

Temperature Dependence of Parametric Snap-Through in Bistable Piezoelectric ScAlN MEMS Plates

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Summary:

For the first time the temperature dependence between 30 °C and 80 °C of snap-through behaviour of bistable piezoelectric MEMS plates is shown. By exploiting mismatch in thermal expansion coefficients between ScAlN and Si the residual in-plane stress, and thus the buckling height, is tuned. An optimized measurement procedure allows for recording over 40 responses per second, enabling a high resolution parametric study. Understanding how dynamic characteristics of bistable plates are modified with ambient temperature change is a crucial step for future development towards commercial applications.

Keywords: MEMS, bistable, PMUT, nonlinear, temperature

State of the Art

In recent years bistable piezoelectric MEMS plates have emerged as promising candidates for applications requiring large stroke levels, like ultrasound generation [1, 2]. The static and small-signal response of such structures has been studied previously for a range of temperatures [3], as has the nonlinear parametric snap-through behaviour at room temperature [4]. The change in snap-through behaviour with temperature however has not been investigated so far. This study focuses on exploring the changes in the inter-well dynamics of the bistable piezoelectric MEMS plates for a temperature range from 30 °C to 80 °C through both metrics of number of snap-throughs and time to first snap-through. Additionally, the minimum voltage for initiating snap-through is investigated.

Methods

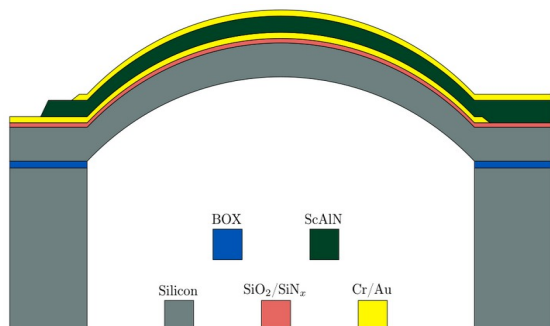


Fig. 1: Schematic, cross-sectional view of the device. The device is made from an SOI wafer with a 2.5 μm device layer. The piezoelectric layer (AlN or ScAlN, 400 nm) is sandwiched between Cr/Au electrodes. The plate is buckled due to the residual stress (up to -1 GPa) introduced in the ScAlN layer during sputter-deposition.

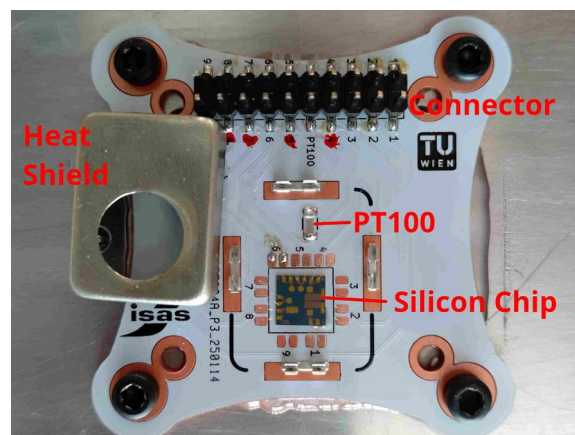


Fig. 2: Sample mounted on copper PCB for efficient thermal transfer. On the Si chip there are multiple plates (rectangular and circular), as well as a gold resistor for on-chip temperature sensing. The PCB incorporates an SMD temperature sensor (Pt100) for precise temperature tracking. Heat shield is removed for illustrative purpose.

The studied device consists of a clamped circular plate with a diameter of 700 μm , with a total thickness of 3.2 μm . Bistability is achieved by engineering the piezoelectric layer ($\text{Sc}_{33}\text{Al}_{66}\text{N}$) to exhibit compressive residual stress (up to -1 GPa), leading to buckling of the plates. A schematic view of a bistable device can be seen in Fig. 1. The fabrication process is described in detail in [2]. The wafer is diced and each die is mounted on a PCB for subsequent tests (see Fig. 2). To study the snap-through behaviour parametrized sine pulses with varying amplitude, frequency and number of cycles are applied to the plate, inspired by [4]. The plate movement in response to the electrical signals is recorded with a Laser-Doppler-Vibrometer. To study the

impact of temperature the measurement setup includes a Peltier heater/cooler to control the device temperature. An example of a recorded signal is shown in Fig. 3.

Experimental Results

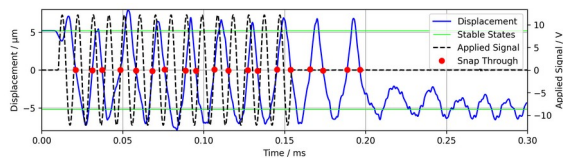


Fig. 3: Example of a recorded signal. Excitation parameters: 104.5 kHz, 24.875 Vpp, 15 pulses, temperature is 65 °C. The device switched, as shown by the sustained change in displacement for $t > 0.2$ ms.

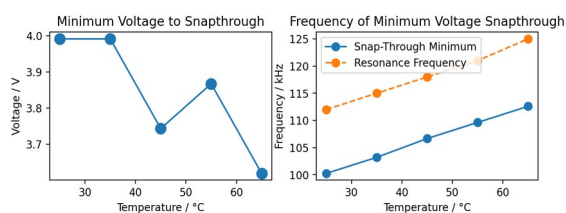


Fig. 4: Snap-through behaviour at different temperatures. Number of pulses is 15. Increasing the temperature shifts resonance frequency upwards, the frequency shift of the minimum voltage snapthrough point shifts by a similar amount.

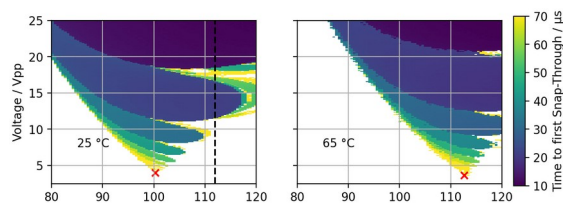


Fig. 5: Time to first snap-through for two example temperatures. The red 'x' represents the points from fig. 4. Each region represents a certain number of oscillations prior to snap-through. For example, the measurement from Fig. 3 has one oscillation before the first snap-through, it would be located in the darkest region at the top of the map.

The parameter space consists of 81 frequency steps by 181 voltage steps, 14,661 sets of parameters in total. Each measurement is repeated 5 times to check for consistency, resulting in 73,305 measurements performed. The fastest achieved time was 25 minutes, or about 48 measurements per second. Fig. 4 shows the analysis of the snap-through behaviour for different temperatures. With increasing temperature, the frequency at which the lowest voltage is required to achieve snap-through (marked by the red 'x' in Fig. 5) increases. This increase

correlates well with the increase in the small-signal resonance frequency of the device. This finding supports the hypothesis that the location of the tongue-like shapes in the parameter space (Fig. 5), and therefore the highly nonlinear snap-through behaviour is linked to the small-signal resonance frequency of the device. In the upper regions of the map (Fig. 5) there is a shift to higher voltages as the temperature increases, which is also comparable to small-signal behaviour [3]. In contrast to that, the minimum voltage to snap-through decreases slightly with increasing temperature. This could be explained by different vibrational modes showing different temperature dependence, but further studies are needed to explain this phenomenon. The distinct regions in Fig. 5 representing a fixed number of oscillations before snap-through, shift smoothly and do not change their shape erratically, which ensures predictable device behaviour. This stability and predictability in behaviour across temperatures highlights the robustness of this nonlinear mechanism, ensuring consistent device behaviour even under fluctuating ambient operating conditions.

References

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