DOI 10.5162/EUROSENSORSXXXVI/PT4.193

Directivity and distance dependence of generated pressure field of bistable PMUTs

Michael Schneider[1,2], Mahdi Mortada[1,2], Dominik Mayrhofer[3], Manfred Kaltenbacher[3], Ulrich Schmid[1]
[1] Institute of Sensor and Actuator Systems, TU Wien, 1040 Vienna, Austria
[2] Christian Doppler Laboratory for PiezoMEMS, TU Wien, 1040 Vienna, Austria
[3] Institute of Fundamentals and Theory in Electrical Engineering, TU Graz, 8010 Graz, Austria

Corresponding Author's e-mail address: michael.schneider@tuwien.ac.at

Summary:

This work presents both the directivity pattern and distance dependence of the pressure field of a piezoelectric micromachined ultrasonic transducer (PMUT). The PMUT comprises a silicon membrane and an integrated piezoelectric transducer based on aluminum nitride (AlN). It exploits bistability to achieve large membrane displacements during switching between both ground states.

Keywords: PMUT, bistability, PiezoMEMS, aluminum nitride, acoustic MEMS

Introduction

Ultrasonic sound has been utilized for decades in medical diagnostics, gesture recognition, non-destructive testing and range finding, to mention a few. Given the ongoing trend towards miniaturization, micromachined ultrasonic transducers based on the piezoelectric effect (PMUTs) have been gaining a lot of attention recently due to operation at lower voltage levels and the lack of any counter-electrodes as required in capacitive MUTs.

One way of increasing the pressure output of a PMUT is to increase the stroke level of the membrane element. There have been many approaches to achieve this, including the use of flexural supports [1] or differential transducers [2]. Due to compressive stress induced buckling however, bistability has been shown most recently to be a highly effective approach to achieve high sound pressure levels from PMUTs [3]. In this work, we study the acoustic emission characteristics of such bistable PMUTs.

Experimental details

The PMUTs are fabricated starting from a 100 mm silicon on insulator (SOI) wafer coated with a stress-compensated silicon oxide and silicon nitride bi-layer for electrical insulation. The piezoelectric transducer comprises thermally evaporated bottom and top electrodes (chromium and gold) and a reactively sputter-deposited aluminum nitride thin film sandwiched between both electrodes. The membrane is defined by backside deep reactive ion etching and a subsequent hydrofluoric acid removal of the buried oxide layer to release the membrane. The stress in the AlN layer is tailored to ensure that the total compressive stress state in the membrane exceeds the critical stress limit required for buckling.

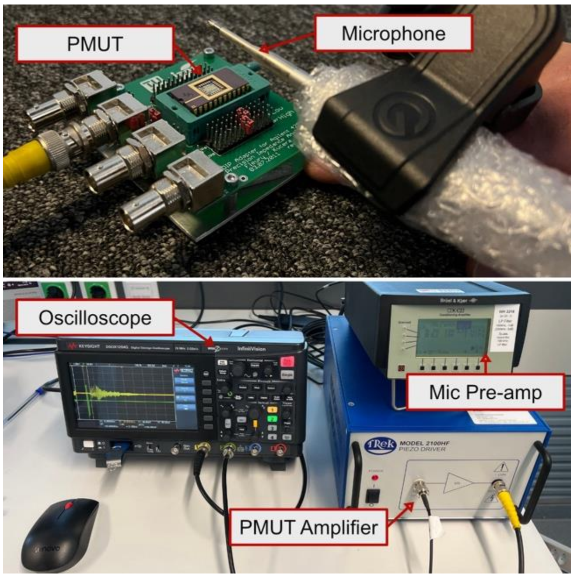

Figure 1. Measurement setup

The PMUT is electrically excited by applying a sinusoidal pulse train with n pulses to the AlN layer. The signal is generated using an Intermodulation products MLA-3 and is amplified by a factor of 50 using a Trek HF2100 broadband piezo amplifier. Membrane velocity is recorded using a Polytec single point laser Doppler vibrometer. Acoustic measurements are done using a Brüel and Kjær 4138 pressure field microphone with a frequency range of 6.5 Hz to 140 kHz. A pre-amplifier 2670 in combination with a Nexus signal conditioner with a 140 kHz bandwidth extension is used, before the signal is recorded using a Keysight DSOX1204G oscilloscope. The measurement is performed inside a soundproof booth by Soundbricks. The setup is shown in Figure 1. More details can be found in [3].

Results and discussion

Figure 2 shows an exemplary measurement signal with the electrical excitation applied to the membrane (a), the membrane velocity (b) and the recorded pressure (c). In the red shaded region, the membrane is undergoing continuous snap-throughs between both ground states, whereas in the yellow shaded region the membrane rings down. The green shaded region marks the transition between these two regimes.

