Development of a Package for a Triaxial High-G Accelerometer Optimized for High Signal Fidelity

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Abstract

Acceleration is an important quantity to be measured in high-speed dynamics. Many other measurands like velocity, force and pressure can be derived from it. A new piezoresistive sensor for the measurement of high-amplitude, short-duration transient accelerations of up to 100,000 g has been developed at the Fraunhofer EMI. Its figure of merit (sensitivity x resonance frequency²) is about one order of magnitude higher than that of comparable state-of-the-art sensors [1]. Fig. 1 shows the basic design of the sensing element, consisting of a stiff frame, a bending plate and four piezoresistive elements interconnected to a Wheatstone bridge. It is a silicon MEMS that has been fully modeled using COMSOL Multiphysics® [2].
Currently, we develop a triaxial sensor which integrates three uniaxial sensor elements onto a single ceramic substrate. As part of this development, we simulate the sensor with different package concepts (Fig. 2) with COMSOL Multiphysics®. The goal of the simulation is to optimize the package of the sensor, in terms of high signal fidelity at high excitation frequencies. The geometry is modeled with Autodesk Inventor and imported via the LiveLink™ for Inventor®. Each package concept is simulated with a variation of different material and geometric parameters using material properties and parametric sweeps.
To examine the behavior of the sensor over the relevant frequency range, we made two approaches. One is a modal analysis of the system which gives us the value and shape of the resonance frequencies. For the second approach, we simulate the sensor with an oscillating volume load that is applied to the system and swept over a frequency range from 0 to 250 kHz. This setup enables us to derive the output signal of the sensor for each frequency and to investigate the influence of the package on the sensitivity curve. Additionally, we get the information about stress and displacement within the package.
We will discuss the results based on an example package. The first mode (Fig. 3a) of the example is a cap oscillation at about 40 kHz. We expect that the influence on the sensor elements of these cap oscillations is pretty small. The oscillation of the package box at 128 kHz (Fig. 3b) will have a much higher influence. These assumptions can be confirmed by taking a look at the frequency spectrum of the second approach. At the resonance frequencies of the cap oscillations small deviations in the sensitivity can be observed (Fig. 4b). For this example, we get accurate signals (i.e. less than 5% deviation) for frequencies up to ~50 kHz. The results of the numerical simulation will be verified with experimental tests.

Reference

[1] R. Külls et al., Novel Piezoresistive High-g Accelerometer Geometry with Very High Sensitivity-Bandwidth Product, Sensors and Actuators, A, Vol. 182, p. 41 (2012)
[2] S. Heß et al., Design and Characterization of a Novel High-g Accelerometer, COMSOL Conference (2011)

Figures used in the abstract

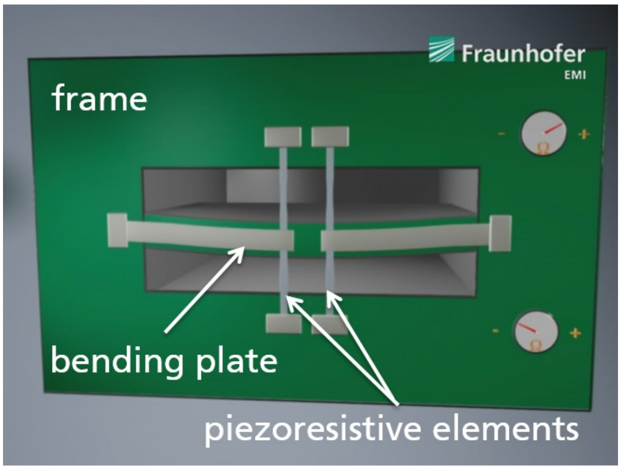

Figure 1: Schematic illustration of the sensor element. Acceleration deflects the bending plate and the piezoresistive elements are compressed/expanded, resulting in a measurable change of resistivity.

