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

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1 Introduction

Vibration monitoring has become an important means for wear state recognition of industrial machinery such as cutting tools, bearings, gears, pumps or engines [1]. The majority of mechanical vibration used to identify the wear state is found in the frequency range from a few Hertz to 10 kHz. Currently, piezoelectric wide band transducers combined with signal analysers are usually used to obtain the spectrum. Due to high costs permanent monitoring is limited to extremely expensive machinery or safety related applications.

For the characterisation of the wear state the observation of a few spectral lines is usually sufficient. This fact suggests a narrow band resonance operation of the sensor structure. It amplifies the vibration signal in a small band around its resonance und eliminates other spectral ranges. Advantages of this frequency selective approach are the improvement of the signal-to-noise ratio and simplifications in the signal conditioning circuitry without Fourier transformation. The fixed resonance of such sensors limits their use to applications with well known and constant measurement frequencies. To overcome this restriction, resonance tuning mechanisms are used.

We develop a vibration measurement system based on micromechanical tunable resonators. As sensor structure, a SCREAM- (Single Crystal Reactive Etching And Metallization) [2] fabricated array of tunable resonators is used. Resonance tuning is achieved by electrostatic softening.

2 Frequency Selective Principle

Vibration sensors usually work as wide band transducers far below their resonance. In this frequency range the sensor output is proportional to the acceleration acting on the sensor. In contrast to this common principle, frequency selective sensors operate directly at their resonance. A small band of the incoming spectrum is amplified at the resonance peak of the sensor structure (Fig. 1). Other spectral ranges are suppressed.

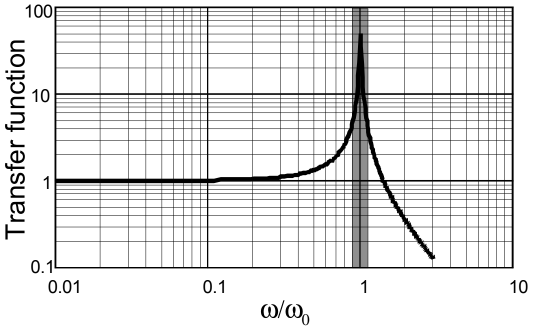

Fig. 1: Frequency selective principle

Advantages of the frequency selective principle are the direct extraction of spectral information without Fourier transformation and the improvement of the signal-to-noise ratio by the quality factor. Furthermore, such a sensor is insensitive to large interfering signals that would overdrive wide band transducers.

3 Resonance Frequency Tuning

Resonance frequency tuning is used to extend the measurement range of a frequency selective sensor.

The structures presented in this paper implement electrostatic softening to vary the resonance frequency. The principle is based on electrostatically generated, amplitude dependent forces acting on the seismic mass (Fig. 2). The total stiffness k_{total} of the tuned resonator is calculated as follows:

$$k_{total} = k_0 - \frac{V_{tun}^2}{2}\frac{d^2C(x)}{dx^2} \qquad (1)$$

(V_{tun} - tuning voltage, k_0 - mechanical stiffness, C - total capacitance between stator and seismic mass).

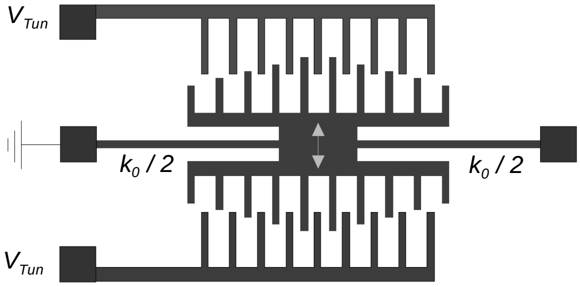

Fig. 2: Scheme of a resonator tuned by electrostatic softening

The forces lead to a softening of the system and therewith to a lowering of the resonance frequency. In this way the resonance frequency and thus the sensitive frequency band are set by a control voltage V_{tun}. To achieve linear sensor characteristics it is essential that the second derivative of the capacitance function $d^2C(x)/dx^2$ is constant over the amplitude range. Otherwise the resonance frequency depends on the signal amplitude. Such nonlinearities implicate large amplitude errors. A quadratic capacitance function implemented by a comb system of linearly varied finger-length using Poly-Si technology is described in [3]. A SCREAM-technology compatible approach using non-overlapping comb fingers is presented in [4].

4 Sensor Structure

The SCREAM-fabricated sensor structures consist of a laterally movable mass supported by four folded flexures. Two different comb systems at the seismic mass are designed either for capacitive signal detection (const. $dC(x)/dx$) or for resonance frequency tuning (const. $d^2C(x)/dx^2$) (Fig.3).

