

COMPACT MEMS HIGH-SPEED FOURIER-TRANSFORM SPECTROMETER



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Motivation and Objectives



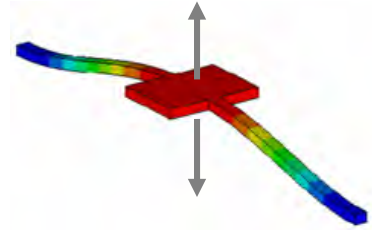
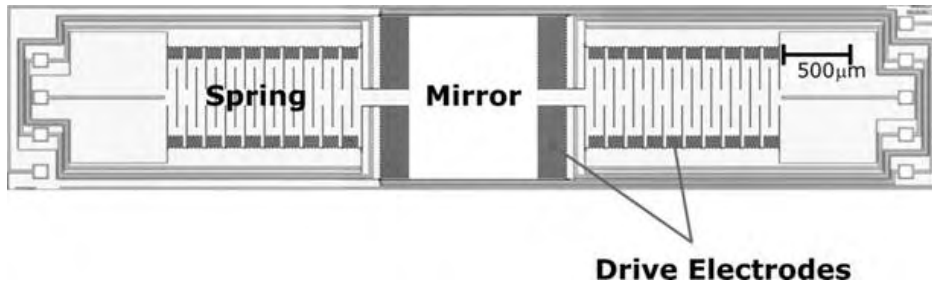
- ☺ mid-IR spectroscopy is nice tool for process analysis
"Chemical Sensor", without need for chemo- or bio-selective layers

BUT

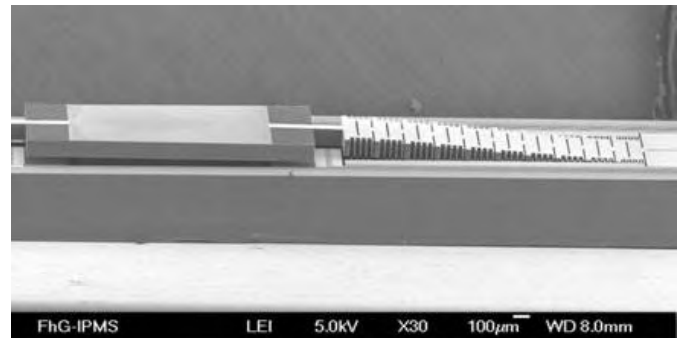
- ☹ FT-spectrometers are rather large and only some are suitable for process environments
- ☹ in the mid-IR, grating systems only cover a limited spectral range
- ☹ long mid-IR fibres are still a problem, making centralised instruments problematic

