Miniaturized FTIR-spectrometer Based on Optical MEMS Translatory Actuator

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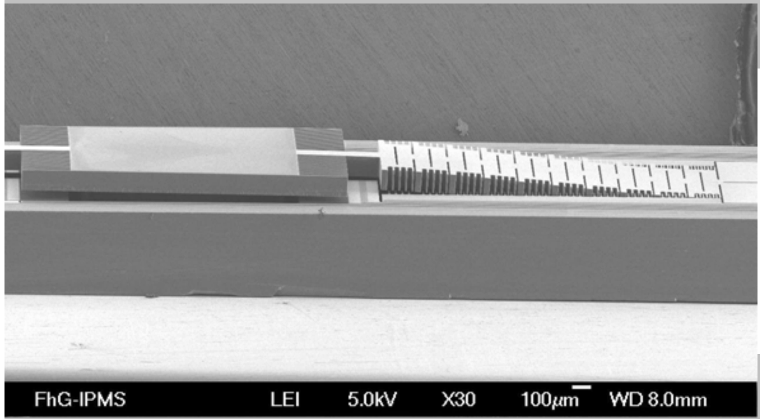

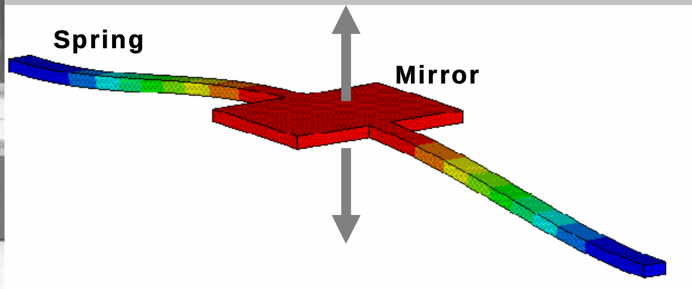

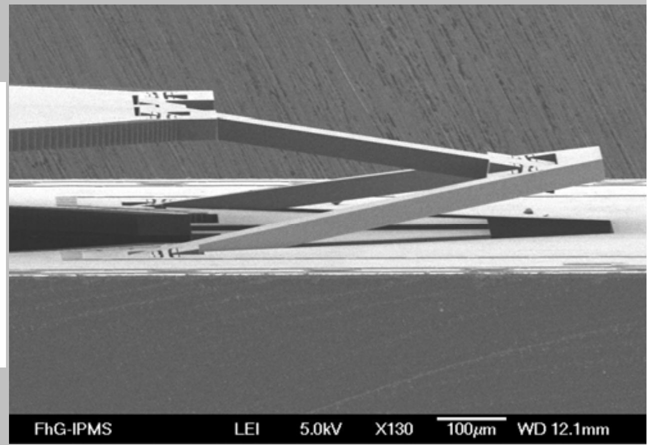

Miniaturized FTIR-Spectrometer based on Optical MEMS Translatory Actuator

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Outline

I Introduction

- Advantages of FT spectrometers
- Motivation for MOEMS based FT spectrometers

II MEMS optical path length modulator

- Translatory mirror design
- Experimental results

III System integration

- FTIR System description
- Interferogram sampling concept
- Results / sample spectra

IV Summary

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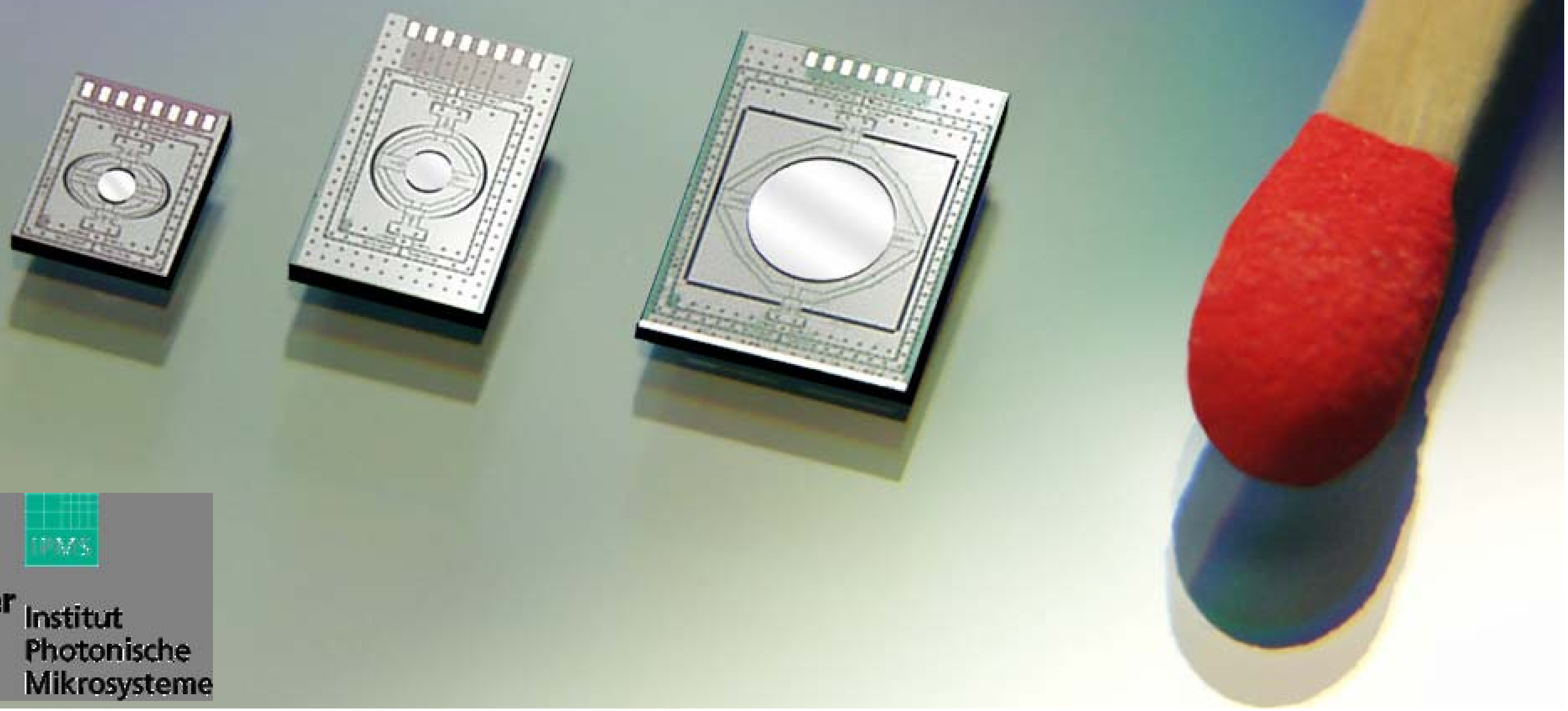
MEMS Scanning Mirror

Properties

- Large optical scan range up to 112°
- High frequencies up to 32 kHz
- Mirror diameter: 0.5 - 3 mm
- 1D and 2D deflection
- High vibration and shock stability
- Excellent long-run behaviour
- Qualified fabrication process
- resonant operation



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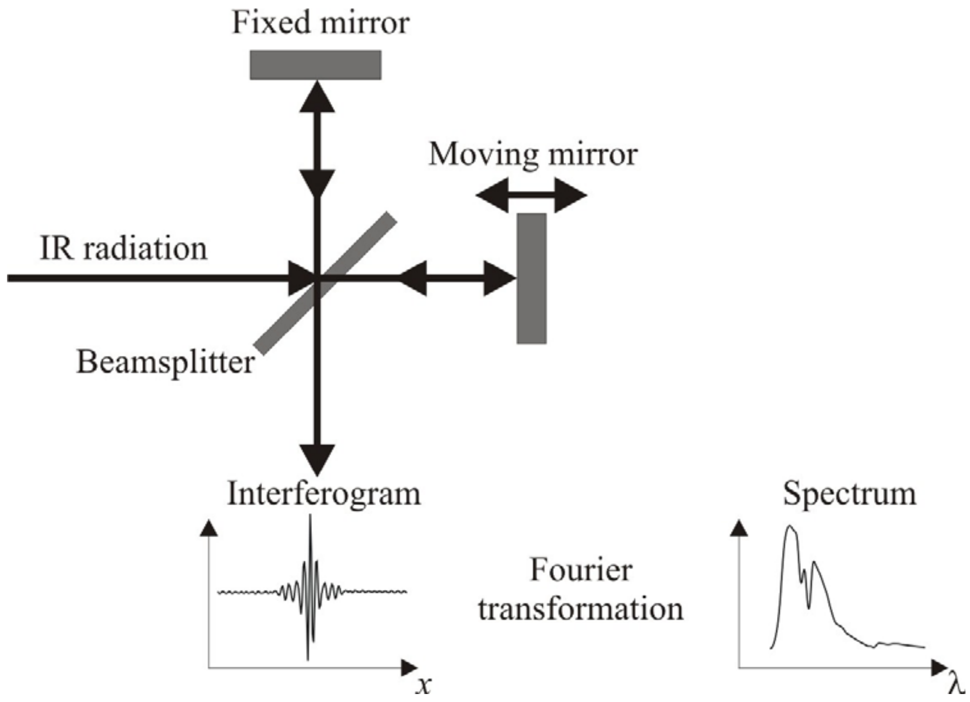
Introduction to FT spectrometry

- The main component of a FT spectrometer is a two beam interferometer e.g. a Michelson interferometer.
- The output signal of monochromatic radiation is a cosine wave or of a polychromatic source it is the sum of all cosine waves which is called interferogram.
- A numerical cosine Fourier transformation from time domain (interferogram) to frequency domain yields the spectrum.
- The spectral resolution $\varDelta\upsilon$ depends on the maximum possible OPD of the interferometer.

$$\Delta\nu \approx \frac{1}{2\,OCD}$$



Schematics of a Michelson interferometer

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FT versus diffractive spectrometry

Advantages

- *Fellget advantage* (multiplex advantage): All frequencies are measured simultaneously.
- *Jaquinot advantage*: No optical stops -> higher energy throughput.
- *Connes advantage*: Laser referenced wavelength classification.
- Wide spectral range accessible: Limited by dispersion and detector response only.
- Constant resolution over the entire spectral range.

