

Asymmetric Snap-through Dynamics in Bistable Piezoelectric MEMS Plates

Mahdi Mortada^{1,2}, Andreas Kraus^{1,2}, Jakob Gruber^{1,2}, Ulrich Schmid¹, Michael Schneider^{1,2}

¹ *Institute of Sensor and Actuator Systems, TU Wien,*

² *Christian Doppler Laboratory for Piezoelectric Silicon MEMS with Enhanced Sensitivity and Responsivity, Institute of Sensor and Actuator Systems, TU Wien
Gußhausstraße 27-29, 1040, Vienna, Austria
mahdi.mortada@tuwien.ac.at*

Summary:

This study experimentally compares the switching behavior of a bistable piezoelectric MEMS plate actuated by an aluminium nitride (AlN) thin film from both ground states using pulse trains with varying voltages and frequencies to investigate nonlinear dynamics. The results show an asymmetry in the double-well potential with a preference for the upper state and demonstrate that adding an additional thin AlN layer to a buckled device modifies the potential energy, enabling tuning of voltage thresholds and snap-through responses, which is valuable for future PMUT applications.

Keywords: Snap-through, Bistability, Asymmetry, Aluminum nitride, Piezoelectric MEMS

Background

Experimental analysis [1] reveals how controlled asymmetries influence the dynamics and efficiency of a bistable energy harvester. Similarly, the study in [2] discussed and showed the asymmetry contribution both in the potential energy model and the unequal energy requirements for switching with bistable piezoelectric MEMS plates, from the lower to the upper state and vice versa. This asymmetry was attributed to the layers stack deposited on top of the plate. Generally, the upper state was observed to be the preferable state. In [3], the authors introduced a better measurement approach using lock-in phase analysis for state detection to characterize snap-through behaviour in bistable piezoelectric MEMS. However, their study was only focused on switching starting from the upper ground state. In this work, we characterize this asymmetry and show the impact of tuning the stress of a bistable plate of 900 μm diameter (Figure 1) behaviour by adding additional layers.

Method

Different electrical pulses are applied with varying the voltage and frequency from 10 to 50 Vpp and 45 to 95 kHz, respectively. Laser Doppler Vibrometry (Single point VibroFlex from Ploytec) is used to obtain the velocity of the plate centre and a Multifrequency lock-in amplifier (MLA3) from IMP is utilized as signal generator and lock-in amplifier to detect the phase of the plate to distinguish its ground state. Subsequently, after characterizing the behaviour of the bistable

plate, an additional layer of AlN is deposited onto its top electrode with a thickness of 35 nm and stress +100 MPa. Similar measurements were done subsequently to study the impact of this additional layer.

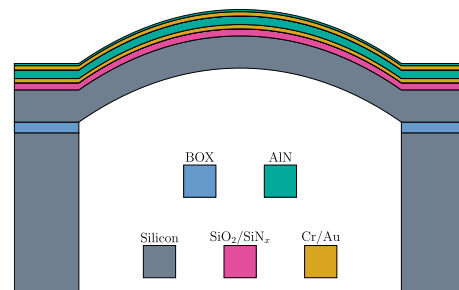


Fig. 1. Scheme of the bistable piezoelectric MEMS device with an additional top AlN layer.

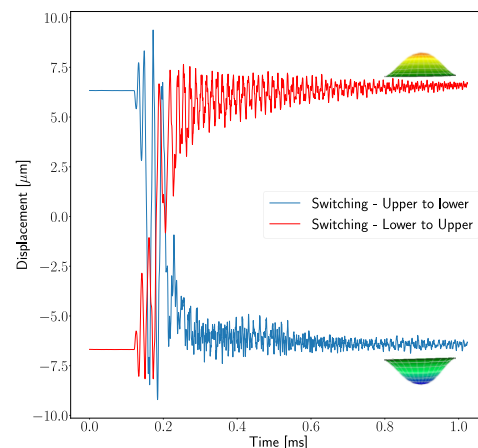


Fig. 2. Two switching events starting from different ground states showing different snap-through events.

Results

An example of switching behaviours are shown in Figure 2 and theoretical potential-well energies are shown in Figure 3. The obtained results showed a fractal nature behaviour of the parameter space similar to that presented in [3] as can be seen in Figures 4 and 5. The dynamic behavior reveals a clear asymmetry in the plates. Switching probabilities in Figure 4 indicate an overall higher probability of switching from the lower to the upper state confirming the asymmetry and the preference for the upper state. This is further supported by the lower voltage thresholds needed to initiate inter-well oscillations in the lower state.