Challenge

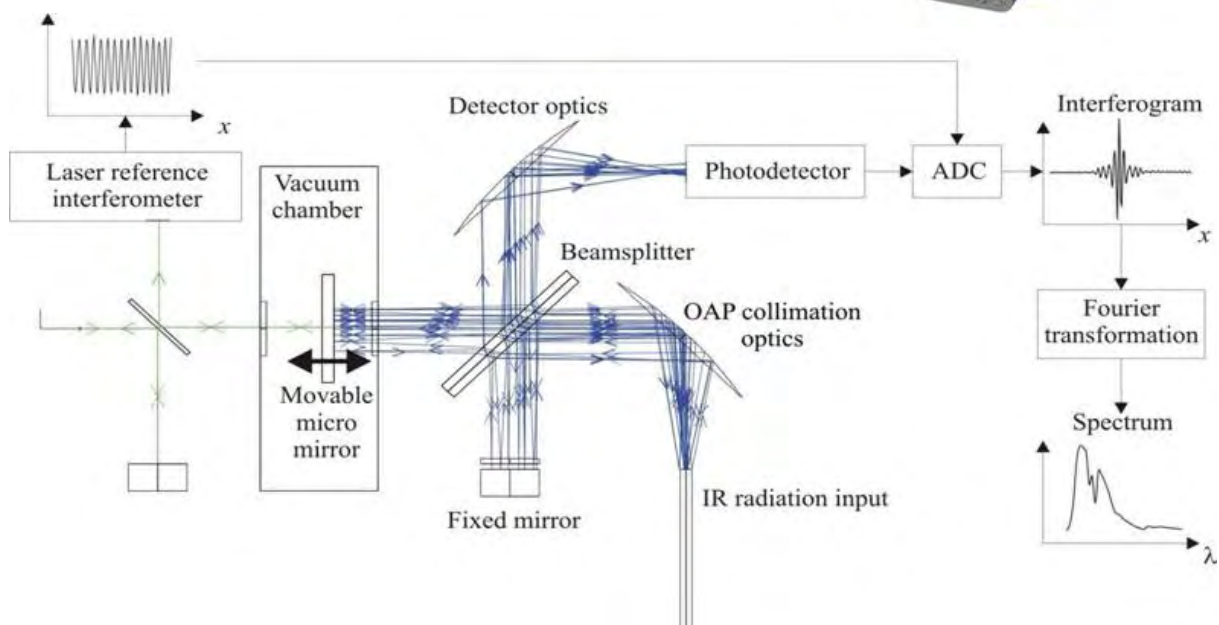
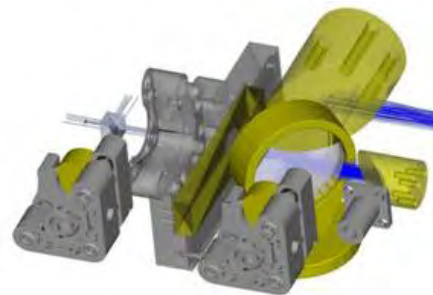
- **Build an OceanOptics-like FT-spectrometer**
 - ❖ miniaturisation
 - ❖ increased ruggedness of the spectrometer
(mechanical shock and vibrations, ...)
 - ❖ significant cost reduction