Drawbacks

- Complex, high precision mirror drives.
- Shock sensitive instrumentation.

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Development objective / motivation

Advantages due to MOEMS technology

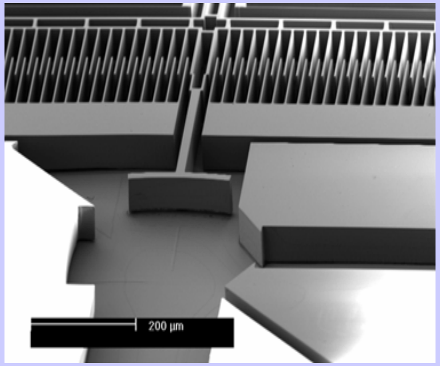
Replacement of the macroscopic mirror and its drive with an oscillating micro-mirror.

- Increased reliability and ruggedness.
- System miniaturization.
- Cost reduction.
- Ultra-rapid scan capability. Acquisition time of 0.2 ms for a single scan.

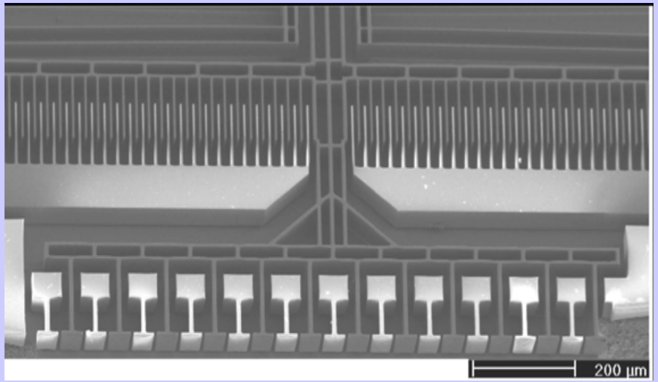
Example of MEMS based FTS:

a) Translatory mirror, b) Lamellar grating booth with in-plane-comb drive

Quelle:
O. Manzardo, Ph.D. Thesis, Neuchatel, 2002



a)



b)

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Outline

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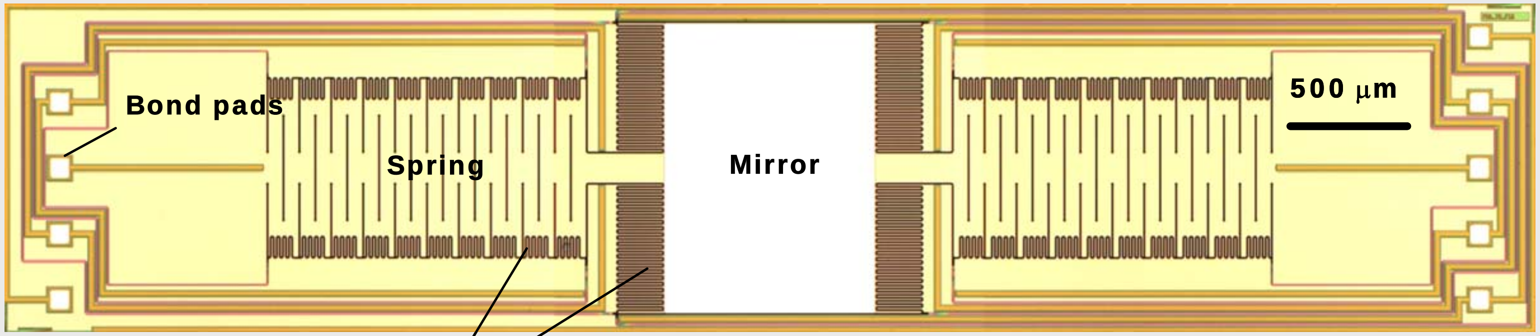
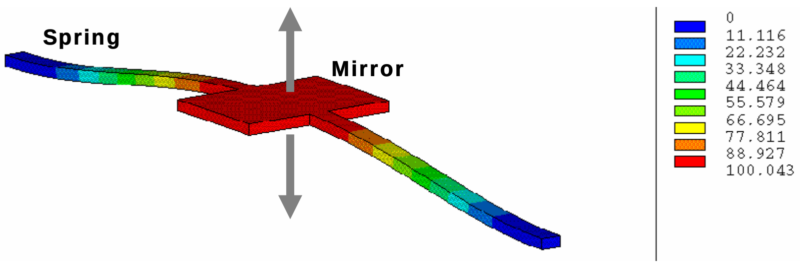
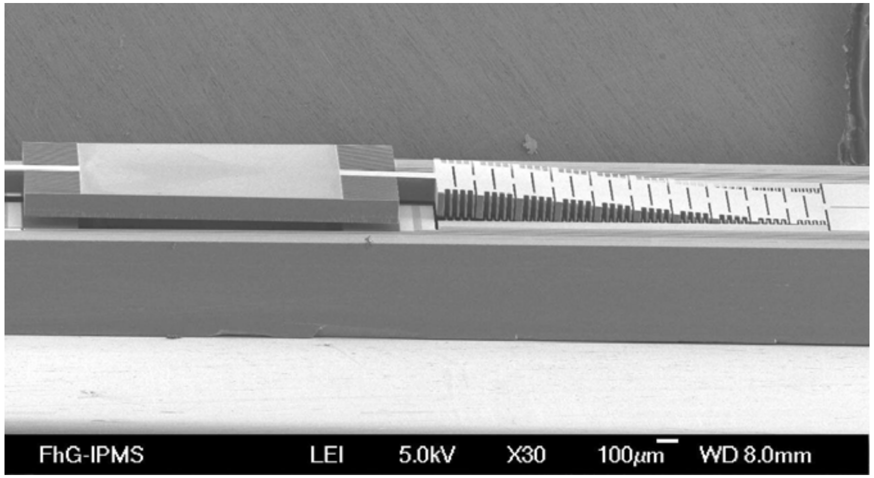
Translatory MOEMS for FT-IR



1.8 x 9.0 mm²

- Fabricated with bulk micromachining technology using 100µm SOI.
- Folded springs to reduce mechanical stress.
- Use for optical path length modulation.





