Subproject A4: “Multiple band sensor arrays for vibration monitoring based on near -surface silicon bulk micromechanics“

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Vibration monitoring has become an important mean for wear state recognition at cutting tools, bearings, gears, engines and other highly stressed machine components. At present vibration measurement systems are usually based on wideband piezoelectric sensors completed with sophisticated analysing electronics to observe the spectrum.

Goal of this project is a micromechanical sensor structure that obtains direct frequency information from the mechanical part without digital signal processing. Therefore the ability of mechanical resonators to filter the spectrum at their natural frequency is used. An additional benefit is the amplification of the measurement signal according to the quality factor of the resonators as shown in Fig. 1a. This effect improves the signal-to-noise ratio and allows the resolution of amplitudes at a nanometer scale. The fact that usually only several spectral lines are sufficient to characterize the wear state suggests the use of an array of resonators as a low-cost mean for predictive monitoring.

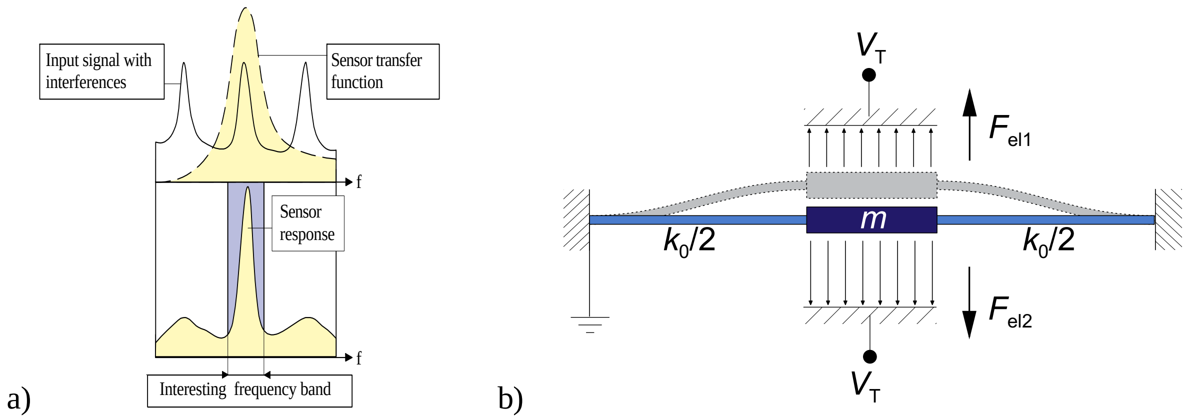


Fig. 1 Operation principle a) Frequency selective principle b) Direct electrostatic stiffness modulation

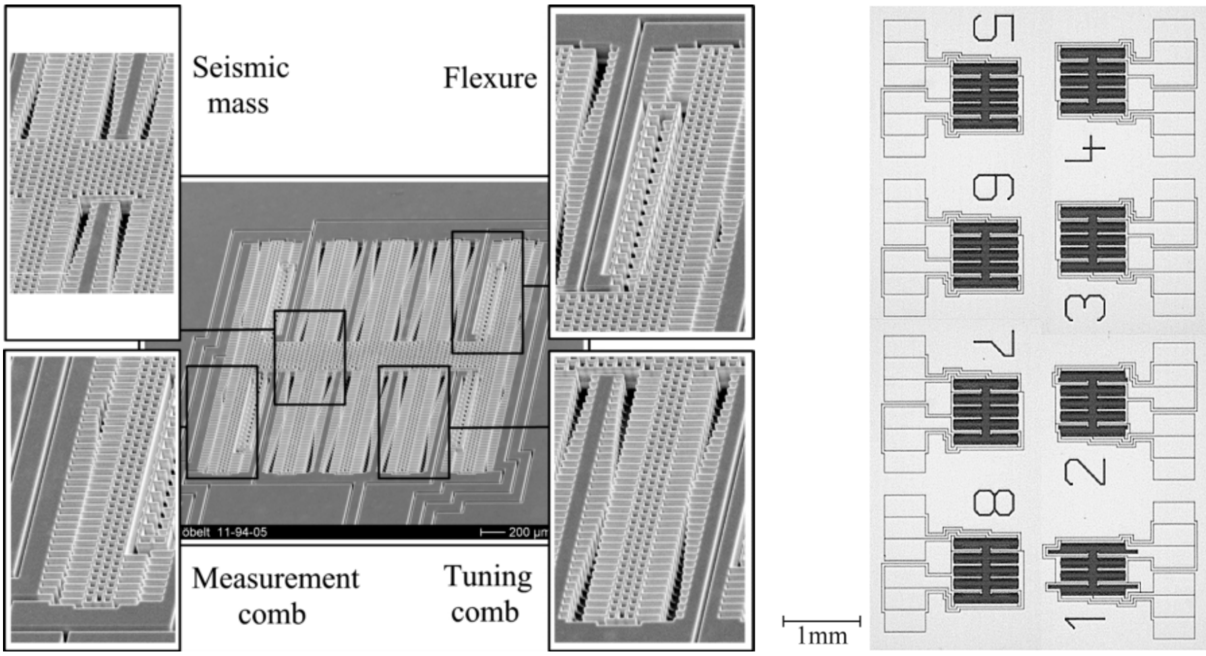
Scanning of a wide frequency range with resonant sensors requires an ability to bias the resonance frequency. The structures use electrostatic forces directly applied to the seismic mass to vary the resonance frequency as shown in Fig. 1b. This is achieved by the electrostatic forces F_{el1} and F_{el2} at the seismic mass influencing the total stiffness

$$k_{total} = k_0 - \frac{V_t^2}{2}\frac{d^2C(x)}{dx^2}$$

where V_t is the tuning voltage, k_0 the mechanical stiffness and C the total capacitance between stator and seismic mass. The forces lead to a softening of the system and wherewith to a lowering of the resonance frequency.

The single-mask SCREAM process represents the technological basis for the fabricated structures. The aspect ratio typically amounts to about 20 µm to 2 µm. Insulated metal layers are used for the generation of electrostatic forces and the realisation of the measurement capacities.

The fabricated structures consist of a seismic mass suspended by four folded flexures. Two different comb capacitor systems at the seismic mass are used for signal detection and resonance frequency tuning. The design of the tuning combs has to provide constant tuning characteristics unaffected by the vibration amplitude. This is achieved by curved comb capacitors with constant second derivative of the capacitance function over the whole amplitude range. Fig. 2a shows a SEM-view of the fabricated structure.



a) b)

Fig 2 Fabricated structures a) SEM view and b) Photo of the sensor array

One single tunable resonator cannot cover the complete interesting frequency range from 1 to 10 kHz. Therefore the sensor array shown in Fig. 2b has been fabricated. It consists of eight cells with stepped base frequencies and overlapping tuning ranges. Continuous tuning from 1 to 10 kHz was achieved with tuning voltages below 40 V.