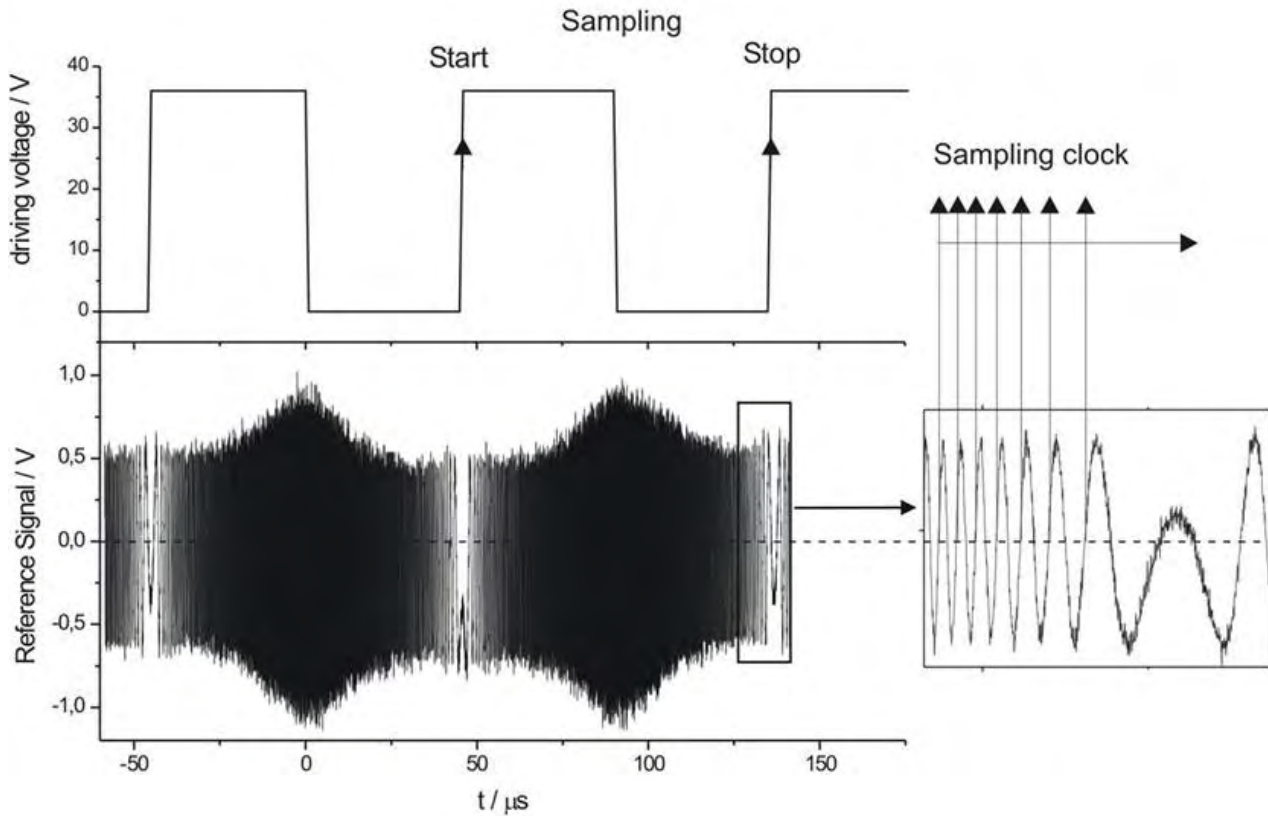


- ❖ electrostatically actuated translatory micro-mirror device
- ❖ mechanical amplitude $\pm 100 \mu\text{m}$ @ 5.2 kHz
- ❖ electrostatic low-voltage drive driving voltage $\leq 36 \text{ V}$
- ❖ resonant operation up to kHz range
- ❖ effective mirror area $\sim 1.6 \text{ mm}^2$
- ❖ manufactured in with semiconductor bulk processes

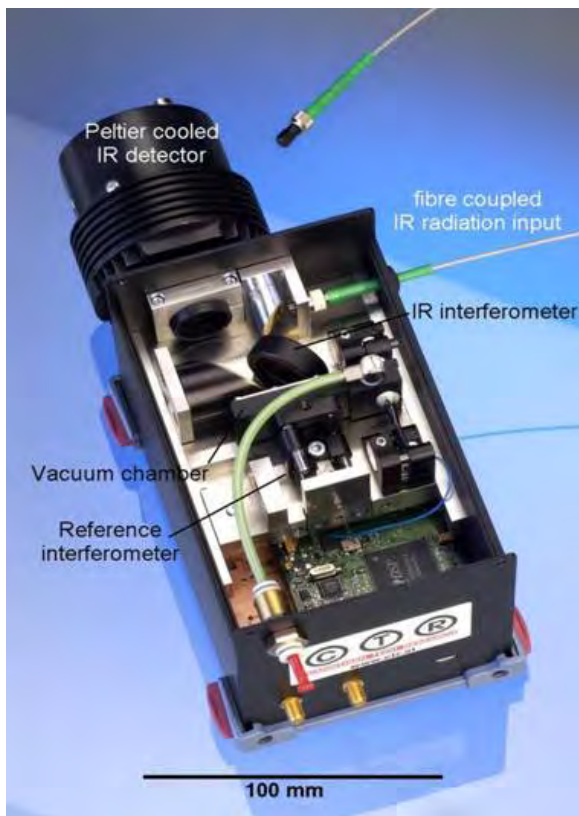


- ❖ compact 90° Michelson layout
- ❖ minimised number of optical components
- ❖ fibre-optics interface, direct interface optional
- ❖ reference laser interferometer for *mirror position encoding* and *mirror control*
- ❖ expected resolution $\sim 30 \text{ cm}^{-1}$



