Development of a high resolution acceleration sensor

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1 Introduction

Presently a new bulk micromachined multi-use acceleration sensor is under development. The sensor should provide a measurement range of ± 8 g, a resolution of 500 µg at 200 Hz bandwidth, and a bias stability better than 100 mg. A differential capacitor design (Fig. 1) based on bulk micro machined and wafer bonded elements is chosen for the sensor, because this approach supplies a large inertial mass in combination with small capacitor gaps. So the sensor can reach a high sensitivity. The differential capacitor arrangement can be used both for detection of small deflections of the movable mass and for force compensation using electrostatic forces. The closed-loop operation principle (Fig. 2) enables a high resolution.

2 The sensitive element

In contrast to a former development of acceleration sensors a new type of spring-mass-system has been designed, simulated and patterned (Fig. 3 and 4). The seismic mass is suspended in the wafer frame by two vertical torsional beams, which have a nearly rectangular cross-section. This shape of the springs can be realised using (100)-Si and wet etching in KOH with a symmetrical etch process from both sides, if the edges of the mask are aligned with an angle of 45° to the [110] direction (wafer flat). With this process, the dimensions of the spring, resp. the spring width, can be easily controlled using a microscope. In order to reduce damping, fluidic channels have been integrated into the surface of the seismic mass (Fig. 4).

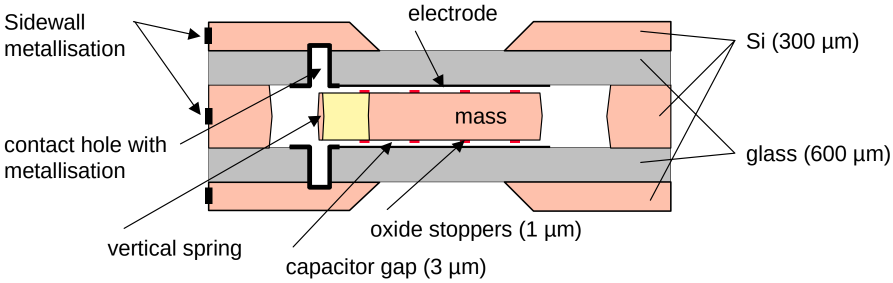

Fig. 1: Cross-section of the acceleration sensor

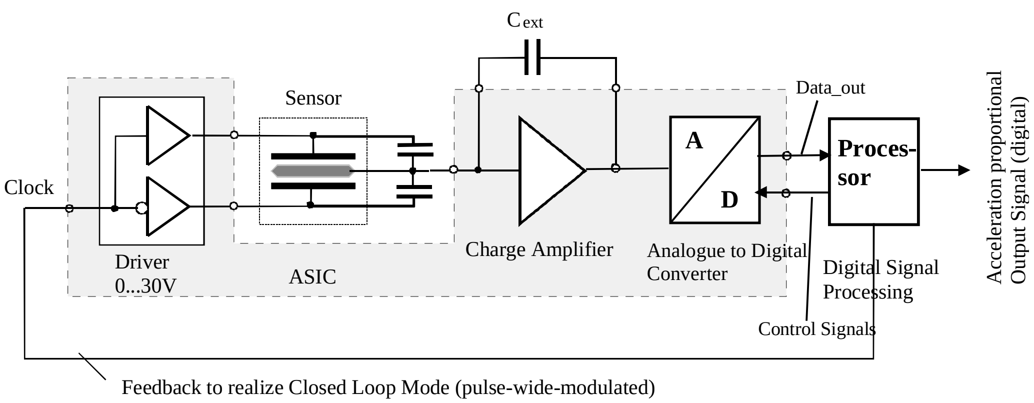

Fig. 2: Feedback control scheme of the acceleration sensor

The dimensions of the spring in Fig. 3 are 660 µm in length, 300 µm in height and 16 µm in width, resulting in a torsional resonant frequency (1st order mode) of about 400 Hz. Fig. 3 shows a FEM simulation of this primary vibration mode, which is used for the acceleration force measurement. The 2nd and 3rd modes, which occur at about 2 kHz and 2.7 kHz, are in-plane-modes, which do not contribute to the detection signal. Higher order vertical modes, which can cause detection signal errors, have frequencies of more than 18 kHz. The fabrication technology of the middle wafers uses 4 masks on each side, creating the capacitor gap, the oxide stoppers, the fluidic channels, the springs and mass.

