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ON MECHANISMS OF ENERGY DISSIPATION AND TRANSFER IN MEMS VIBRATORY GYROSCOPES OPERATED IN VACUUM

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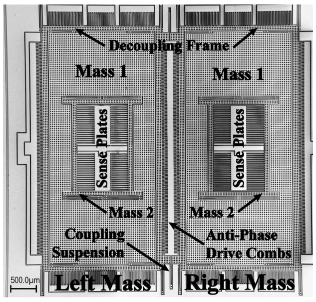
ABSTRACT

In this paper, we study mechanisms of energy transfer and dissipation in SOI bulk micromachined vibratory gyroscopes. Existing publications on vibratory MEMS mainly focus on viscous and thermoelastic dissipation of energy, [1,2]; limited literature is available on non-viscous damping mechanisms. This work aims to provide some additional insight into non-viscous energy loss mechanisms, specifically focusing on energy transfer from the device die to the package.

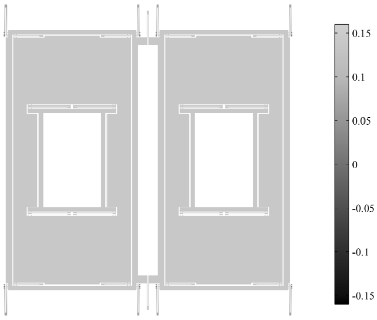
Figure 1(a) shows an SOI micromachined gyroscope used for the experimental study. The drive-mode of the gyroscope is a 2-DOF dynamically coupled system with an in-phase and anti-phase mode. The sense-mode consists of two 2-DOF systems for improved robustness [3]. The limiting non-viscous quality factor Q_{lim} of most MEMS gyroscopes measured in vacuum is in the range of $10^4 - 10^5$, which is often attributed to thermoelastic dissipation, [2]. In the first part of this study, thermoelastic dissipation in the gyroscope was modeled numerically using COMSOL Multiphysics. Finite Element Modeling (FEM) of the gyroscope's in-phase and anti-phase modes are shown in Figure 1(b) and Figure 1(c), respectively. For both the in-phase and the anti-phase modes thermoelastic damping (TED), $Q_{TED} \approx 10^6$, that is several orders of magnitude higher than the commonly observed Q_{lim}. These results suggest that there exists a different non-viscous energy loss mechanism, such as energy dissipation through support or anchors.

A vacuum setup shown in Figure 2(a) was used for the experiments. Quality factor as a function of pressure $Q(P)$ and the limiting non-viscous quality factor Q_{lim} were measured for both the in-phase and the anti-phase modes of the gyroscope. A comparative study of the measurements is presented in Figure 2(b) and reveals the following trends. The quality factor of the in-phase mode operated devices is limited to $0.5 * 10^4 - 10^4$; it is strongly dependent on the die attachment technique and is thus attributed to the dissipation of energy through the support. The quality factor of the anti-phase mode does not show significant dependency on the die attachment technique. In the tested range of vacuum it is governed by the viscous damping laws, $Q(P) \propto 1/P$, and measures $70,000$ at 20 mTorr.

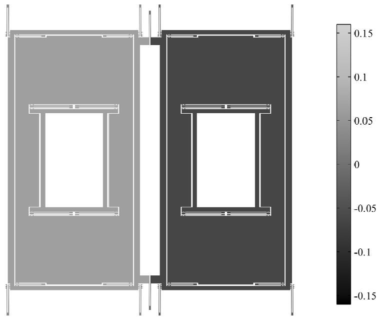
We experimentally identified dissipation through the die support as the dominant limiting damping mechanism in in-phase driven gyroscopes. This loss mechanism depends strongly on the die attachment technique, where more rigid die attachment decreases the dissipation at the cost of decreased isolation of the MEMS device from external vibrations. Anti-phase operation decreases dissipation through support by orders of magnitude and provides inherent robustness to external vibrations [3].



(a) SEM image

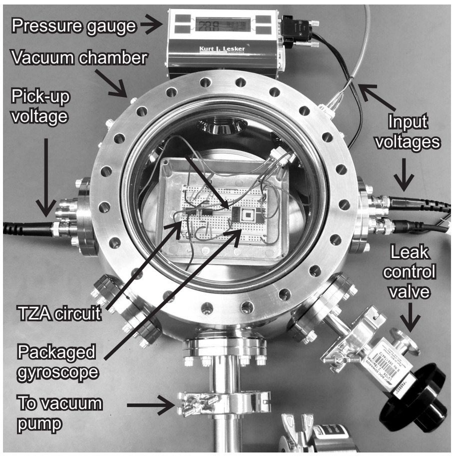


(b) In-phase mode, $Q_{TED} = 1.7 * 10^6$ at 1.46 kHz resonant frequency

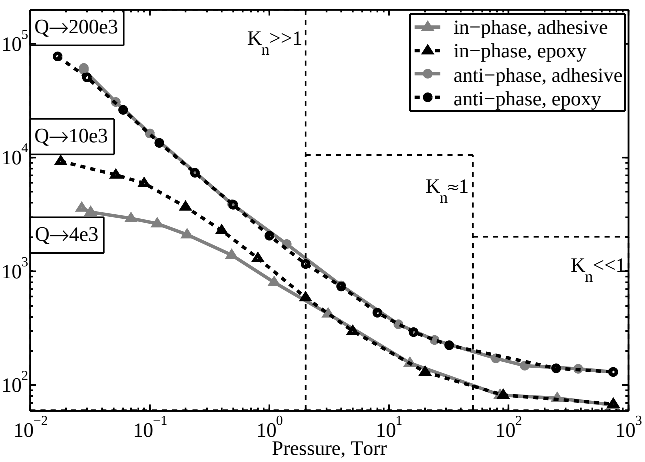


(c) Anti-phase mode, $Q_{TED} = 1.3 * 10^6$ at 2.18 resonant frequency

Figure 1: (a) SEM of the bulk micromachined anti-phase driven vibratory gyroscope with multi-DOF sense-mode. (b,c) COMSOL FEM of thermoelastic damping (colors represent x-displacement).



(a) Experimental setup



(b) Measured Q versus Pressure

Figure 2: Experimental measurement of quality factor Q for the in-phase and anti-phase modes. “Epoxy” and “adhesive” stand for the die attachment techniques using CircuitWorks conductive epoxy and SPI conductive double sided carbon adhesive tape respectively. K_n is the Knudsen number and is calculated assuming 5 μm characteristic gap.

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