SAND2014-2127C

LARGE VIBRATION AMPLITUDE REALIZED IN AN ALUMINUM NITRIDE PMUT

B.A. Griffin[*]*, S.P. Lemon, and M.D. Williams*
Sandia National Laboratories, Albuquerque, New Mexico, USA

ABSTRACT

This paper describes vibration measurements of an aluminum nitride (AlN) piezoelectric micromachined ultrasonic transducer (pMUT) driven at large voltages. Results demonstrate that AlN is a suitable material choice for large amplitude pMUTs.

INTRODUCTION

Zinc oxide (ZnO) [1] and lead zirconate titanate (PZT) [2, 3] have been common piezoelectric material choices for micro-scale actuators such as pMUTs because of large piezoelectric coefficients. Although AlN has a relatively low piezoelectric coefficient (Table 1), it does possess high dielectric strength and is not susceptible to coercive field effects, so it can be driven at much larger voltages to compensate for lower sensitivity. AlN possesses other attractive benefits, including CMOS compatibly, sputtered fabrication process, low dielectric loss, and low permittivity. However, AlN has only recently been explored as a material choice for PMUTs [4, 5]. This work shows that large amplitude AlN actuators are promising.

DEVICE DESIGN

The PMUT was fabricated by Avago Technologies in Fort Collins, CO, using a variant of their film bulk acoustic resonator (FBAR) process [6]. A dimensioned cross-section is shown in Figure 1. The operation of the PMUT is based on deflection of the circular diaphragm due to voltage-induced strain in the piezoelectric annulus at the diaphragm boundary. The diaphragm is composed of passivation, electrode (molybdenum), piezoelectric (AlN), and structural layers. As proprietary features of the FBAR-variant process, the materials used in the passivation and structural layers are not disclosed.

EXPERIMENTAL RESULTS

Vibration of the pMUT was measured using a Polytec MSA 400 laser scanning vibrometer. The laser was scanned across the diaphragm to capture the fundamental mode shape (Figure 2). For the vibration study at large amplitude drive voltage, the vibration at the center of the diaphragm was measured. A frequency response measurement yielded a resonant frequency of 79 kHz and associated deflection sensitivity of 0.2 µm/V.

Single-tone measurements at the resonant frequency were conducted at drive voltages up to 50 V. As shown in Figure 3, after approximately 5 V, the diaphragm begins to stiffen and displacement per drive voltage declines. The total harmonic distortion (THD) was calculated as the sum of the harmonic displacement amplitudes normalized by the amplitude of the fundamental,

$$\mathrm{THD} = \frac{\sum_{i=2}^{N} U_i}{U_1}. \qquad (1.1)$$

It was found that collecting the first ten harmonics was sufficient for a converged THD calculation over the range of drive voltages. Surprisingly, the displacement THD was less than 1% over the entire range.

The loss in displacement sensitivity was hypothesized to be due to the geometric nonlinearity since the displacement is on the order of the device thickness. To explore the nonlinearity, the excitation frequency was swept from 70 to 100 kHz for increasing drive voltage amplitudes (Figure 4). The hysteresis loop of the up and down frequency sweep is shown for 50 V drive amplitude in Figure 5. The peak amplitude is 4.2 µm at 86 kHz.

CONCLUSIONS

The results demonstrate that, despite its low piezoelectric coefficient, the AlN PMUT can be driven at a sufficiently large voltage to incur nonlinear Duffing behavior. The onset of the Duffing nonlinearity is dictated by geometry and material stiffness and will limit large amplitude vibrations of PMUTs regardless of piezoelectric coefficient. Given AlN's other favorable material and fabrication properties, this work demonstrates that AlN large amplitude actuators are not necessarily limited by low piezoelectric coefficients. Future work will involve implementing controls to stabilize vibration amplitudes while operating above the Duffing nonlinear onset.

WORD COUNT: 600

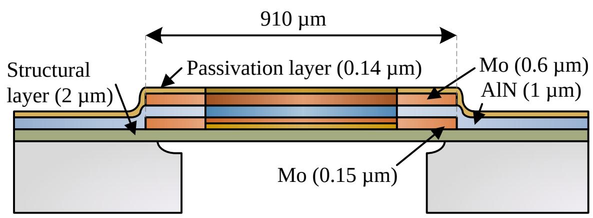

Figure 1 Cross-section of AlN PMUT.

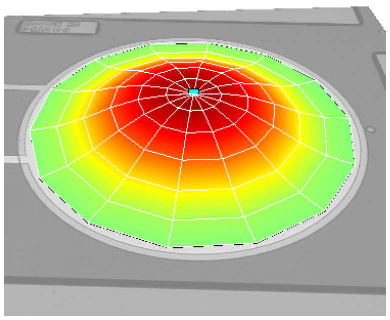

Figure 2 Mode shape at the first resonant frequency measured using a scanning laser vibrometer.

