Electronic compensation of fabrication tolerances demonstrated for a novel micromachined gyroscope

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Within the project EKOFEM a novel high precision Si gyroscope fabricated by a special high aspect ratio technology is under development. The planar structure (Fig. 1) exhibits two in-plane vibration modes for drive and detection. Comb drive electrodes (Fig. 2) are used to force the resonator to vibrate with it's primary mode resonance frequency, and differential detection electrodes (Fig. 3) measure the vibration amplitude of the secondary mode caused by Coriolis forces. Due to the very high requirements to accuracy and resolution (bias stability 10°/h, angle random walk $< 0.3°/\sqrt{h}$), it is necessary to compensate fabrication tolerances as well as other influences (e.g. thermal drift). This is achieved by electronics; the control loops are implemented in a digital signal processor. As an example see Fig. 1 for the PLL and amplitude control of the excitation motion .

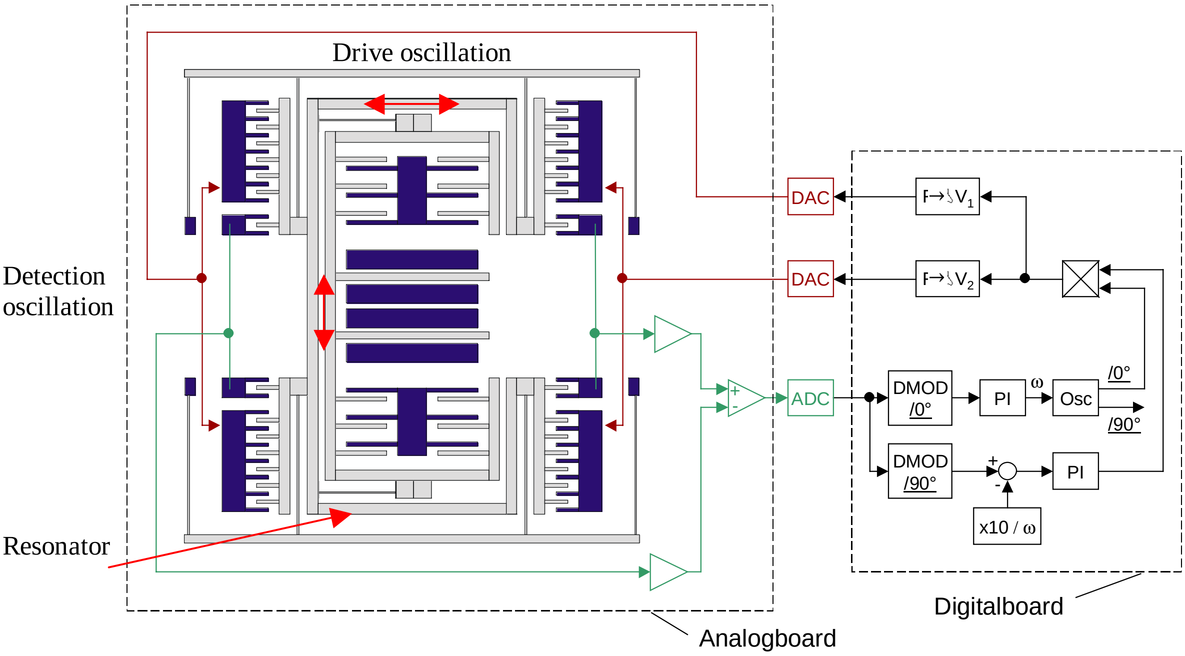

Fig. 1: Block diagram showing the design, PLL and velocity amplitude control of the excitation oscillation

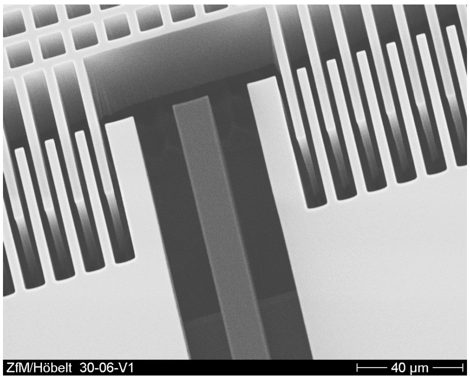

Fig. 2: Comb drive

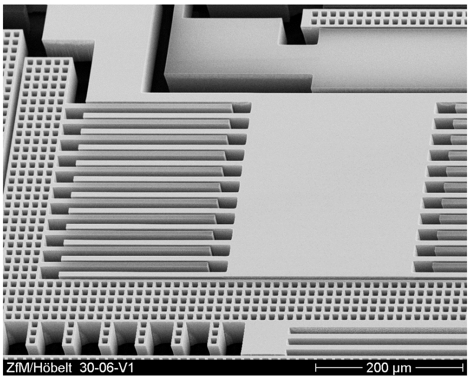

Fig. 3: Detail of the detection system

Matlab/Simulink, MEMSPro and ANSYS simulations allow a careful design and structure optimisations for the resonator. The FEM 3D volume model is based on the mapped mesh method. Substructure techniques are used for the periodic structures, typical "basic" elements are defined and can be described by parametric scripts. With this method a very exact simulation of resonance frequencies (modal analysis) is possible. The influence of fabrication tolerances (e.g. side-wall angle and it's symmetry) can be evaluated. As an example, Fig. 4 shows the vertical (undesired cross-axis) motion of the structure during primary vibration due to a side-wall angle of trenches > 90°. In order to minimise the cross-axis motions, the spring profile should be as close as possible to a rectangle.

