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Snap-through Mode Shape Reconstruction of Bistable PiezoMEMS Membranes through Parametric Exploration

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Summary: In this work, snap-through modes shapes of bistable piezoelectric micro-electromechanical devices are presented based on a prior investigation of its parametric behavior. These devices make use of compressive aluminium nitride thin film in order to achieve bistability, hence the ability of switching between two ground states.

Keywords: Snap-through, Resonance mode, PiezoMEMS, Bistability, Aluminium nitride

Background

Typically, resonance modes of resonators are investigated using sweep measurements, which mainly involve low-amplitude chirp signals. While effective for characterizing linear behavior, this approach only reveals the device's response under small excitation conditions. When subjected to high-amplitude excitations, the device response deviates significantly, exhibiting nonlinear behavior. In our PiezoMEMS devices, characterized by its bistability, such nonlinear effects become prominent, making it insufficient to rely solely on traditional linear analysis. Previous work, such as [1], has explored this nonlinear behavior, but their analysis did not relate the observed response to the broader parametric behavior of the device, an important step for distinguishing between linear and nonlinear regimes. In our work, we aim to bridge this gap by combining the approach from [1] with the method used in [2], providing a more comprehensive understanding of the behavior of bistable membranes.

Method

In this work, we have emploied a hybrid static–dynamic approach to reconstruct the shape of the snap-through, following the methodology in [1]. The process begins with a static analysis using white light interferometry (WLI, Polytec MSA400), generating an 11×11 mesh that captures the surface topography of our piezoMEMS device of 800 μm diameter. The dynamic analysis is performed using laser Doppler vibrometry (LDV). Selecting the point of interest requires prior parametric studies to ensure relevance, hence the implementation of correlation maps to assure that all measurements done for the full 11x11 mesh have similar profile. To this end, we adopt the method introduced in [2] to construct a parameter space that characterizes the snap-through behavior, specifically a systematic variation of the applied electrical signals, namely voltage and frequency, to map out the parameter space.

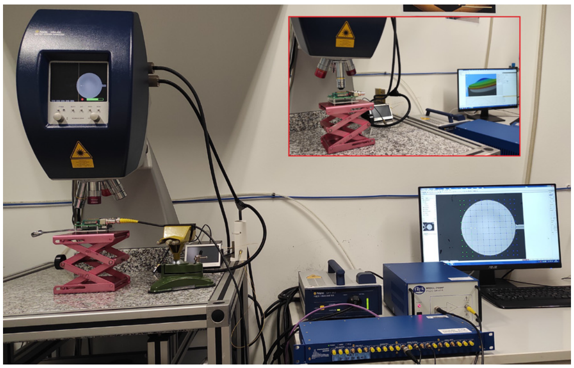

Fig. 1: The used setup, from left to right: The MSA400 system used for LDV and WLI outputs, the bistable device under the lens, MLA3 as the DAQ unit, voltage amplifier of fixed gain x50, and finally PC screen showing the built 11x11 mesh. In the center, the WLI scanning of the used device is done.

Results

The results exhibit similarities to those reported in [2], particularly in the appearance of complex fractal patterns. In our case, we applied nearly double the voltage levels used in previous work. As a result, a new fractal region was observed at approximately half the frequency of the original fractal region, which was located near the first linear natural mode at 105 kHz, see Figure 2.

To explore this further, we extended the voltage range up to 165 volts to better reveal the newly developed fractal region. We conducted 8 repeated measurements within the newly observed region. This repetition enabled us to correlate velocity data across different excitation conditions as shown in Figure 2. As a result, we identified highly correlated regions, from which points of interest were selected for the subsequent snap-through shape reconstruction mea-

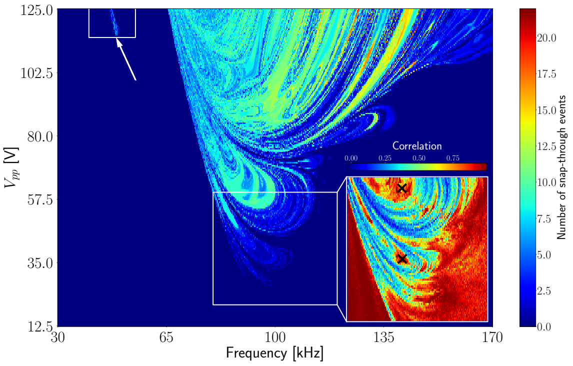

Fig. 2: The built parameter space made up of voltage and frequency variation. To the lower right cornerm correlation maps for the region of interest is shown. Selected points of interest are of (96 kHz, 37.5 V) and (95 kHz, 57.5 V). In the upper left, the subharmonic region starts to show up which is extended in Figure 3

surements. Similar step was done for the correlated region in Figure 1.