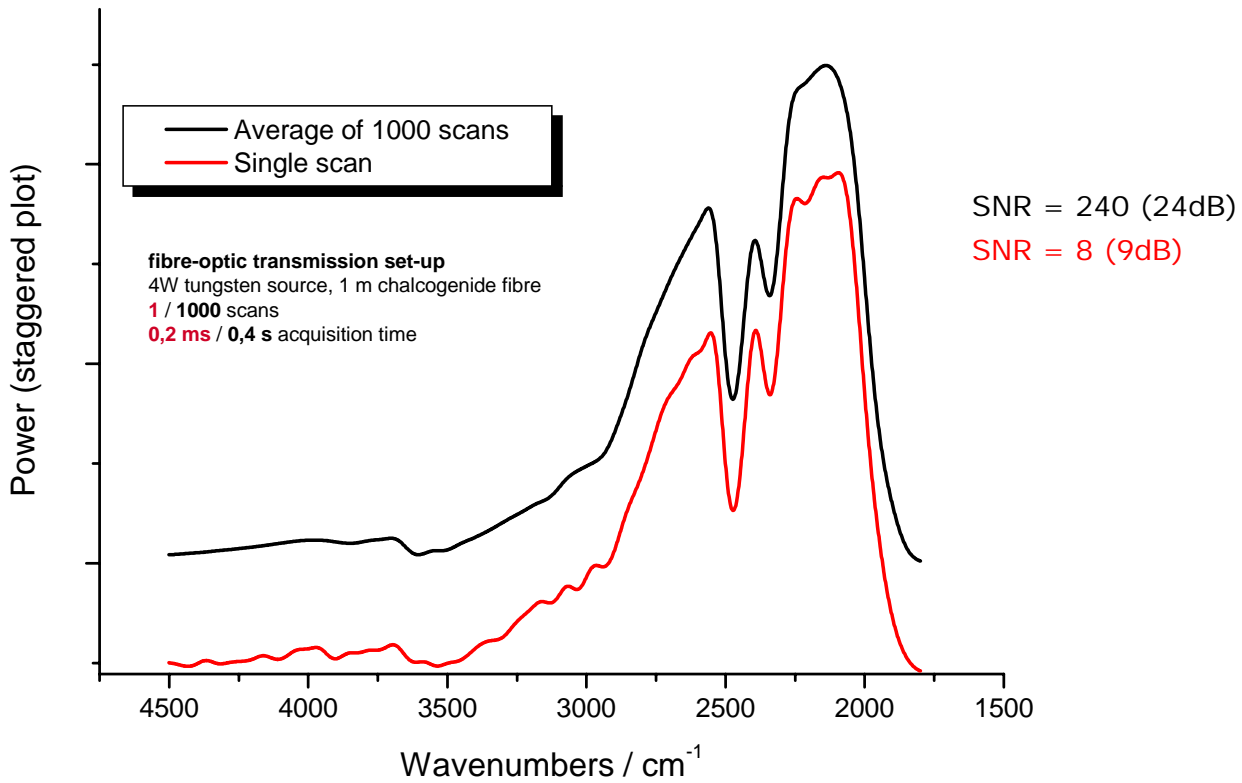


Reference signal clocked sampling eliminates distortions due to the mirror's nonlinear motion.