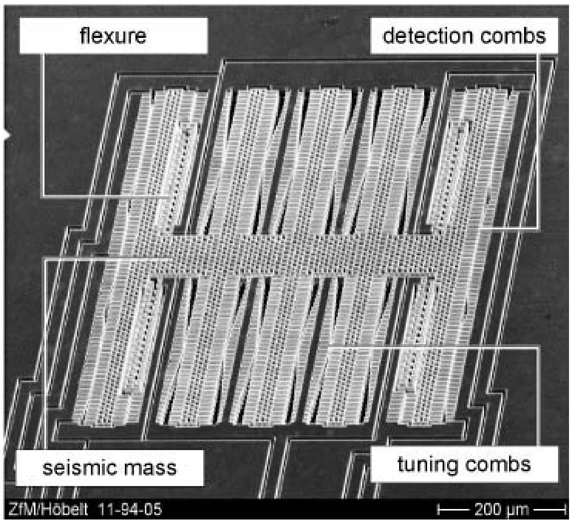

Fig. 3: SEM-view of a resonator structure

The tuning range of a single tunable resonator is limited by the maximum tuning voltage. By grouping eight resonators with stepped base frequencies and overlapping tuning ranges into an array, the frequency range covers 1..10 kHz (Fig. 4).

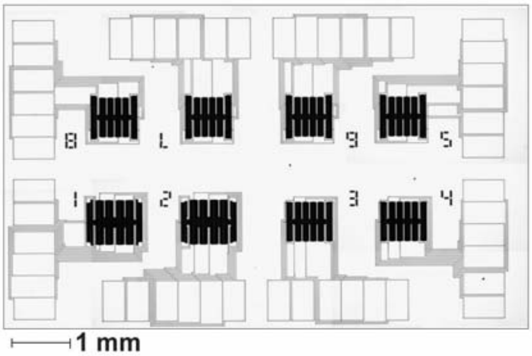

Fig. 4: Tunable resonator array

Damping effects are reduced by providing a low ambient pressure with hermetic sealing of the sensor structure using glass-frit bonding (Fig. 5).

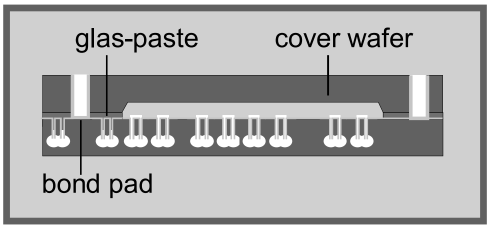

Fig. 5: Hermetic sealing by glas-frit bonding

For a successful use of the sensor it is necessary to protect the microstructure against ambient influences. This is necessary because the structure is damageable to particles and moisture. The protection and the provision of the low pressure are done at the same process step. For this purpose a glass-frit material is used. This material is deposited on a cover wafer with a screen printing process. This allows the creation of frame-like structures around the sensors. The cover wafer has etched contact holes for the electrical contact of the sensor.

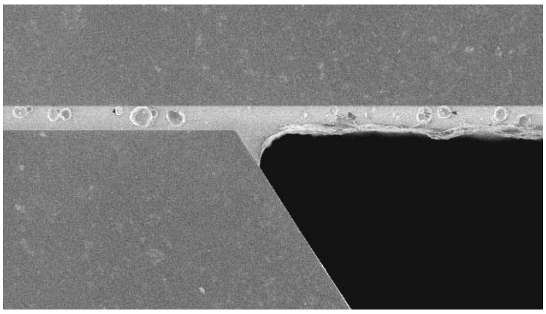

Fig. 6: Joint between silicon wafers using glass frit

To create a firm bond between the sensor wafer and the cover wafer the two wafers are pressed together and heat is applied to them. The heat melts the glass material. The melted glass joins both wafers and the encapsulated cavities hold the same pressure that is applied in that moment in the process chamber. Control of that pressure allows the adjustment of the correct pressure for low damping effects. Fig. 6 shows a SEM picture of a typical joint between silicon wafers using glass frit material.

5 Measurement System

The measurement system contains the micromechanical structure, analog, digital control -and interface (Fig. 7). For low backlash to the object to be measured, the mass of the connected part has to minimized. Therefore a miniaturized system is under development.

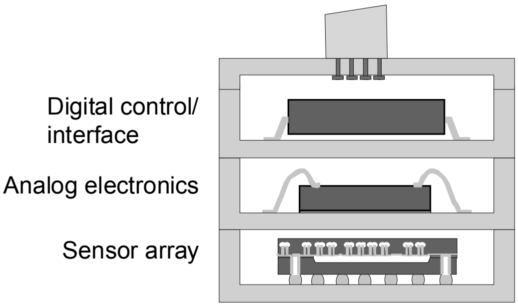

Fig. 7: Scheme of the miniaturized measurement system

6 Conclusions

SCREAM-fabricated resonators are suitable for frequency selective vibration measurements. Electrostatic softening turned out to be an appropriate means for resonance frequency tuning for the range from 1 to 10kHz.

Further work includes a characterization of the fabricated structures. Important aspects are bandwidth, resonance tuning effect and linearity of the resonators. Based on the micromechanical structure, a miniaturized vibration measurement system will be developed and tested in industrial environment.

7 Acknowledgements

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8 References

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