DOI 10.5162/EUROSENSORS2025/M3.3.3

Capacitive Excitation of Out-of-Plane Modes in MEMS Resonators with a Planar Electrode Design

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Summary:

This paper reports on a novel planar electrode design for the capacitive excitation of out-of-plane (OOP) resonance modes in MEMS test structures to study local material parameters. A simple device fabrication process is developed consisting of 4 process steps only. As a straightforward result, the fabricated plate resonator bends in the OOP directions due to a release of the intrinsic thin film stress. The planar electrodes and the bent resonator feature electrostatic forces in the OOP direction, thus actuating the OOP vibrational modes of the resonator.

Keywords: MEMS resonators, capacitive excitation, planar electrode, out-of-plane modes

Background, Motivation, and Objective

MEMS resonators are relevant for measuring non-electrical signals, such as rotation rate with gyroscopes [1], the viscosity of liquids [2, 3], and time [4]. Typical actuator principles for MEMS resonators are based on thermal, magnetic, piezoelectric, and electrostatic effects [5]. A relevant drawback of thermal and magnetic actuation is the high power consumption due to Joule losses. Piezoelectric, in contrast to capacitive actuation, covers the resonator with a piezoelectric layer, thus reducing the Q-factor. Despite their widespread use, the fabrication of electrostatic actuators is not straightforward since considerations on sticking and the pull-in effect must be taken into account. An external electrode configuration to handle the pull-in effect was demonstrated by Rosa et al. [6]. However, the wafer needs to be patterned before the thin film deposition for the stepwise deposition of electrode and cantilever material with a sacrificial layer in between.

This paper reports on a novel electrode design using electrostatic forces to actuate Euler-Bernoulli (EB), torsional (T), roof-tile-shaped (RTS) [7], and higher order plate (HOP) modes in single-side clamped plate-shaped (SSCP) MEMS resonators. Since resonators fabricated from any conducting material can be actuated, the presented devices can be used as a test structure to study local and device-relevant material parameters. The advantage of the simple fabrication process is described, and the application of a polycrystalline silicon (PCSi) MEMS resonator with several resonance modes in the range of up to 220 kHz is demonstrated.

Description of the New Method or System

At 600 °C, a 2 µm thick PCSi thin film is deposited within a low-pressure chemical vapor deposition (LPVCD) process on a 4-inch <100>-silicon wafer with a wet thermal oxide of 500 nm on its top surface.

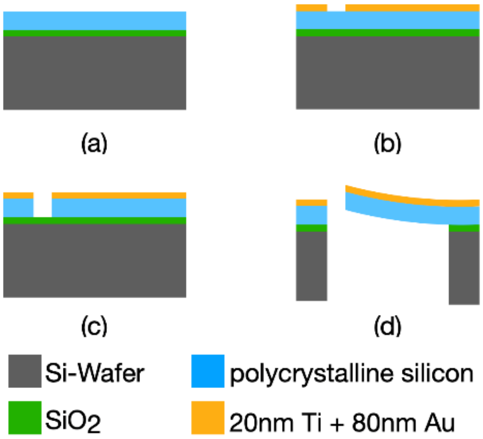

Figure 1: Fabrication process of SSCP MEMS resonators with a planar electrode arrangement.

Subsequently, titanium-gold contacts are evaporated and the device and the handle layer are etched with a Bosch process. The buried oxide is removed in the last step releasing the resonator structure. Consequently, the thin resonator releases intrinsic stress from the thin film fabrication while bending in the OOP direction. The fabrication steps are shown schematically in Figure 1 and an SEM image of a MEMS resonator with the novel arrangement of the electrodes in Figure 2. The asymmetric arrangement of the small and large static electrodes allows the excitation of T and especially RTS modes. The gap size between the resonator and the static electrodes is set to 5 µm as a tradeoff between reliable dry etching results and high electric fields, thus high actuation forces.

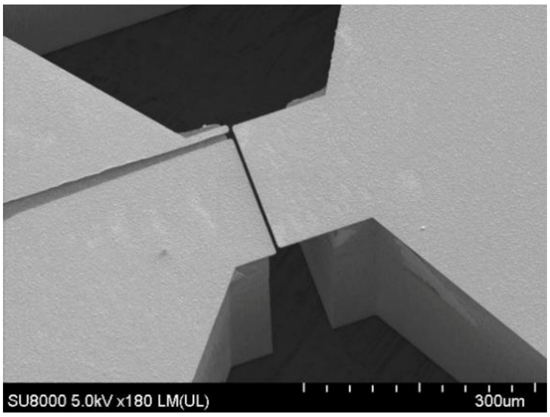

Figure 2: SEM image of a 100 µm long and 220 µm wide SSCP MEMS resonator.

Results

Intrinsic stress in the device layer causes the fabricated MEMS resonators to bend out of the horizontal position. Figure 3 shows a representative topography measurement with white light interferometry (WLI), demonstrating the OOP bending of the resonator with a typical maximum deflection of 3 µm at the tip region.

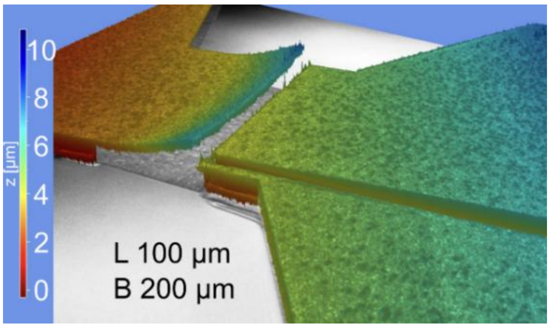

Figure 3: Topography measurement of a fabricated SSCP MEMS device.

The device is operated under vacuum conditions with a pressure level of 10^{-5} mbar. The actuation is done with a sinusoidal signal with an amplitude of 5 V and a constant offset of 5 V. The offset is necessary to mechanically pre-stress the resonator to maximize the amplitude. The vibrational response characteristics are measured with laser Doppler vibrometry (LDV) at the edge of the SSCP MEMS resonator to cover all possible OOP modes. A frequency sweep from 10 to 220 kHz demonstrates the ability of the electrode design to actuate seven OOP and one in-plane resonance modes within this frequency range, as shown in Figure 4. The measured vibrational amplitudes range from 0.02 nm to 50 nm and, hence, are small compared to the static deflection.

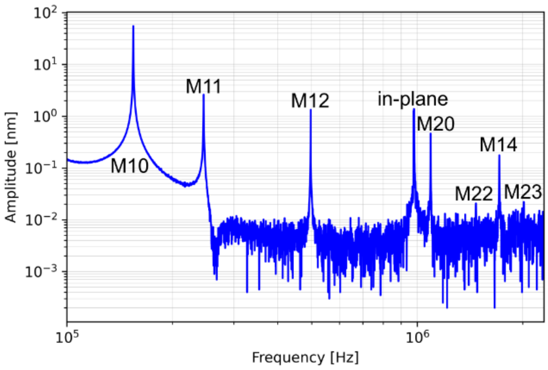

Figure 4: Frequency sweep of the capacitively actuated wide SSCP MEMS resonator from 10 to 2.2 MHz.

The few standard steps of device fabrication, inherent to many MEMS fabrication processes, and the prevention of sticking and pull-in effects are clear benefits of the presented design. In future studies, doped device layers will be investigated since the metallic electrode material must not cover the MEMS resonator's surface so that the bare device layer can be studied. In the near future, this test structure concept will be exploited for Q-factor analysis of different MEMS materials.

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