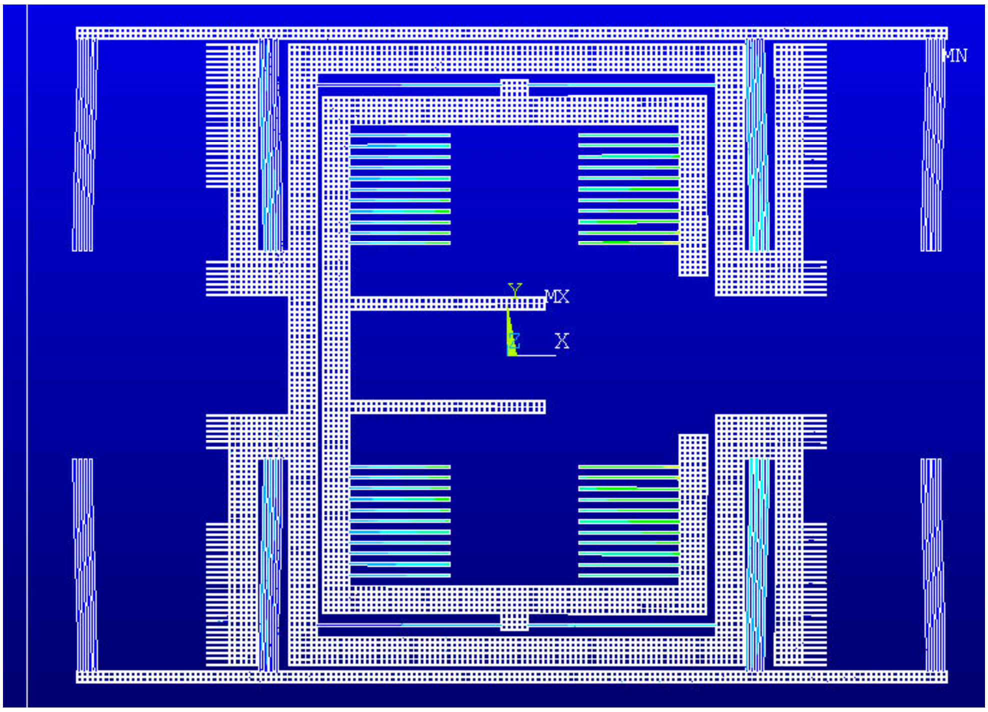

Fig. 4: Vertical component of primary mode (f = 7999 Hz) illustrated by colours (green = largest)

The gyroscope is fabricated by a new technology approach based on SOI-wafers with a buried cavity (see Fig. 5). The thickness of the active layer is 50 µm. Deep dry RIE etching via photoresist mask is used for the trench patterning process (Fig. 5, 7). Aspect ratios up to 25:1 (smallest trenches 2 µm) have already been demonstrated. Presently much effort is put on the optimisation of this trench etch process (rectangular and symmetric trench profile, reduced ARDE and notching).

For hermetic encapsulation of the resonators (Fig. 6), a special direct bonding regime has been developed and applied. Sensors with residual cavity pressure of 1 Pa and 100 Pa were fabricated. The resonators show very high quality factors (up to 120,000 at a pressure of 1 Pa for excitation mode). Other promising measurement results of the capped sensors presented in [1] are the very low noise (< 0.3°/√h) and a long term stability of 5.4°/h.

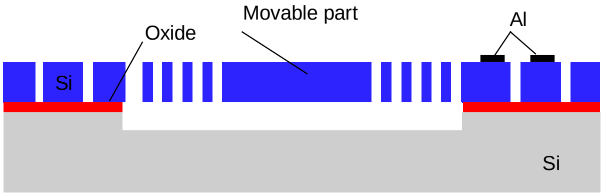

Fig. 5: HARM Technology with buried cavities

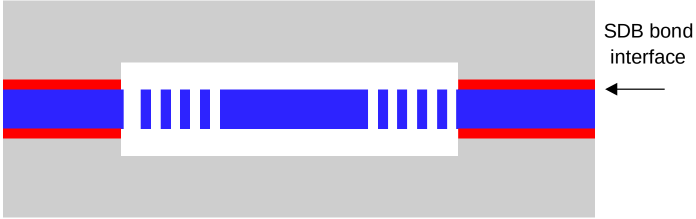

Fig. 6: Hermetic vacuum packaging by Silicon Direct Bonding

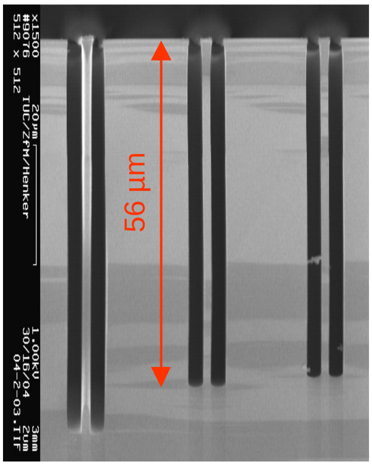

Fig. 7: Trench profiles for 2 µm gaps

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[1] W. Geiger et al.: *The micromechanical Coriolis Rate Sensor µCORS II*, Symposium Gyro Technology, Stuttgart 2003