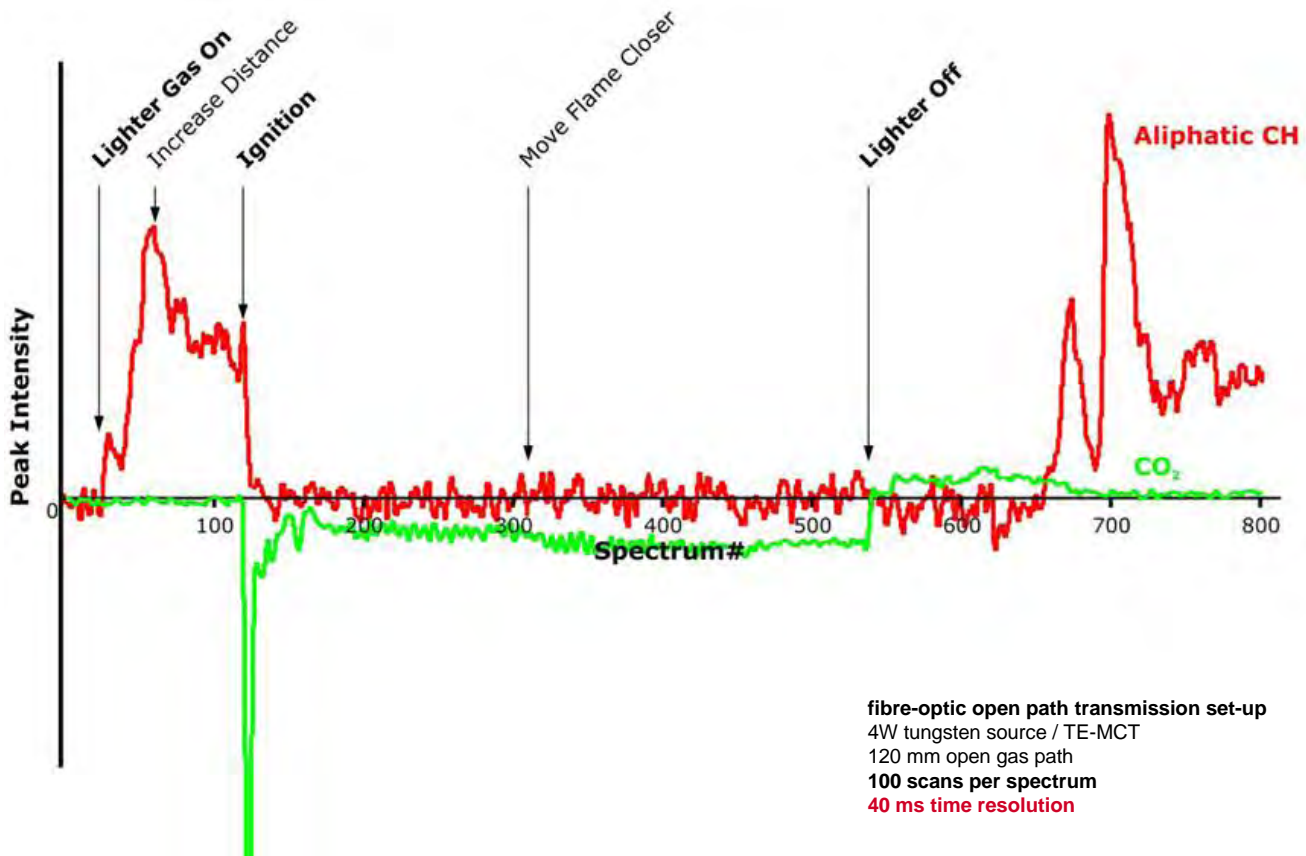


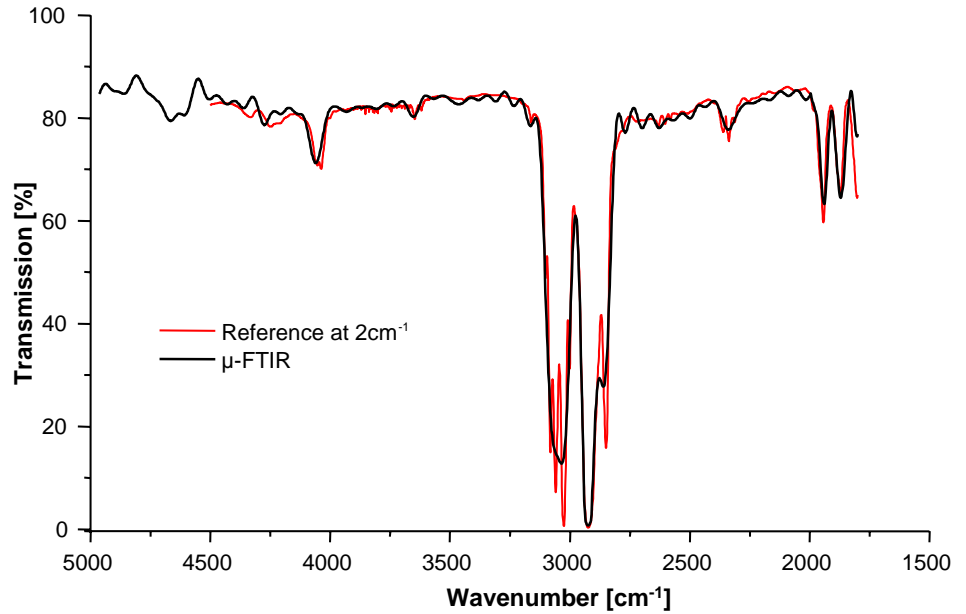
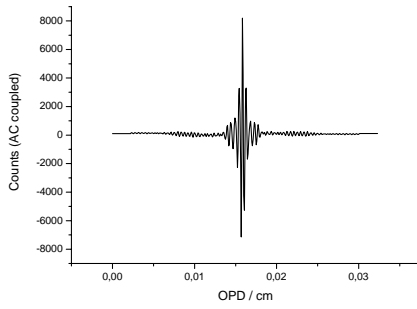
MEMS- μ FTIR prototype I

- ❖ compact single-detector FT-IR / FT-NIR spectrometer (180 x 120 x 100 mm³, 1,7 kg)
- ❖ low power consumption
- ❖ spectral range 2,2 – 5,5 / 9,5 μm depending on detector, beamsplitter and fibre optics