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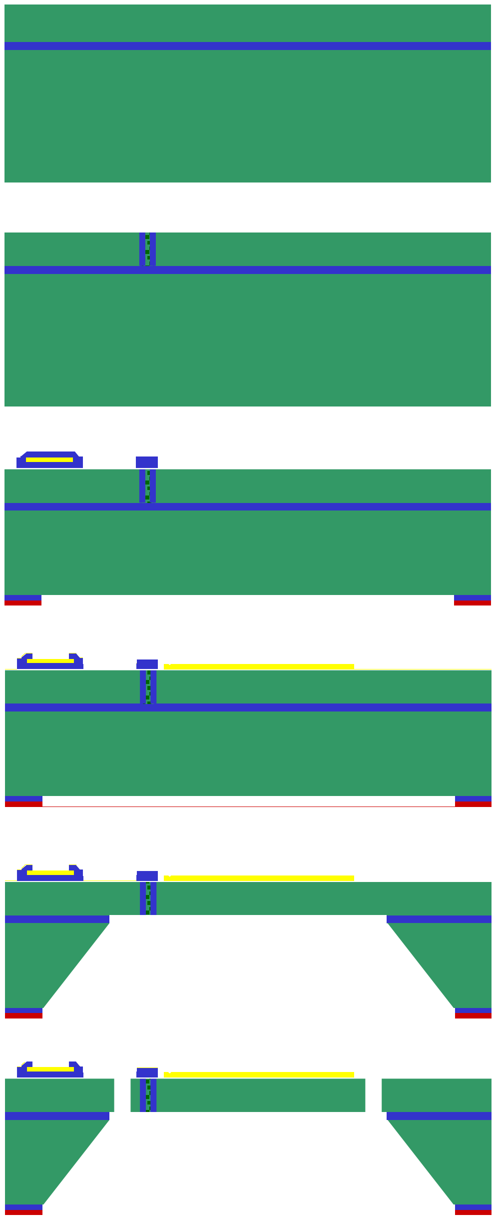
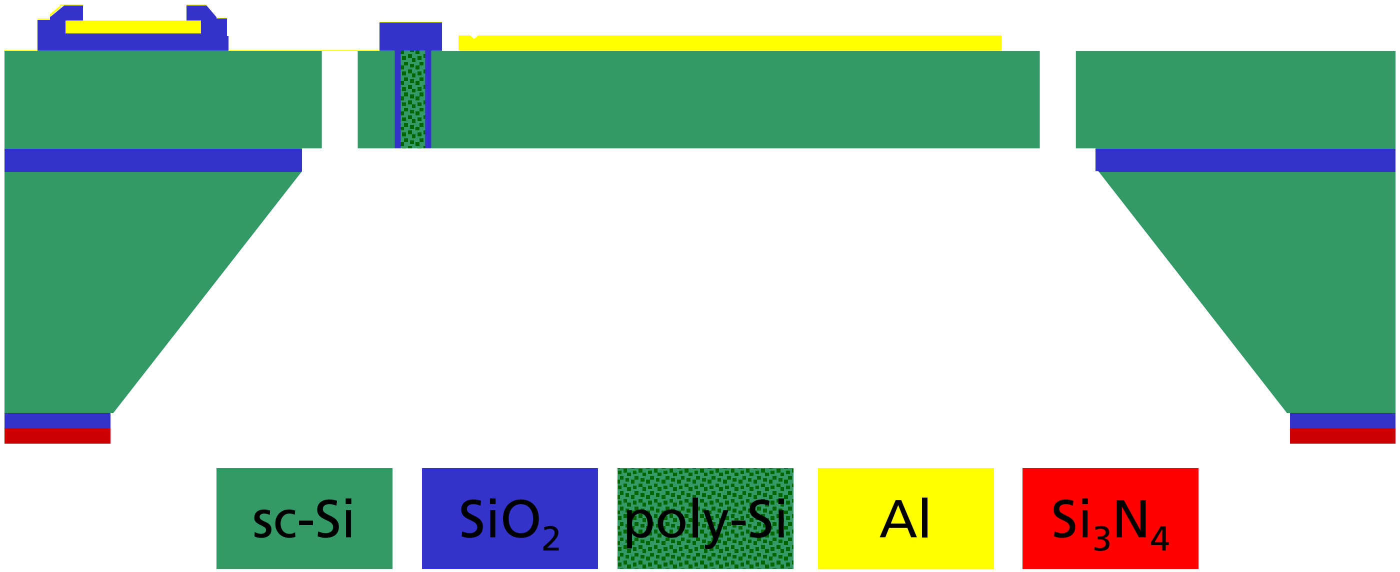
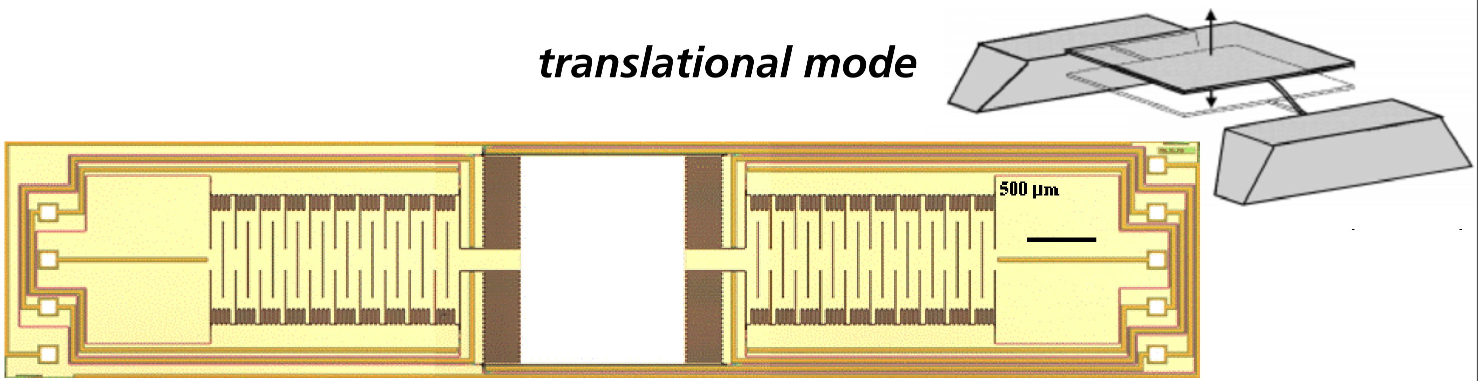
MEMS-Process ame1





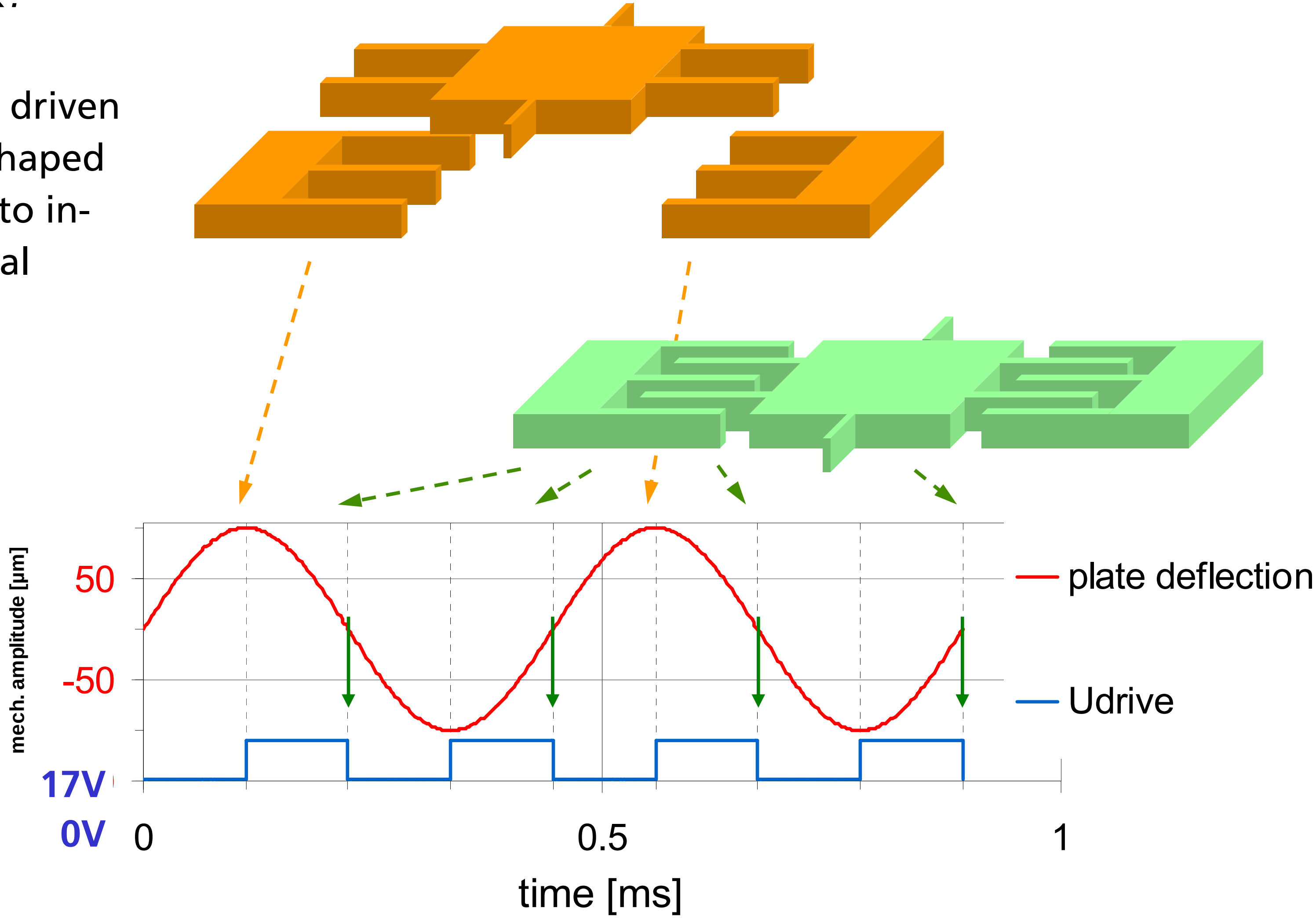


Comb-Drive for resonant operation

How does it work?

- Electro-statically driven by rectangular-shaped voltage applied to in-plane inter-digital comb fingers.
- Sense cross-over (optical)
- Switch off drive voltage
- for ¼ period

➔ large deflection at low voltage



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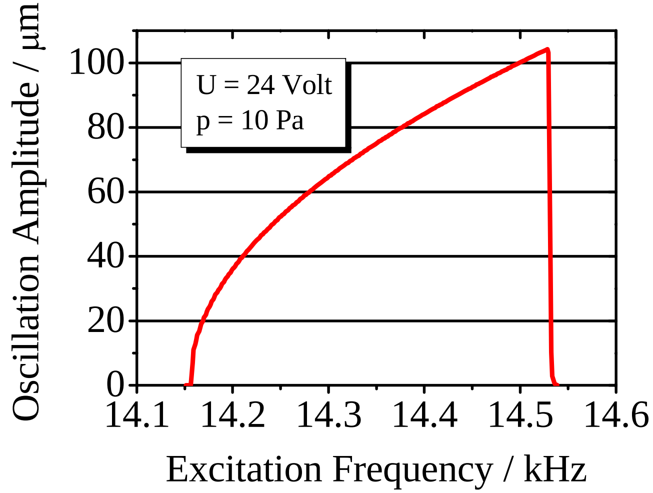
Translatiory MOEMS for FT-IR



- Mech. amplitude +/-100 µm ⇒ resolution >25 cm^{-1} (single sided acquisition)
- Oscillation frequency ~5 kHz ⇒ interferogram sampling bandwidth 1...10 MHz
- Mirror area ~1.6 mm^2
- Mirror deformation 200 nm (RMS)
- Driving voltage 36 V