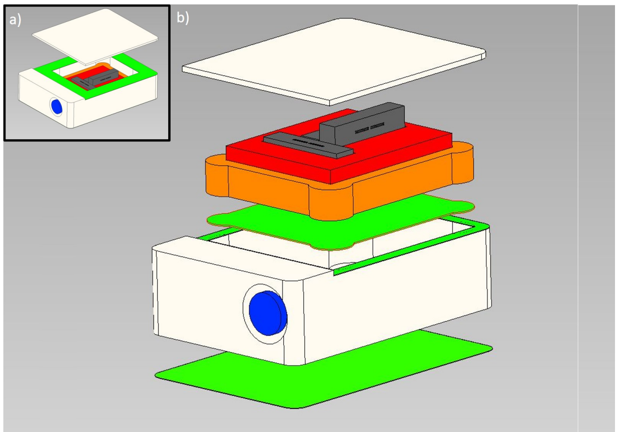

Figure 2: Example package design. a) Concept 1+ with lifted cap. b) Exploded view of concept 1+. The parts are color-coded: white/transparent: package box + cap, red: ceramic substrate, grey: sensor elements, orange: grouting, green: adhesive layers, blue: cable dummy.

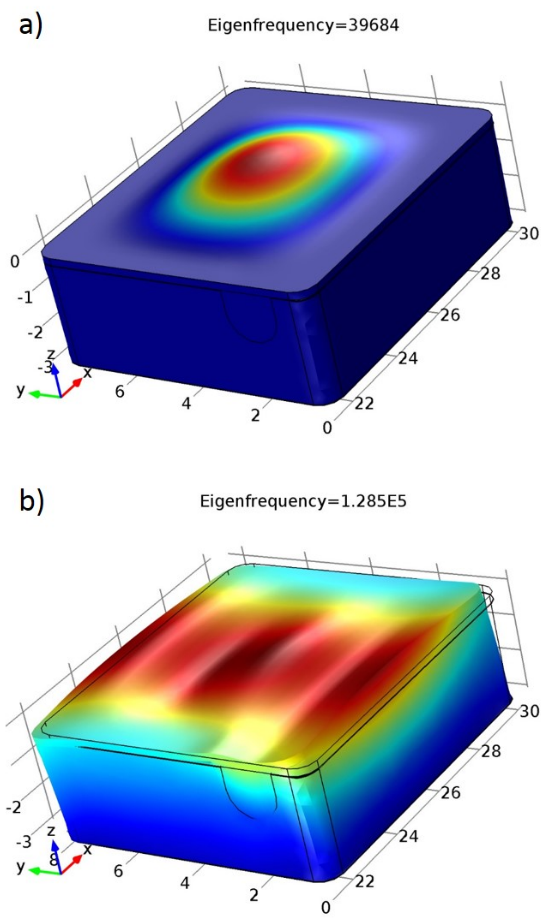

Figure 3: Example of results of the modal analysis: a) First “cap mode”: cap deflects in z-direction, b) First

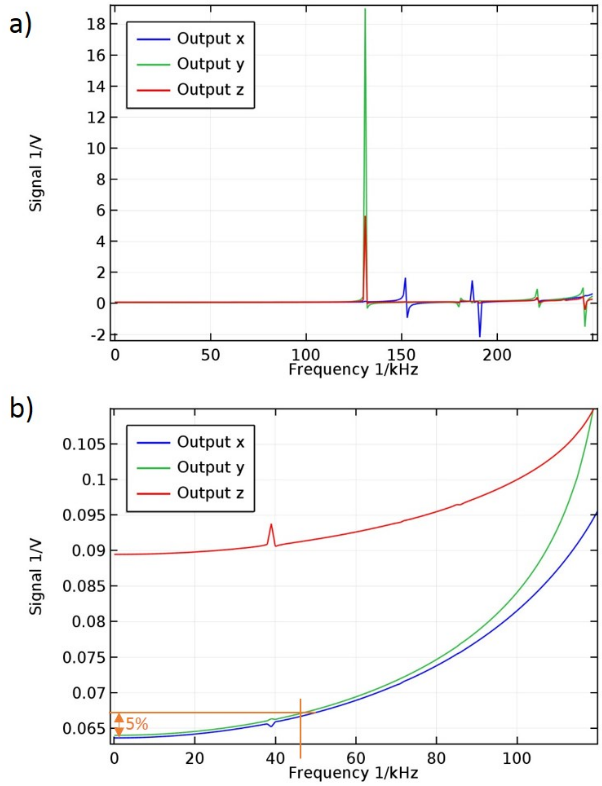

Figure 4: Example of the results of the frequency spectrum analysis. The diagrams show the output signal in volt over the excitation frequency. a) Whole frequency spectrum from 0 to 250 kHz, showing a high resonance peak at ~130 kHz. b) Zoomed in to frequencies from 0 to 100 kHz. A 5% accuracy is achieved up to 46 kHz. A small resonance peak occurs at ~40 kHz due to the cap modes.