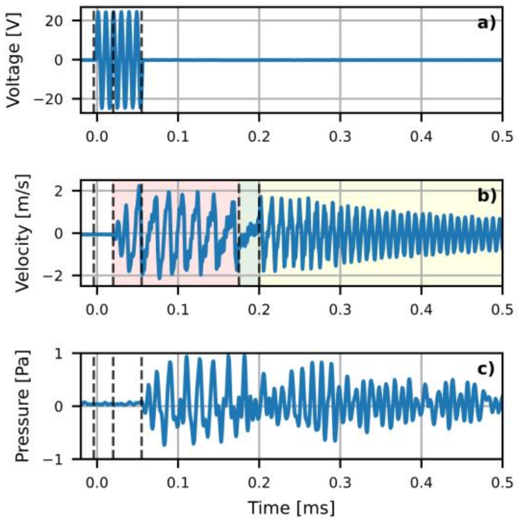

Figure 2: a) Excitation signal. b) LDV signal. c) Pressure measured with the microphone.

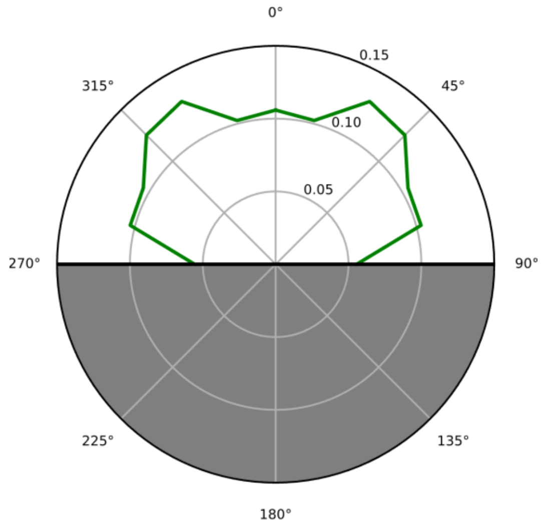

Figure 3: Emission pattern of the PMUT. The gray area is not measured, since the PMUT is mounted in such a way as to not allow downwards emission.

Figure 3 shows the directivity pattern of the PMUT measured at a distance of 92.5 mm. Distance is calibrated using the delay between electrical signal and sound (delay between electrical signal and LDV signal is compensated) and a speed of sound of 343 m/s. The PMUT featured an almost omnidirectional emission pattern with a significant drop only at 90° and 270° off-axis, which is due to the geometry of the measurement setup.

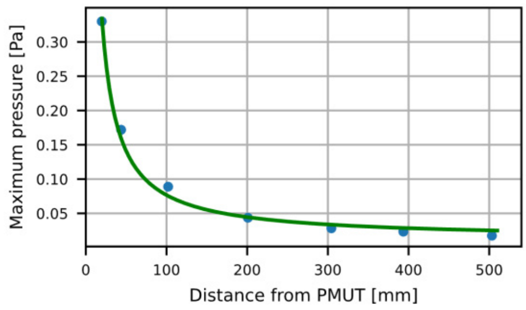

Figure 4: Distance dependence of pressure.

Figure 4 shows the impact of microphone distance r to maximum detected pressure measured at 0° on-axis and features the expected $1/r$ behavior. The straight line is a fit of a reciprocal function to the data. Distances were set by eye and subsequently calibrated using the same method as mentioned above.

Conclusion

The emission pattern of a bistable PMUT has been shown for the first time as well as the expected pressure decrease with distance. Future work will focus on a more in-depth study of these PMUTs, especially in continuous operation to provide proper sound pressure level values.

References

[1] A. Guedes, S. Shelton, R. Przybyla, I. Izyumin, B. Boser and D.A. Horsley, Aluminum nitride pMUT based on a flexurally-suspended membrane, Proc. 16th International Solid-State Sensors, Actuators and Microsystems Conference (2011); doi: 10.1109/TRANSDUCERS.2011.5969223.

[2] F. Sammoura, S. Shelton, S. Akhbari, D. Horsley and L. Lin, A two-port piezoelectric micromachined ultrasonic transducer, Proc. Joint IEEE ISAF/IWATMD/PFM (2014); doi: 10.1109/ISAF.2014.6923004.

[3] M. Schneider, M. Dorfmeister, P. Moll, M. Kaltenbacher and U. Schmid, Bi-Stable Aluminum Nitride-Based Piezoelectric Micromachined Ultrasonic Transducer (PMUT), *Journal of Microelectromechanical Systems* 29, 1-6 (2020); doi: 10.1109/JMEMS.2020.3004243.