

Improving Cavity Pressure Stability as Enabler for High-Performance 2-Cavity MEMS Chips

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Summary:

The integration of multiple sensors, such as gyroscopes and accelerometers for Inertial Measurement Units (IMUs), onto a single MEMS chip requires separate, stable cavity pressures. This paper presents a systematic analysis to quantify mechanisms which lead to changes in cavity pressure using a dedicated test vehicle. We demonstrate that gas diffusion through buried oxide layers is the dominant cause of pressure drift. Based on this finding, we developed and validated a gas diffusion barrier that reduces pressure drift by 97%, enabling the fabrication of high-performance, long-life 2-cavity MEMS chips.

Keywords: MEMS, IMU, cavity pressure, gas diffusion, desorption

Background, Motivation and Objective

Modern Inertial Measurement Units (IMUs) combine multi-axis gyroscopes and accelerometers to provide comprehensive motion sensing. For optimal performance, these sensors have conflicting environmental requirements: gyroscopes require a high-vacuum cavity to achieve a high quality-factor, while accelerometers are typically operated in a damped environment at a higher pressure. Integrating both sensor types onto a single 2-cavity MEMS chip is desirable for miniaturization and cost reduction, but it presents two significant challenges. The first challenge is to seal different cavity pressures on one and the same chip. This has been enabled by enhanced process techniques such as laser reseal [1]. The second challenge is to prevent gas diffusion between the adjacent, pressure-differentiated cavities over the product's lifetime. Any drift in the gyroscope's vacuum cavity pressure degrades its performance. Therefore, understanding and mitigating the mechanisms of pressure change - such as gas diffusion, adsorption, or desorption - is essential for enabling high-performance, single-chip IMUs. This paper describes a detailed analysis to identify the dominant leakage paths and presents a structural solution to ensure cavity pressure stability.

Description of the New Method or System

To accurately measure smallest changes in cavity pressure, the quality-factor measurement of a yaw rate sensor was employed, which is highly sensitive to smallest changes in damping and thus in gas pressure [2] as shown in *Fig. 1*. In order to analyze potential cavity pressure affecting mechanisms such as gas diffusion, adsorption

and desorption separately, a MEMS chip layout including dedicated test structures on one and the same wafer was developed and utilized as sketched in *Fig. 2*. Each test structure addressed a different mechanism. The left picture shows the concept of a group of structures in which the eutectic AlGe separator was varied in width and designed with and without an interruption aiming for diffusion effects via the separator. In the second group shown in the center an additional material (Al, Ge or AlGe) was deposited on Si and a direct access to the gyroscope cavity was implemented through the separator addressing de-/adsorption effects. The right group featured an accelerometer core which was enclosed by a rectangle where certain buried layers were removed. This meant that if these layers act as diffusion path, this path was interrupted. By measuring all test structures before and after High Temperature Storage Life (HTSL: 150 °C, 1000 h), the cavity pressure change due to each individual mechanism could be quantified.

Results

The cavity pressure change of all test structures upon HTSL is shown in *Fig. 3*. The test structures clustered in the blue and red rectangles, addressing gas diffusion via the eutectic AlGe separator between the cavities (blue) and potential outgassing from the Al / Ge / AlGe material (red), respectively, led to cavity pressure changes below 0.01 mbar of N₂ damping equivalent. The test structures clustered in the green rectangle were designed to investigate the gas diffusion via the buried SiO₂ and Poly-Si layers. For these test structures with accelerometer MEMS structure, the change in gyroscope cavity pressure

was much higher than for the other test structures, ranging from 0.08 – 0.16 mbar. To activate this diffusion path, these test structures incorporate an accelerometer MEMS structure with direct contact between the gases of the accelerometer cavity and the buried SiO₂ / Poly-Si layers. In the test structures of the blue and red groups this path was blocked by a closed Si surface. Nevertheless, within the green group, the interruption of the lower and upper oxide layers reduces the pressure increase when compared to the test structure where the poly-Si layers were interrupted. This indicates that gas diffusion between the cavities via the buried SiO₂ layers is the dominant mechanism leading to gyroscope pressure changes upon HTSL [3].