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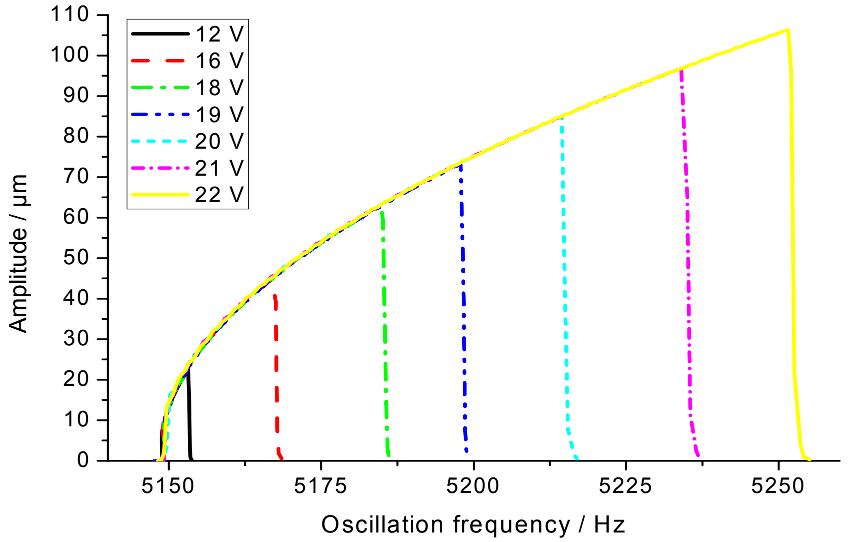
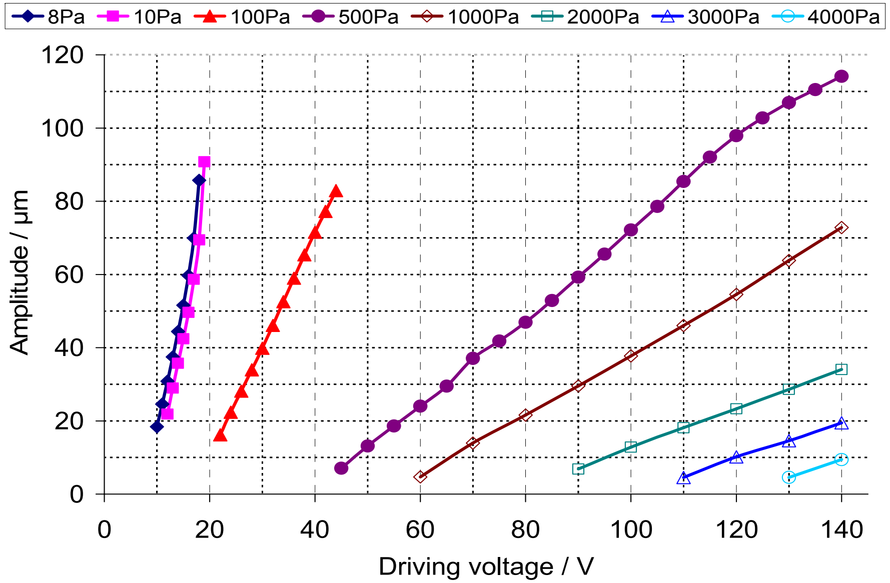
Translatory MOEMS for FT-IR

- At low pressures (10 Pa - 100 Pa) the oscillation starts with an increasing frequency sweep.
- The amplitude grows with increasing frequency.
- The oscillation breaks down as the mech. oscillation gets in phase with the driving signal.
- Due to the strong damping no oscillation was detected at higher pressure levels.



Amplitude versus frequency at 10 Pa



Maximum amplitude versus voltage for varying pressure

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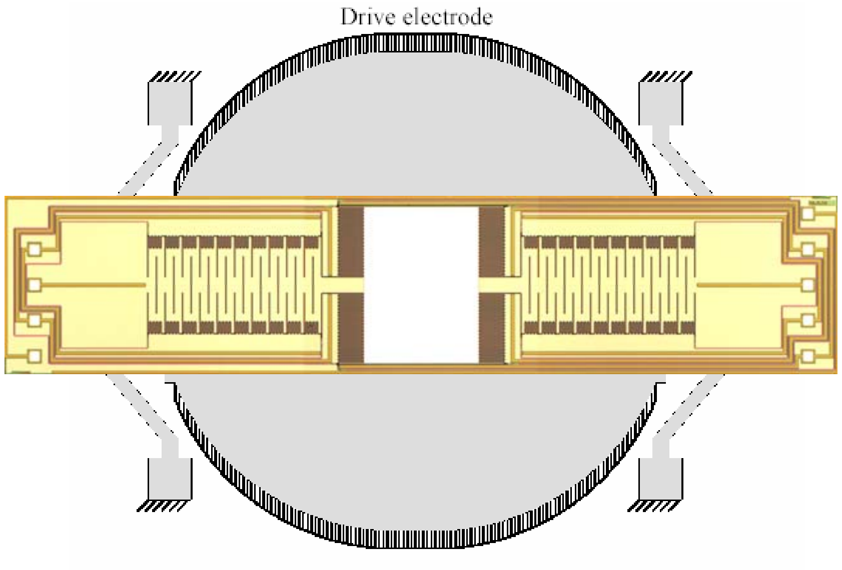
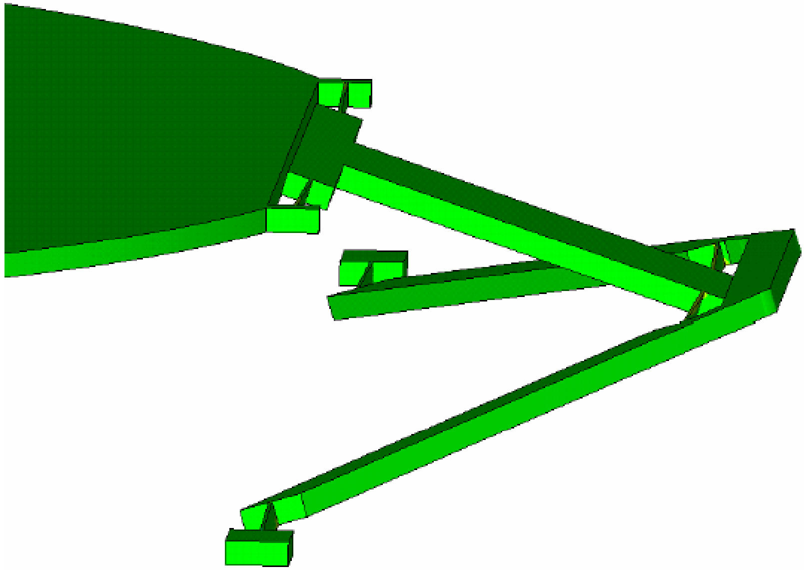
Novel translatory MOEMS for FT-IR



MOEMS mirror device (new design)



Novel design of mirror suspension (Pantograph)

- **Objectives for novel MOEMS device**
  - Increased deflection (OPD) up to 1 mm $\Rightarrow \Delta\nu$=10cm^{-1}
  - Increased aperture up to 7 mm² (will raise SNR)
  - Reduced oscillation frequency (500 Hz) to reduce electronical bandwidth

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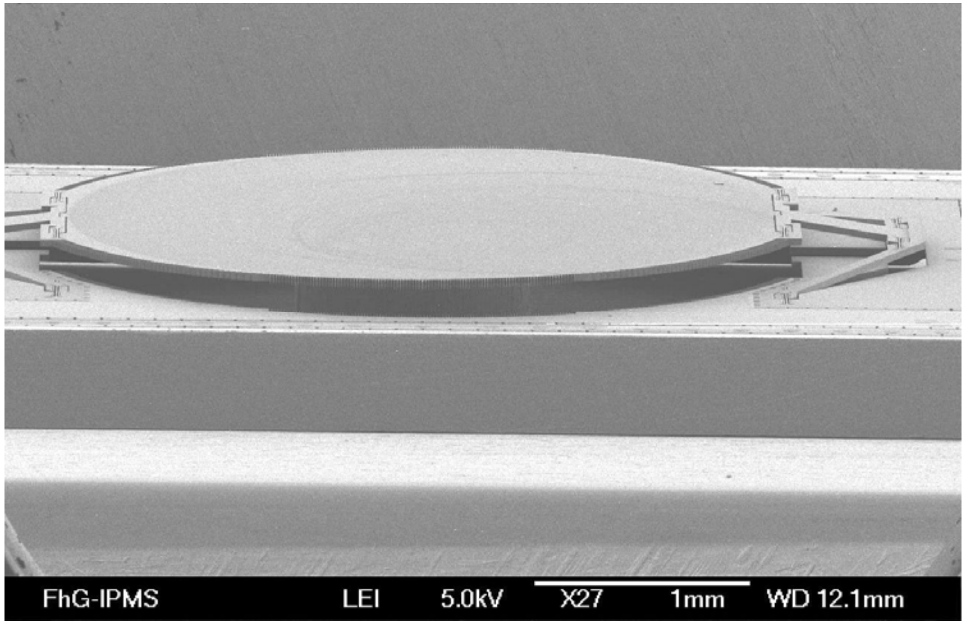
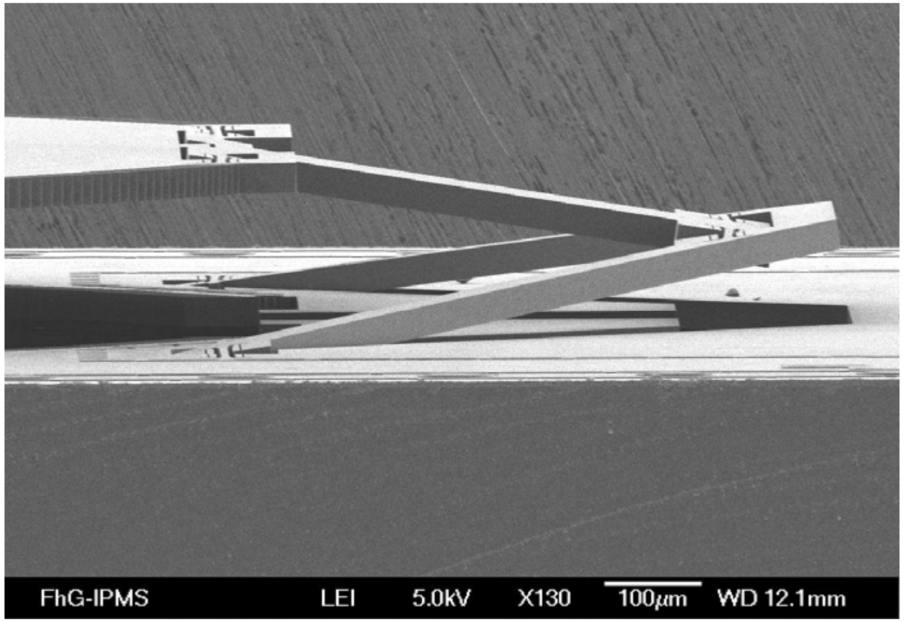
Novel translatory MOEMS for FT-IR