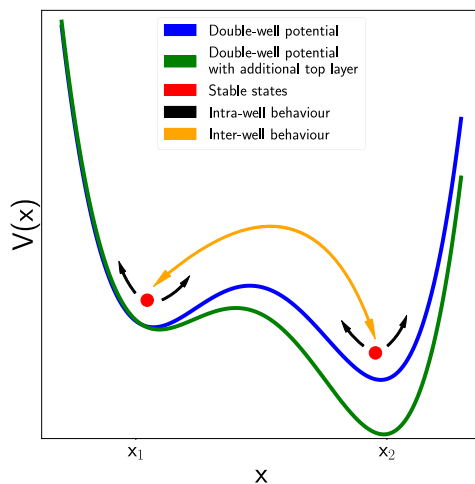


Fig. 3. Expected theoretical potential wells of bistable device where $V(x)$, x_1 and x_2 represent the potential energy, lower and upper ground states positions respectively.

We also show that careful thin-film deposition on a fully fabricated plate can alter its potential energy, thereby affecting its dynamic behavior. Specifically, the results showed that the upper state acquires a lower potential energy and requires about 5 V higher voltage levels for snapping, whereas the lower state retains its original required voltage (see Figure 5). Adding an additional layer, primarily increases thickness rather than stress and therefore shifts the neutral axis upward further, favoring the upper state. By carefully adding layers on the top or bottom of the plate, the device can be made more symmetric improving the uniformity of its dynamic response. Also, it is observed that the modifications primarily affect the required voltage levels while the frequency and snap-through dynamics remain largely unchanged as evidenced by the similar alignment along the frequency axis and comparable ranges of snap-through counts.

References

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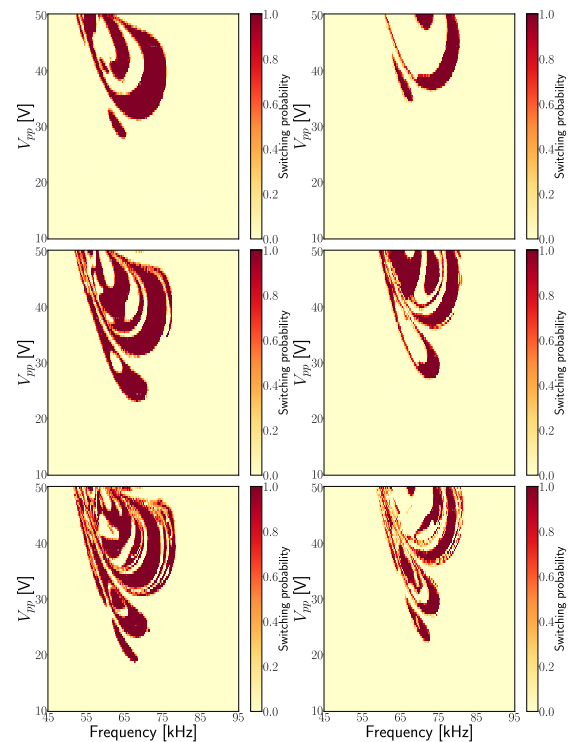


Fig. 4. Switching probabilities without the top AlN layer for 3, 4, and 5 pulses; left: lower state as initial state, right: upper state as initial state.

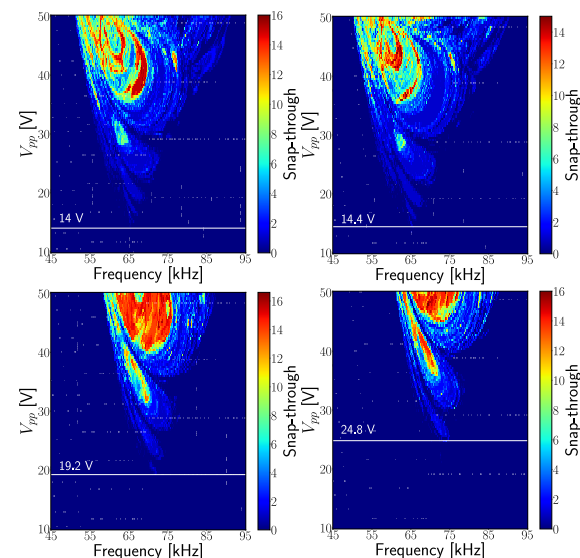


Fig. 5. Snap-through parametric presentation before (left) and after (right) deposition of AlN top layer starting from the lower state (top) and upper state (bottom) for 15 applied electrical pulses. White horizontal line serves as the threshold voltage for inter-well oscillations initiation.