- ❖ spectral resolution < 30 cm^{-1}
spectral accuracy < 4 cm^{-1}
- ❖ **time resolution < 1 ms**
- ❖ DSP-based integrated electronics



SNR behaviour follows the classical $\text{SNR} \propto \sqrt{N}$ relationship pretty closely



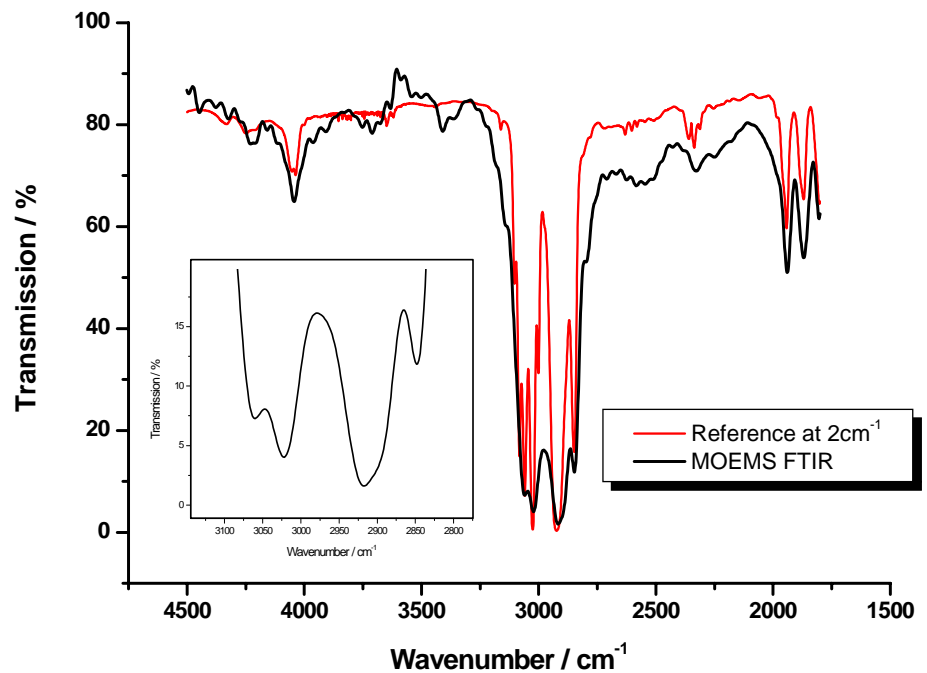
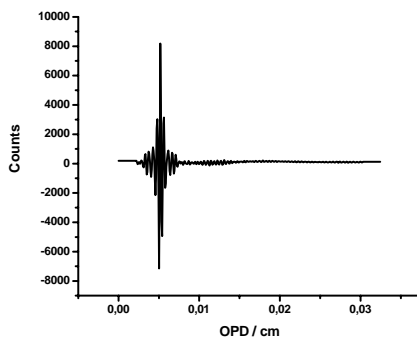