SEM of Pantograph suspension



Detail

Parameters of noved translatory MOEMS device

- Large mirror aperture of ø = 3 mm
- Resonant oscillation @ 500 Hz / 1000 Hz
- Target amplitude up to ± 250 µm @ pressures < 500 Pa
- Fabrication in standard IPMS scanner process using 30 µm SOI

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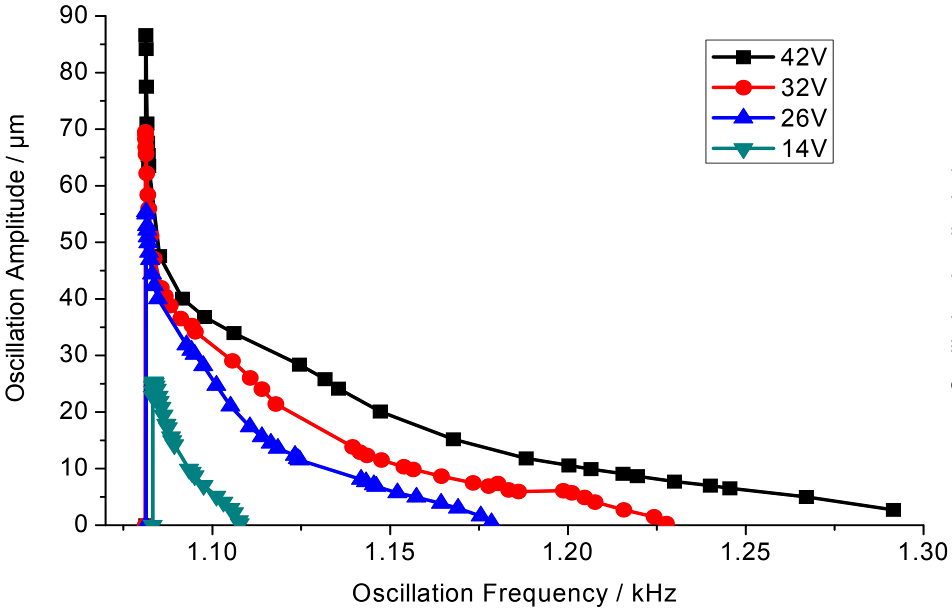
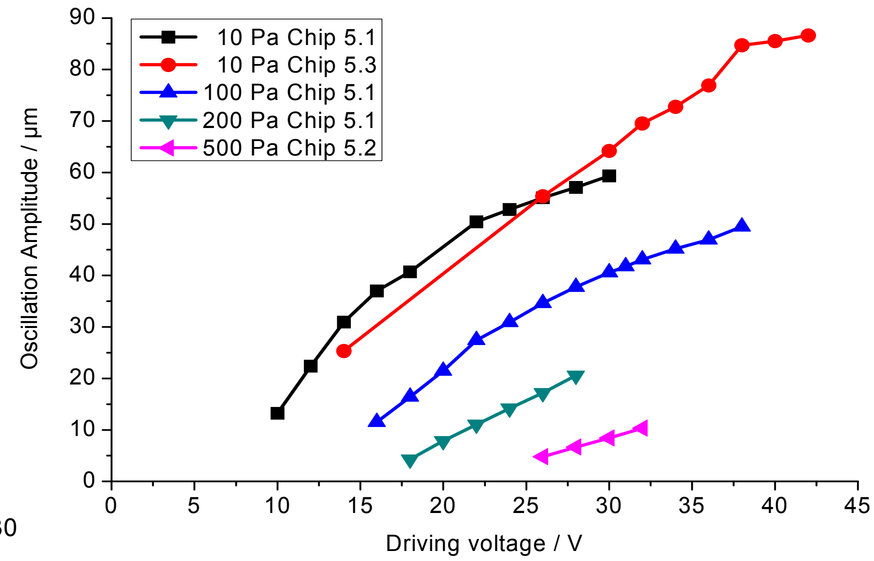
Novel translatory MOEMS for FT-IR

Preliminary results:

Amplitude versus Frequency (1 kHz)



Amplitude versus Voltage (1 kHz)



Measurement Setup

- Michelson interferometer
- Ambient pressure: 10 Pa - 500 Pa
- Driving voltage: 10 V - 42 V

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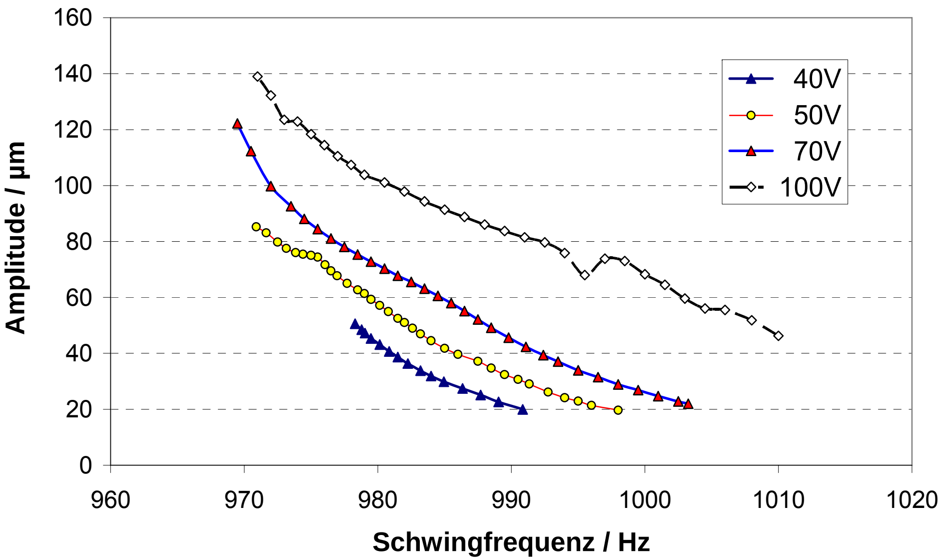
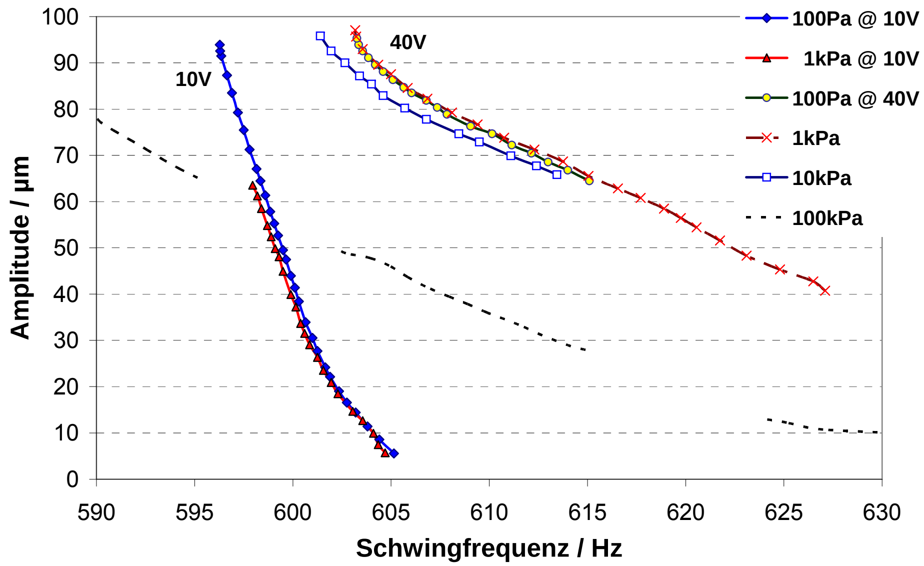
Experimental Results

Amplitude versus Frequency @ 1kHz, 20Pa



Amplitude versus Druck @ 500Hz



- Maximale Amplitude von ± **240µm** bzw. **OPD** von **960µm** @ 20Pa & 100V
- Deutliche Reduzierung der Squezze-Filmdämpfung durch erhöhte Rückseitenkavität
  ➔ ± 95µm Amplitude @ 10kPa (40V) bzw. ± 80µm @ 100kPa
- Optimierung der Modentrennung erforderlich

