Strongly Passively Damped MOEMS Vibration Sensor

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Abstract

Usually, one favors a low resonance peak for vibration sensing, since this expands the measurement range. Furthermore, one wants to avoid ringing. Both requirements are met by a high damping, i.e. a low quality factor of $Q \sim 1$. In this contribution, we show that it is possible to design a micro-opto-electro-mechanical system (MOEMS) vibration sensor featuring a strong passive damping leading to a quality factor of ~2. Starting point for this is a basic understanding and analytic modeling of the relevant damping mechanisms which in our case (at ambient pressure) is air damping. The analytical models revealed the relevant parameters determining the air damping of the MOEMS. We compared the results of our analytical models to finite volume method (FVM) simulations conducted with the open source software OpenFOAM to account for effects not covered by the analytics. Finally, measurements of the designed structure confirm the low Q-factor close to the critical value $Q = 1$.

Motivation

Micro-electro-mechanical systems (MEMS) are very commonly used as accelerometer or for vibration sensing. One can find them almost everywhere in today's consumer electronics, automotive applications and other applications. The-state-of-the-art commercial sensors are based on a capacitative readout, i.e. a suspended electrode that is deflected by the acceleration/vibration moves against a fixed one. The more sensitive the sensor, the closer the electrodes should be. The drawback of this principle is the necessity of an active force feedback (damping) to avoid pull-in of the moving electrode. An alternative is offered by the optical readout of the MOEMS device presented in [1]. There, the electrodes are replaced by a fixed and a moving grid of rectangular holes arranged in such way that the light flux through the sensor is modulated if the moving part is deflected (Fig. 1). Advantages of this readout principle are, e.g., large possible deflection range or no necessity for an active feedback. It could also be shown that, apart from the effective mass or stiffness, the passive damping can be adjusted in a wide range to fit the needs of almost any given application [2,3]. We use these findings to design a low Q vibration sensor with passive damping only.

Results

Since the mechanical Q-factor depends on the angular resonance frequency ω_0 and the decay constant γ only, i.e. $Q = \omega_0/2\gamma$, we aimed at a microstructure with $\omega_0 \geq 2\gamma$. The decay parameter corresponds to the damping force $F_d = v \cdot \gamma / 2m$ exerted by the surrounding air onto the sensor's seismic mass m oscillating with velocity v (Fig. 2). Assuming a perfect fabrication process without underetching or other difficulties, we wanted to design a sensor with $\gamma = 800\ \mathrm{s}^{-1}$ and $\omega_0 = 2000\ \mathrm{s}^{-1}$. In reality we observe a broadening of etched holes by ~1 µm for each edge which significantly influences the Q-factor. Taking this into account, the FVM simulations suggest a reduced decay parameter of $\gamma = 448.45\ \mathrm{s}^{-1}$. We then tested this value against actual measurements of the sensor (Fig. 3), where we recorded the transfer characteristic. The values for γ and ω_0 were extracted thereout by a least-squares fitting routine (Fig. 4) yielding $\gamma = 449.21\ \mathrm{s}^{-1}$ and $\omega_0 = 2043.96\ \mathrm{s}^{-1}$, which corresponds to $Q = 2.275$.

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[3] A. Kainz. W. Hortschitz, F. Keplinger, Air damping as design feature in lateral oscillators, in: to be published, 2015.

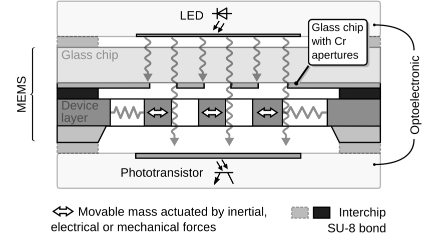

Figure 1. Sensor principle. The fixed Cr apertures and the moving apertures etched into the Si seismic mass modulate the light flux from an LED depending on the deflection of the mass. This flux is then registered by a phototransistor.

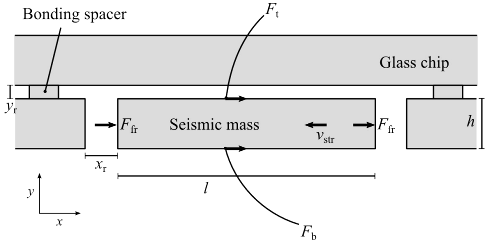

Figure 2. Relevant components of the damping force. The total damping force F_d consists mainly of three contributions: Couette type damping F_t, free shear damping F_b and squeeze damping F_{fr}. The distances x_r and y_r determine the strength of F_d.

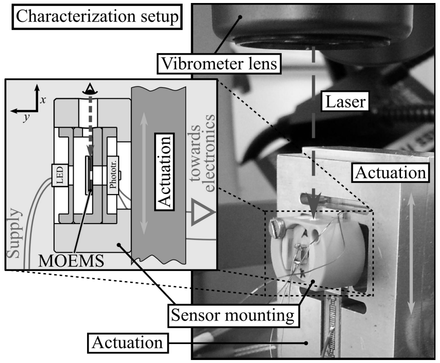

Figure 3. Characterization setup. The MOEMS sensor is actuated by a piezoelectric shaker. The actuation amplitude is measured by a Polytec MSA-400 vibrometer while the sensor modulates the light flux from LED to phototransistor.

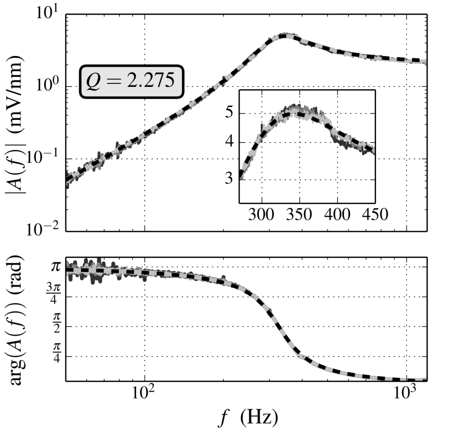

Figure 4. Transfer function $A(f)$ (top: amplitude, bottom: phase) of the low-Q sensor measured for three different actuation amplitudes. The gray solid lines represent the actual sensor output divided by the respective actuation. The black dashed curve corresponds to the fit of the measured data.