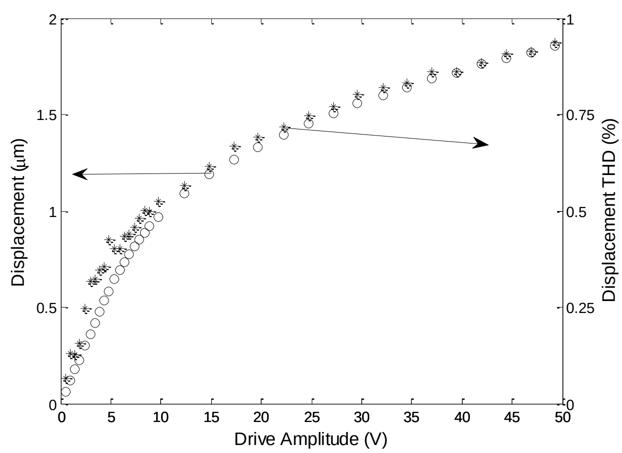

Figure 3 Displacement and THD percentage versus increasing drive voltage.

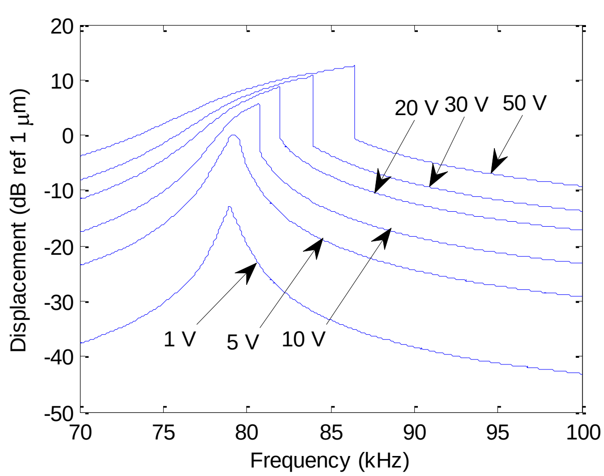

Figure 4 Displacement response under increase drive voltage amplitude.

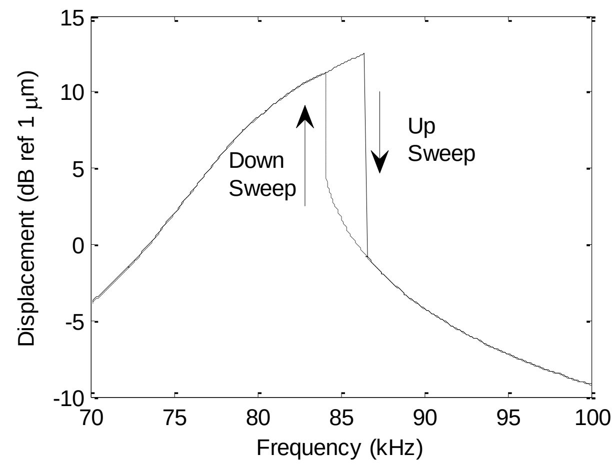

Figure 5 Duffing behavior for a drive voltage of 50 V showing the hysteresis loop.

Table 1 Typical piezoelectric coefficients.

	AlN	ZnO	PZT
d_{31} **[pm/V]**	**-2**	**-5.4**	**-274**

REFERENCES

[1] G. Percin, *et al.*, "Micromachined two-dimensional array piezoelectrically actuated transducers," *Applied Physics Letters*, vol. 72, pp. 1397-1399, Mar 1998.

[2] S. Horowitz, *et al.*, "Development of a micromachined piezoelectric microphone for aeroacoustics applications," *Journal of the Acoustical Society of America*, vol. 122, pp. 3428-3436, Dec 2007.

[3] P. Muralt, *et al.*, "Piezoelectric micromachined ultrasonic transducers based on PZT thin films," *Journal of Electroceramics*, vol. 52, pp. 2276-2288, 2005.

[4] B. A. Griffin, *et al.*, "Aluminum Nitride Ultrasonic Air-Coupled Actuator," *J Microelectromech S*, vol. 20, pp. 476-486, 2011.

[5] R. Przybyla, *et al.*, "An Ultrasonic Rangefinder Based on an AlN Piezoelectric Micromachined Ultrasound Transducer," presented at the IEEE Sensors Conference, Kona, HI, 2010.

[6] R. C. Ruby, *et al.*, "Thin Film Bulk Wave Acoustic Resonators (FBAR) for Wireless Applications," in *Proc. IEEE Ultrason. Symp.*, Atlanta, GA, 2001, pp. 813-821.

ACKNOWLEDGEMENTS

Devices for this study were provided by the University of Florida. This work was supported by the Laboratory Directed Research and Development (LDRD) program at Sandia National Laboratories. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

CONTACT

B. A. Griffin, tel: +1-505-844-7370; bagriff@sandia.gov