As a layout measure to reduce the observed gyroscope cavity pressure drift, a 2-cavity MEMS layout was introduced featuring a gyroscope core enclosed by a gas diffusion barrier. This barrier consists of a line where the oxide is removed and the gap is filled with the subsequently deposited poly-Si layer [4].

In Fig. 4, the gyroscope cavity pressure drift of a reference 2-cavity MEMS chip without the measure is compared to the drift of a chip with the implemented measure of an enclosing gas diffusion barrier. The measure reduces the resulting cavity pressure change by 97%. This enables the positioning of an accelerometer and a gyroscope on the same chip (2-cavity MEMS) while keeping the gyroscope cavity pressure stable over its lifetime.

Illustrations, Graphs, and Photographs

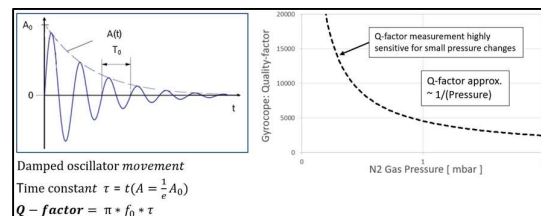


Fig. 1. Left: Damped oscillator movement with decaying amplitude. Quality-factor as a quantity to describe damping. Right: Measured gyroscope quality-factor versus N₂ cavity gas pressure.

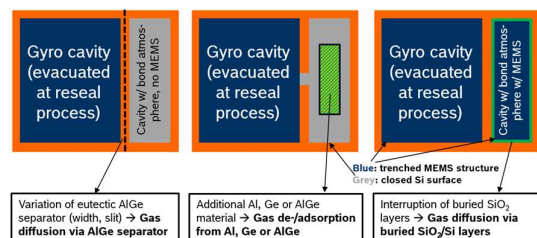


Fig. 2. Sketch of test structures to analyze different mechanisms affecting gyroscope cavity pressure on a 2-cavity MEMS chip with two different cavity pressures and atmospheres. Blue: Trenched MEMS structure, Grey: Closed Si dummy area.

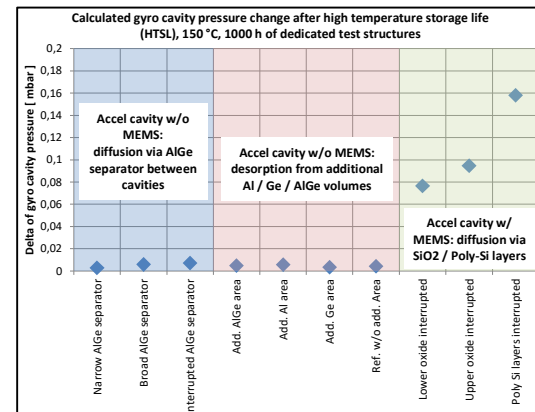


Fig. 3. Change in cavity pressure after HTSL of different test structures addressing various mechanisms contributing to changes in gyroscope cavity pressure.

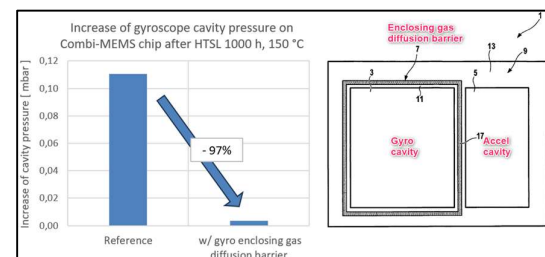


Fig. 4. Change in gyroscope cavity pressure on a 2-cavity MEMS chip after HTSL without (left) and with (right) gyroscope enclosing gas diffusion barrier [4].

References

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