internal path transmission set-up

20 W Globar source / DTGS
1,5 mm polystyrene sample
50 scans / 118 s acquisition time

fibre-optic transmission set-up

4W tungsten source / TE-MCT
1,5 mm polystyrene sample
500 scans / 0,2 s acquisition time

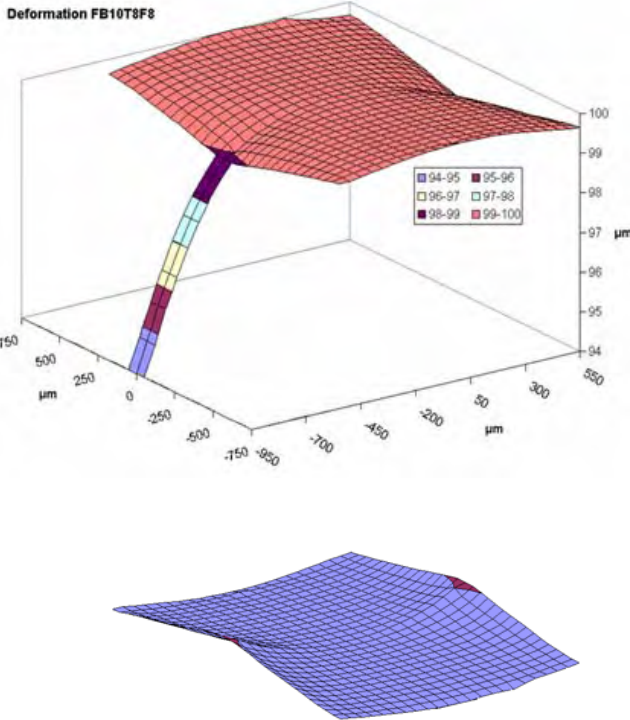


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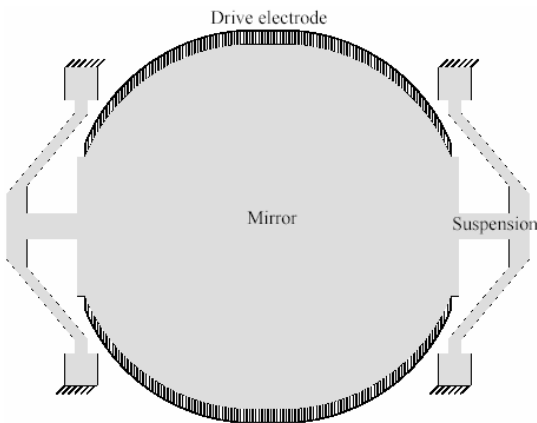
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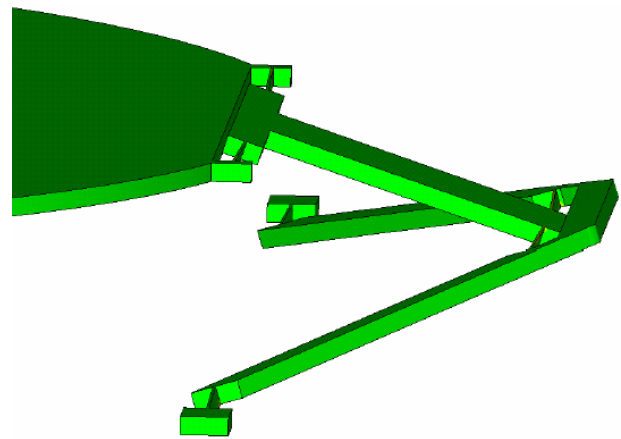