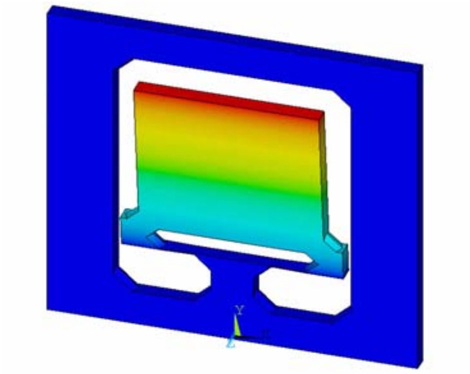

Fig. 3: FEM simulation of the 1st order mode

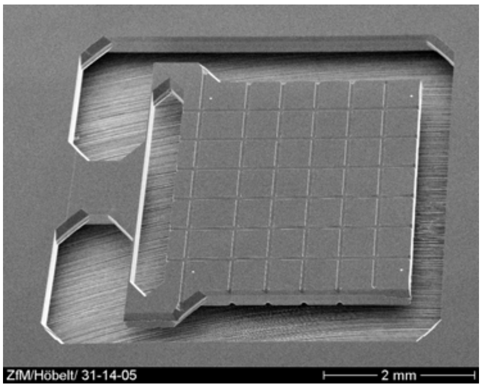

Fig. 4: SEM picture of the spring-mass-system

3 Packaging

The cover wafers must provide the fixed electrodes, hermetic electrical feed through and wire bonding areas. In order to achieve low parallel capacitances of the wafer frame, glass (Hoya SD2) has been chosen for the substrate material. The electrical connections to the outer side are realised using ultrasonic drilled holes, which are covered by Si islands, and therefore are hermetically sealed. Al is sputtered in these holes via a hard mask, this way connecting the fixed electrode areas (Al) with the Si islands. The mounting of the sensors is done by two subsequent Anodic bonding processes with temperatures of 400°C and voltages of 300 ... 350 V. The second bonding step can be carried out in a vacuum chamber in order to reduce damping. Afterwards the compound is diced into pieces, and the sidewall metallization is realised. Fig. 5 shows complete sensors. Sensor and electronics are packaged together in a waterproof box, which is shown in Fig. 6.

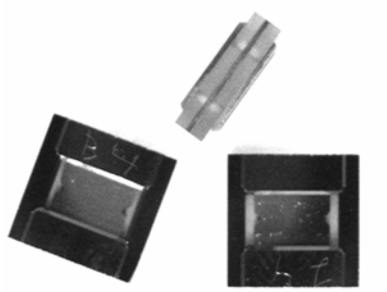

Fig. 5: Acceleration sensor chips (7 x 7 x 2.1) mm³

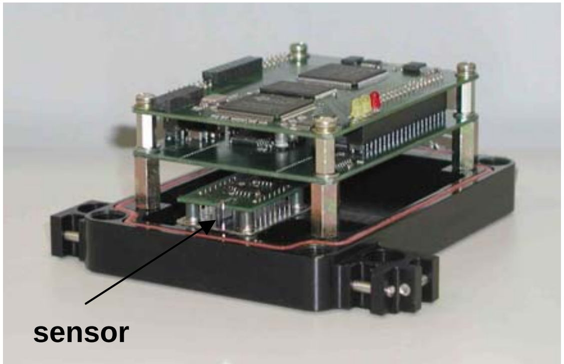

Fig. 6: Ground plate with mounted inner box and electronics

4 Results

Several sample tests of sensors prototypes together with electronics have been carried out. Four-point-tumble tests as well as tests on the rotation table have shown that both measurement range and resolution meet the specification. Typical measured values of bias are 10…40 mg. The bandwidth was measured to be 210…220 Hz. All sensors passed shock tests with loads higher than 80g over 5ms, vibration tests with 0.04 g²/Hz, and full temperature tests from -40°C to 70°C. Based on these promising results, a second phase for development of prototype II is planned.

This acceleration sensor will be applied e.g. in a cooperation project with FARA New-Tech Development Co. in Xián (China).