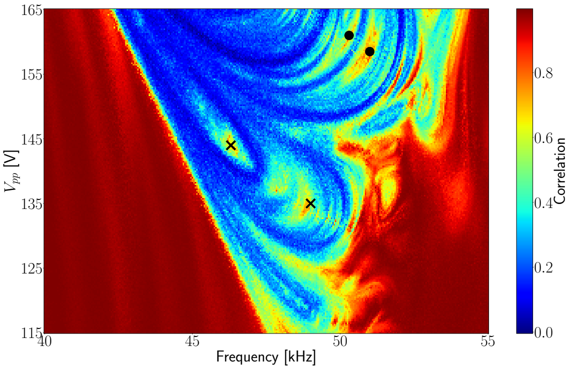

Fig. 3: The correlation map of the second fractal region. The selected points are (46.3 kHz, 144 V) and (49 kHz, 135 V)

From the selected points in both regions, as seen in Figure 4, it is evident that the bistable device undergoes a transitional mode of 11 during its snap-through behavior. A clear similarity is observed between the two modes generated from the distinct regions, the subharmonic fractal region shows a 90-degree shift in the radial nodal line, suggesting similarity to degenerate modes.

We also examined points of interest at higher voltage levels, around 160 volts, within the subharmonic fractal region denoted by ● in Figure 3. These measurements revealed a noisier representation of the snap-through behavior. It is likely that, at these specific points, the device exhibits different snap-through patterns, as the high-energy, nonlinear dynamics become too complex to be accurately captured using simple correlation maps based solely on the center point velocity of the membrane. As a direction for future work, exploring alternative materials such as ScAlN may help reduce the required voltage to access this region. This study highlights the importance of combining the methods from [1] and [2], particularly for such devices that exhibit nonlinear behavior.

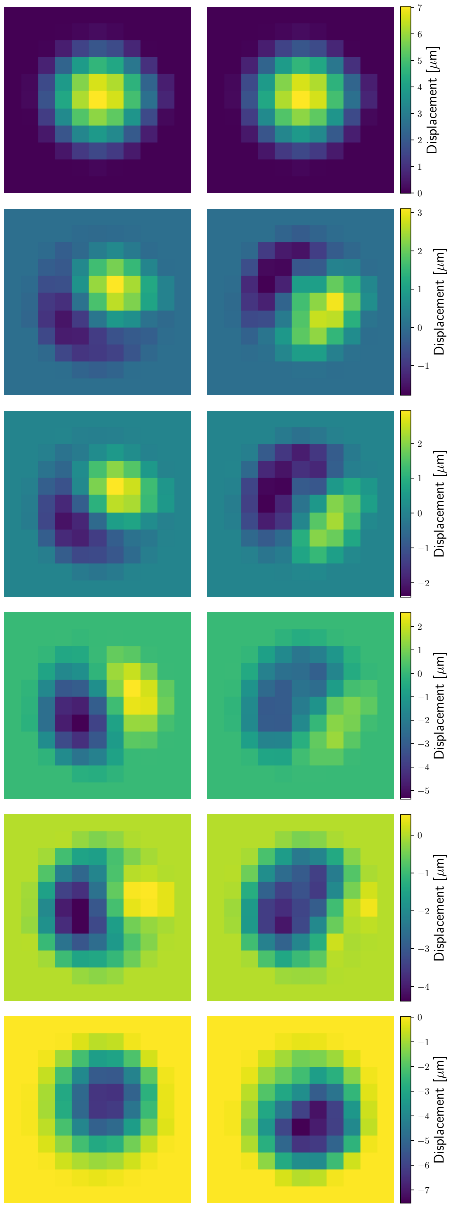

Fig. 4: Different snap-through snippets taken at different times from time = 0 until the first snap-through. First column represents points taken from the fundamental mode fractal region, Figure 2, and second column represents points taken from the subharmonic fractal region, Figure 3.

References

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