- ❖ peak-to-valley distortion: $\sim 2 \mu\text{m}$
 - ❖ global distortion: $\sim 4 \mu\text{m}$
- **dynamically asymmetric interferograms**

Distortion data from whitelight interferometric imaging at maximum amplitude



MOEMS mirror device (new design)



Bearing spring structure (simulation)

<i>Mech. Amplitude</i>	$\pm 250 \mu\text{m}$	⇒ resolution $\sim 10 \text{ cm}^{-1}$ (single-sided acquisition)
<i>Oscillation Frequency</i>	1 kHz	⇒ sampling $< 1 \text{ MHz}$
<i>Usable Mirror Area</i>	7 mm²	(circular shape)
<i>Mirror Deformation</i>	155 nm	RMS, simulated
<i>Driving Voltage</i>	$\sim 20 \text{ V}$	rectangular tooth saw actuation



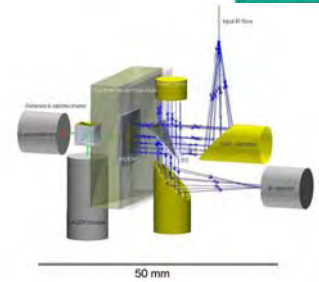
MEMS-μFTIR prototype Generation II



- ❖ MEMS micro-mirrors can be used to design compact FT-spectrometers
- ❖ combination of proven classical spectrometer layouts with novel micro-devices successfully accomplished
- ❖ MEMS spectrometers prove to be compact, thermally and mechanically robust and reliable
- ❖ scan rates up to the kHz range allow direct real-time monitoring at millisecond time resolutions
- ❖ compact size and high scan rate allowing to acquire multiple spectral scans in short time should allow to design cost-effective process analysers with acceptable SNR behaviour

❖ *Optical Bench*

- ❖ Increase mirror OPD up to 1 mm (500 μm amplitude)
- ❖ Generation III Miniaturisation
- ❖ Beam folding for resolution improvement
- ❖ Classical source – FTS – Sample - Layout



❖ *Data Evaluation*

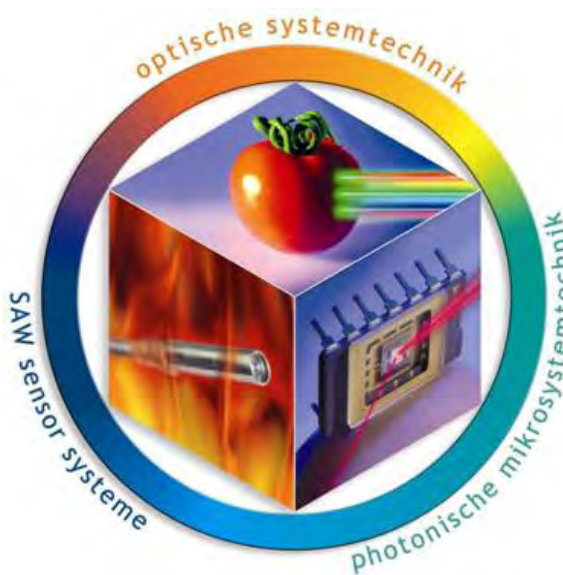
- ❖ integration of data evaluation into instrument application dependent dedicated real-time data evaluation on the integrated DSP platform pass/fail, material identity, concentration information, etc. rather than spectra requiring expert knowledge to interpret

❖ Identification of (Key) Applications

- ❖ (industrial) process control, making use of inexpensive distributed spectrometers
- ❖ time-resolved monitoring, e.g. of chemical reactions

❖ *Evaluation of further Application Areas*

outside (FT-IR) spectroscopy for (optical) MEMS components / systems



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