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Outline

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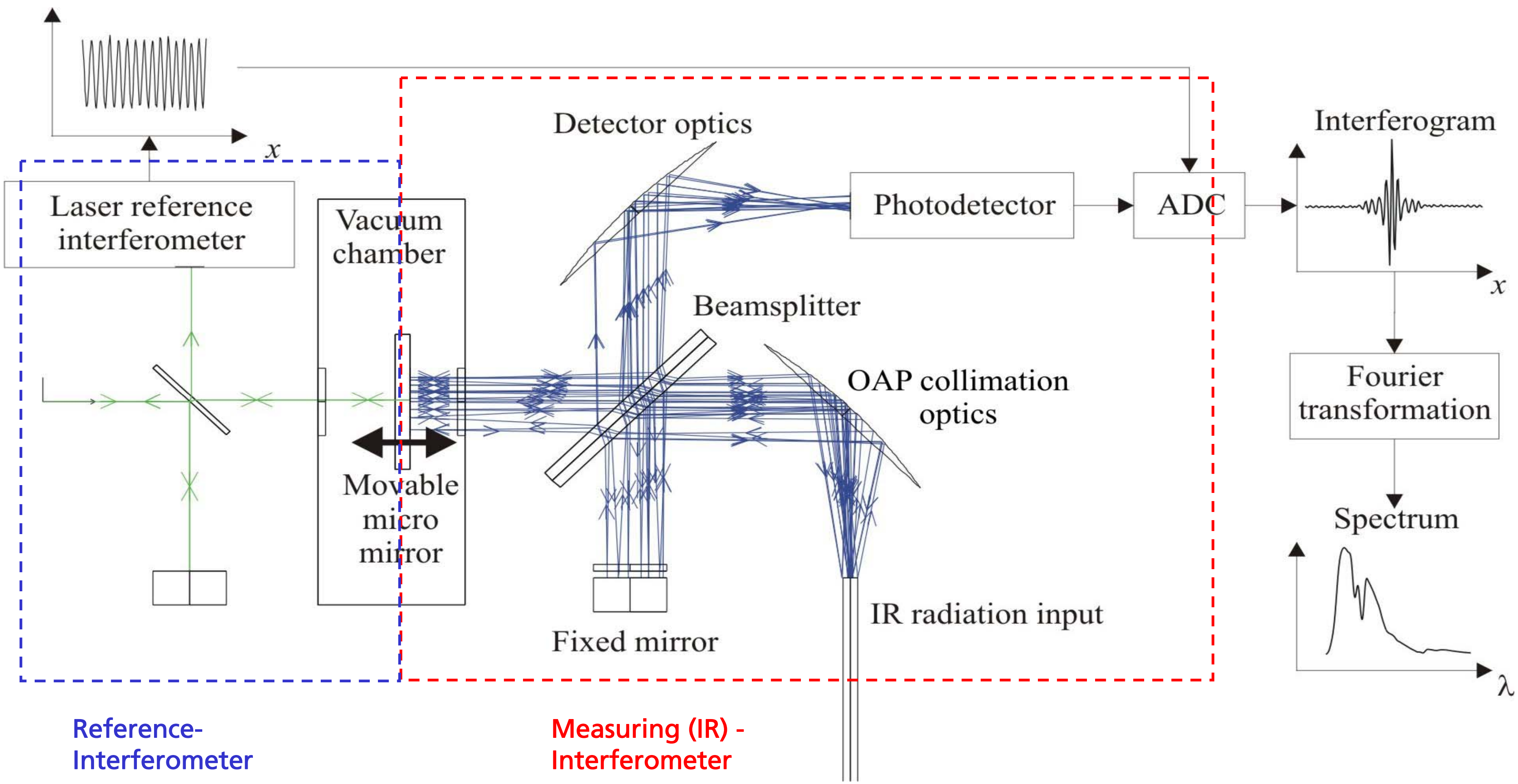
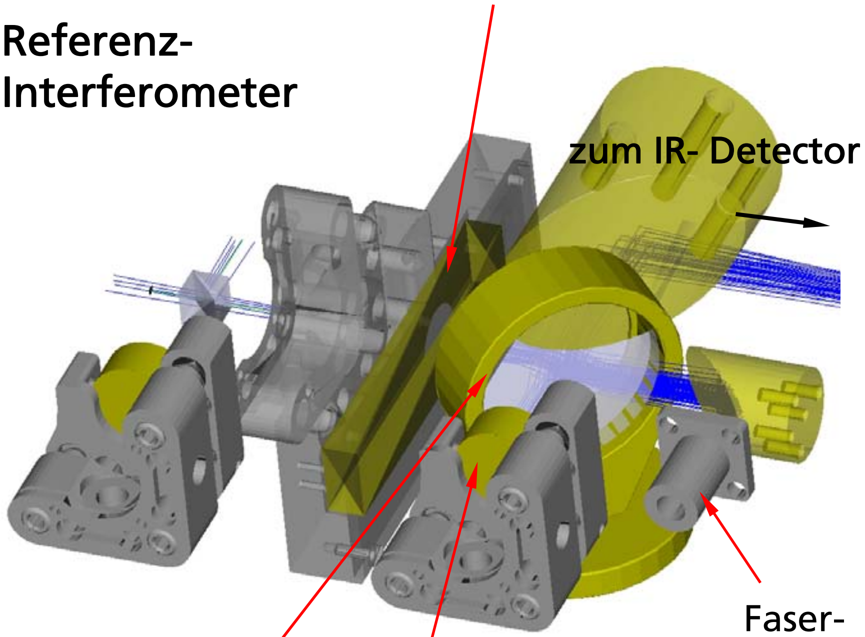
MOEMS FTIR system schematics



Optical layout and block diagram of the signal path of the FTIR system.

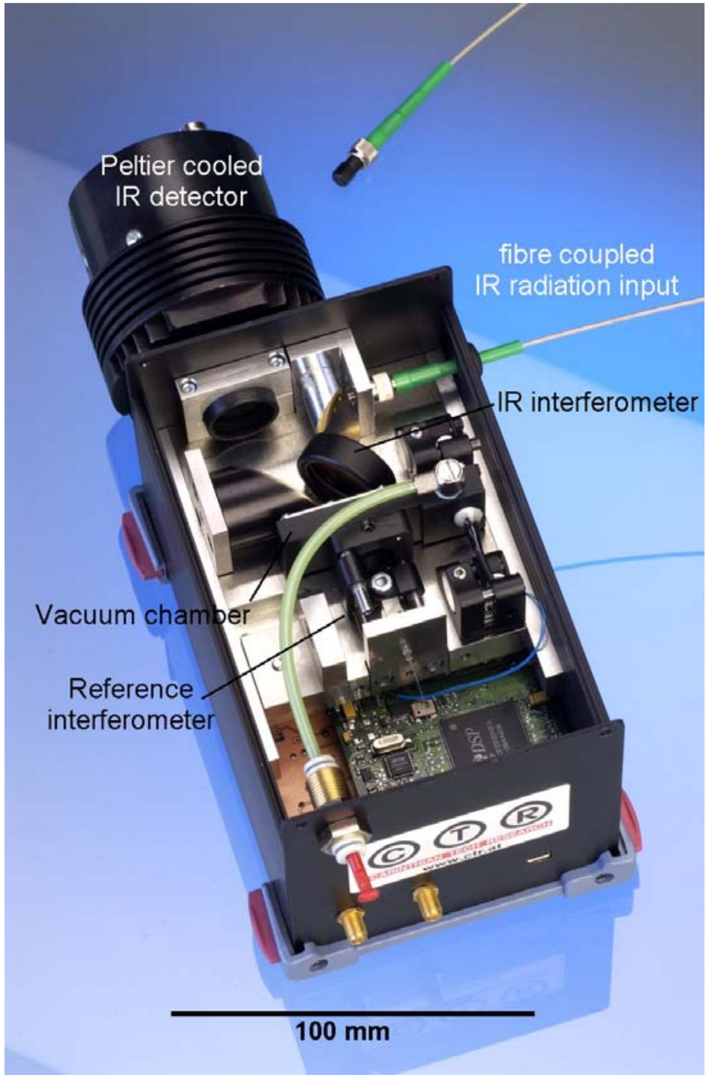
MOEMS FTIR prototype



- Fibre coupled optics (Chalcogenide fibre).
- Operation of the MOEMS device within a vacuum chamber.
- Detector: Themoelectrically cooled photovoltaic MCT.
- CaF_2 Beamsplitter and windows.
- Reference Laser interferometer accesses the backside of the MOEMS device.
- Laser cource: Temp. Stabilized VCSEL λ=760nm.
- DSP based data acquisition and processing.

- Dispersive optical elements and detector response define wavelength range to ~2...6 µm.

