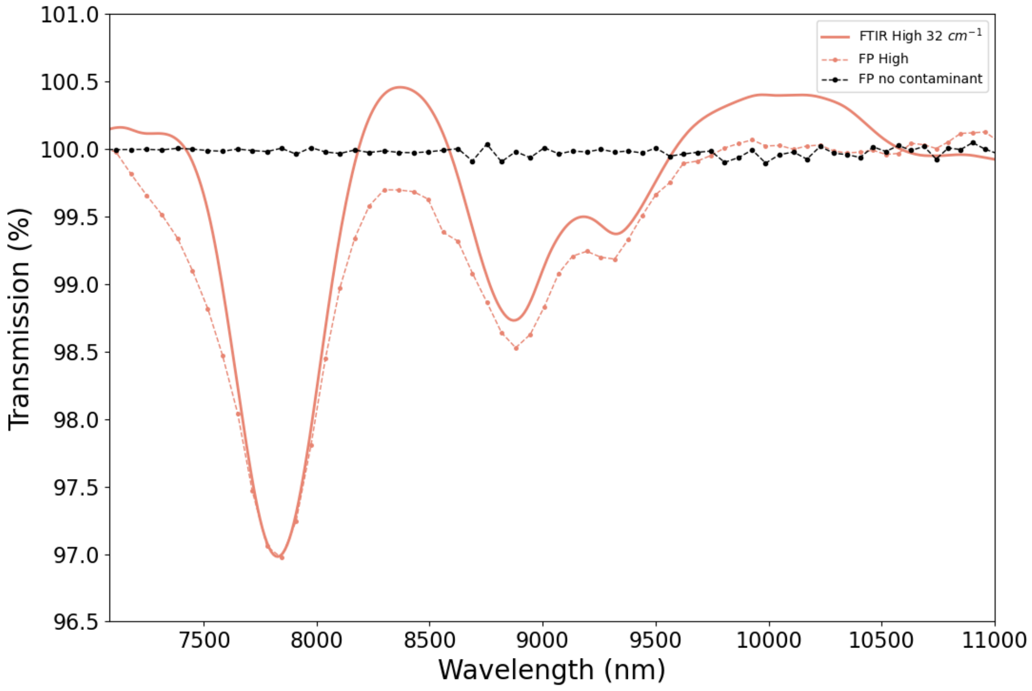
(6) R. Dahl-Hansen et al. Appl. Phys. Lett 121,132901 (2022)

A few examples of measurement

- Measurement performed using the MEMS spectrometer on two references samples
- Compared with FTIR measurement performed at 32 cm^{-1}
- Very good agreement between the two measurements showing that the FWHM is as expected



poly (dimethylsiloxane)



bis (2-ethylhexyl) phthalate

Conclusion

- In a project with ESA, we are aiming at developing a MEMS spectrometer for in-situ monitoring surface contamination for clean room and in-flight applications.
- We have developed a MEMS spectrometer using a MEMS Fabry Perot tunable filter at TRL 3 and performed tests showing that the spectrometer perform as required.
- The next step is to develop a stand alone unit allowing to collect contamination spectra in situ and establish calibration models for the four mains contaminants

Acknowledgement

Activity undertaken under ESA contract No. 4000139400

https://www.tunable.com/: Design the chips and developed and deposited the coatings, developed methods and equipment for assembling the chips, the electronics, calibrated the filters and developed the control algorithms.

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