MOEMS FTIR prototype



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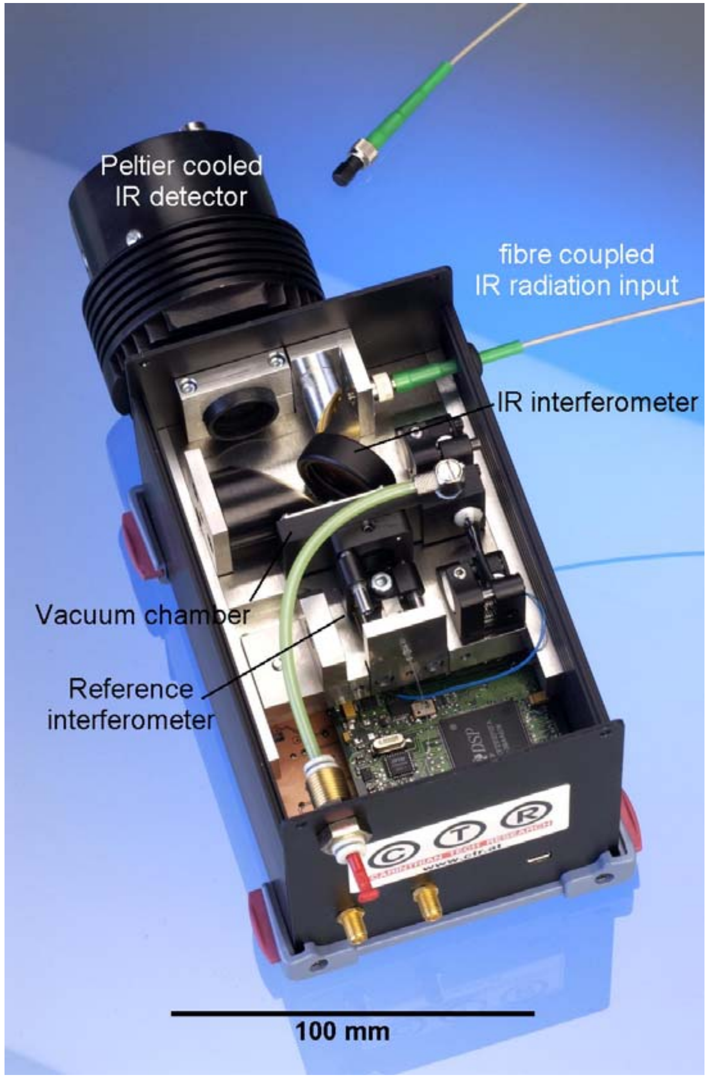
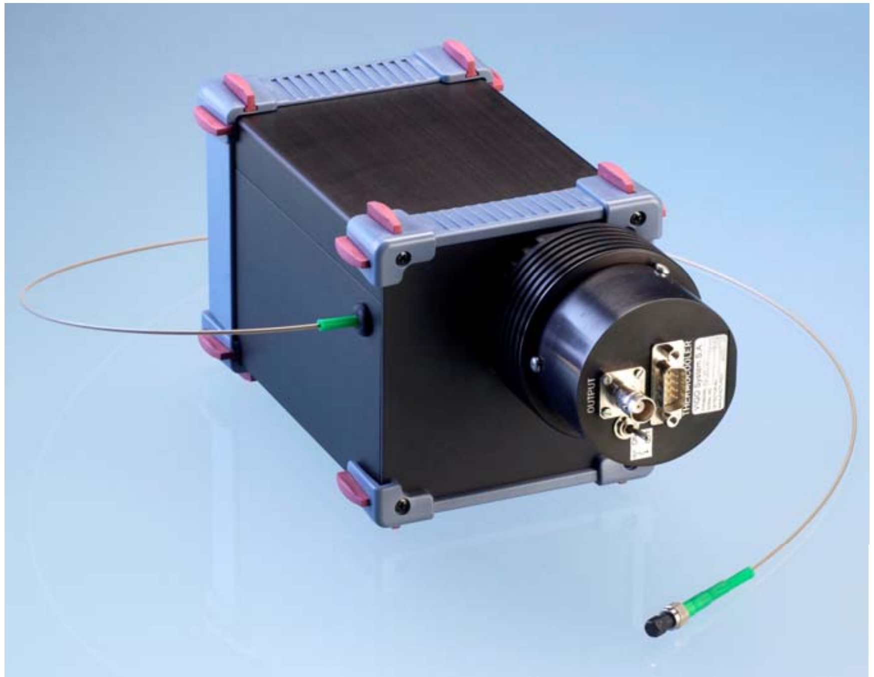
MOEMS FTIR prototype





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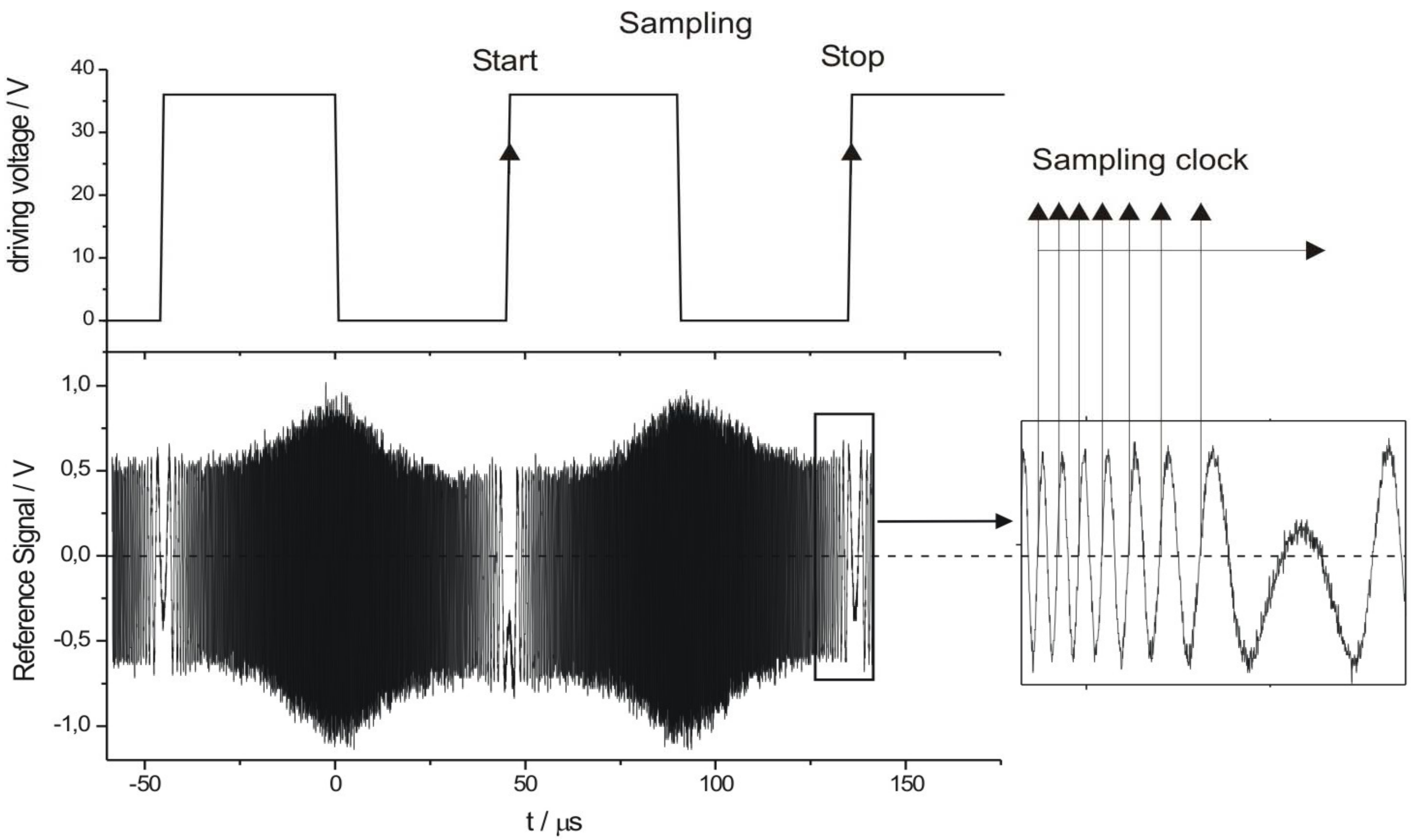
Interferogram sampling



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

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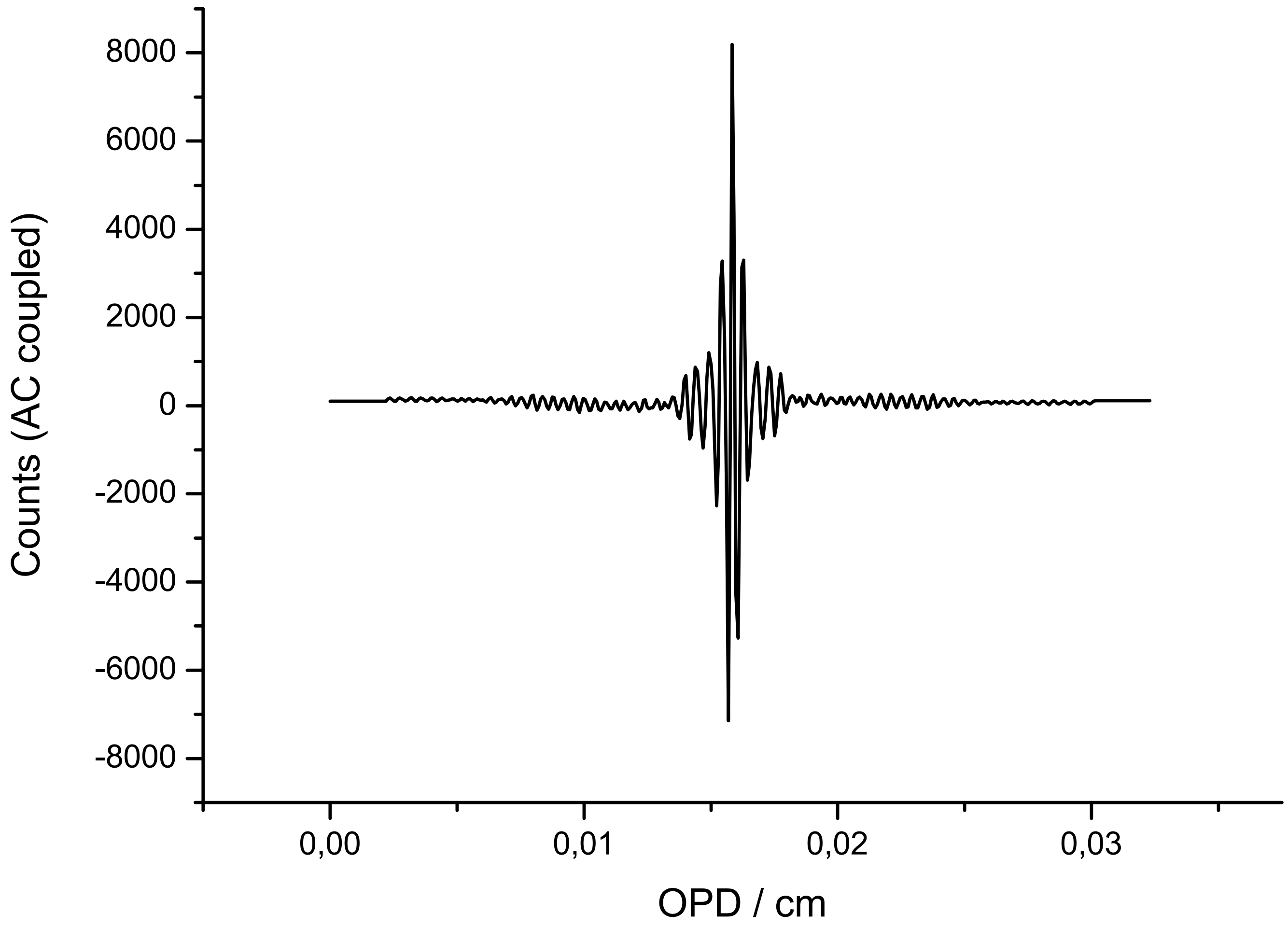
Interferogram

Interferogram of polychromatic infrared radiation



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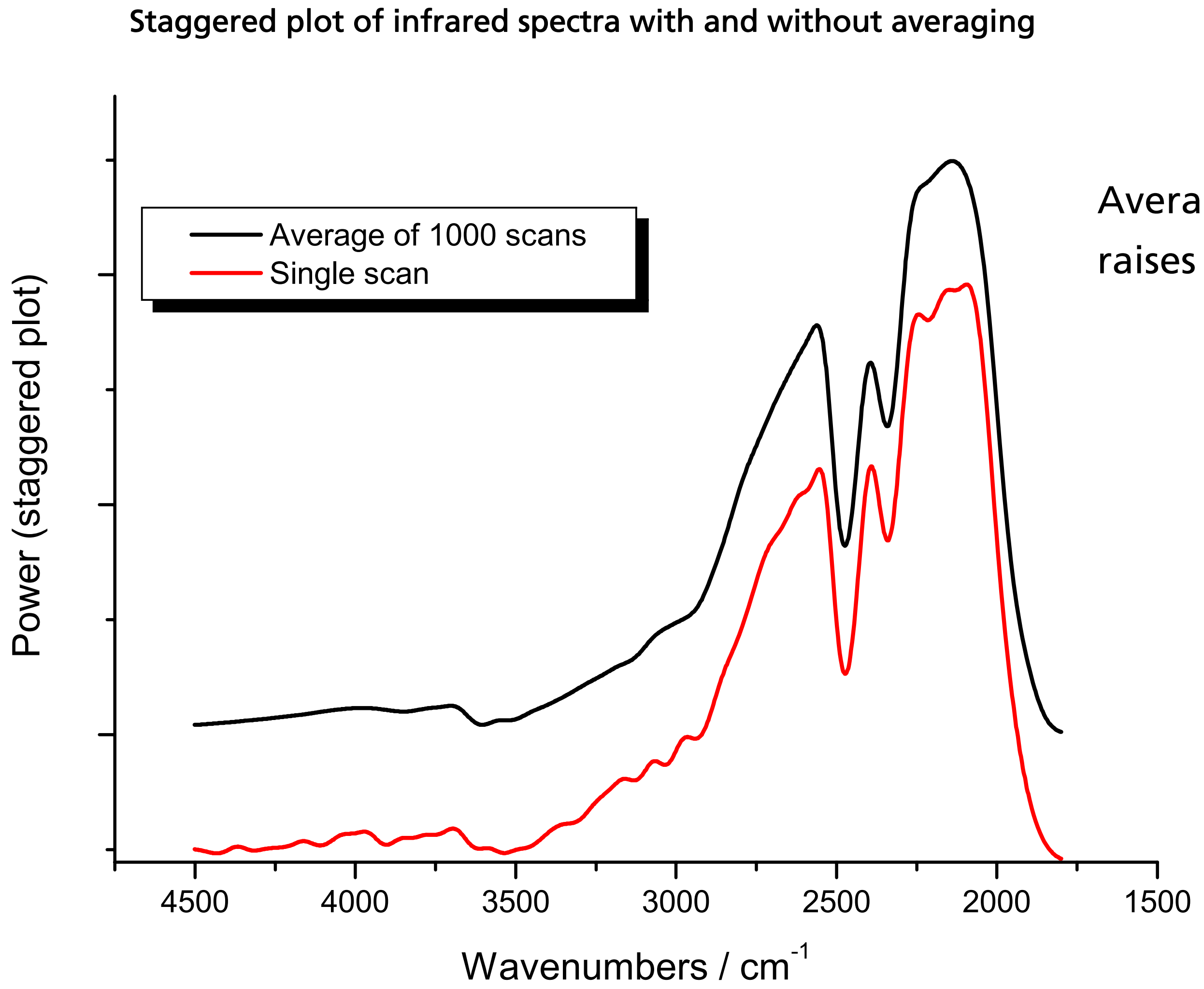
Spectrum (FFT Power plot)



Averaging of single scans raises SNR a $(n)^{0.5}$

- SNR 240, 24dB
- SNR 8 , 9dB

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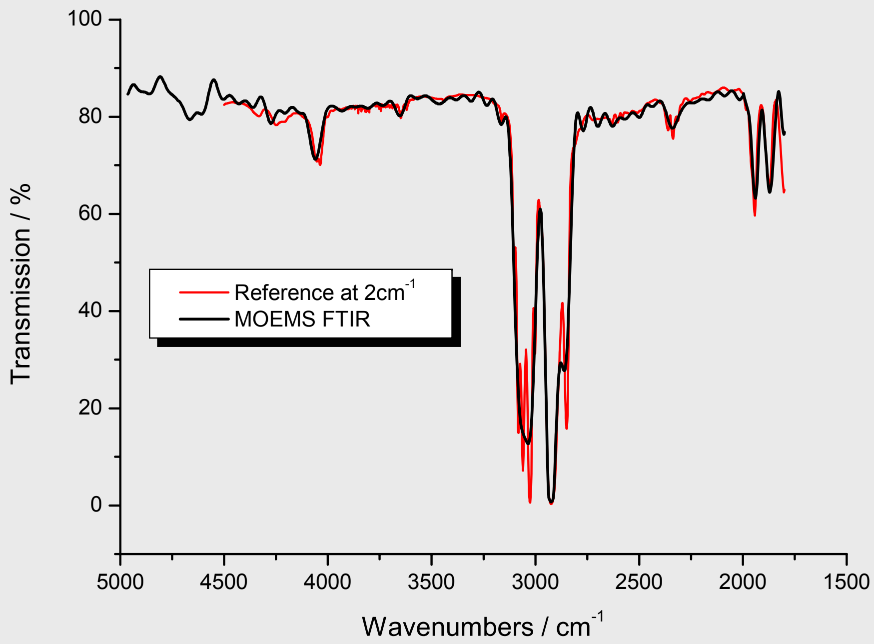
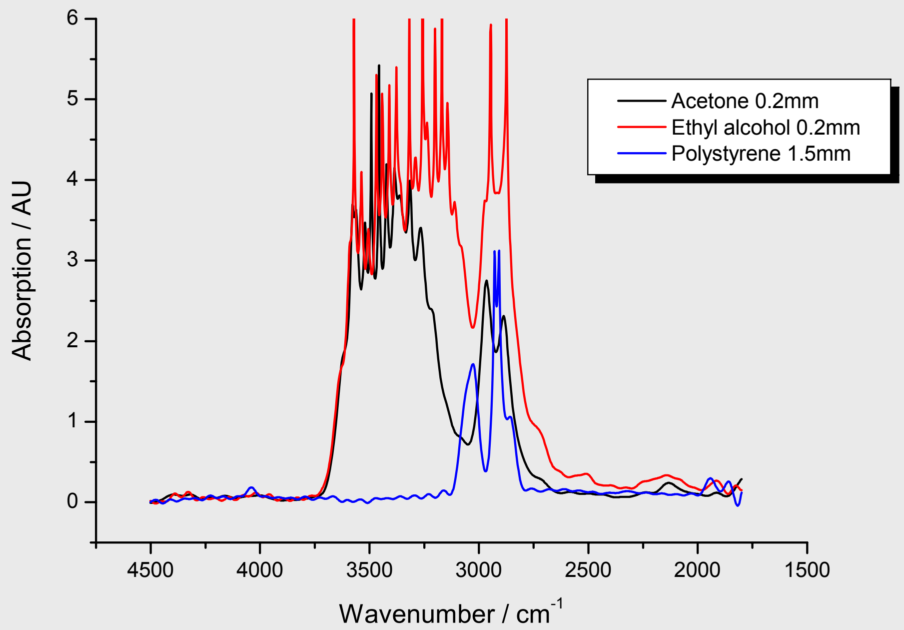
Measured spectra

Transmission plot

1.5mm Polystyrene



Absorbance plots



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