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Characterization of AlN-Based MEMS Kineto-Electric Transducer for Cultural Heritage Conservation

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Summary:

In this study, an Aluminum Nitride (AlN) MEMS device is analyzed and characterized for kineto-electric conversion. The device has been designed, fabricated, and tested with the primary goal of being employed in the field of preventive conservation and conservation of cultural heritage. For this purpose, the system is capable of detecting low-frequency vibrations of weak intensity and has the ability to generate voltage, enabling kineto-electric conversion without relying on batteries. This feature significantly reduces the overall power consumption of the entire sensing system.

Keywords: AlN, Generating sensor, Kineto-electric conversion, MEMS, Preventive conservation

Overview and Motivation

The rise of low-power, wireless sensor nodes has spurred interest in vibration-based sensors, particularly energy-generating devices designed to replace or extend battery life. Materials such as PVDF, PZT, and AlN are widely used due to their ability to convert mechanical stress into electricity. AlN stands out for its CMOS compatibility, low toxicity, and stability, offering significant advantages in miniaturized, energy-efficient systems. Despite its lower piezoelectric coefficient, AlN achieves a competitive Figure of Merit, making it suitable for energy harvesting and sensing applications [1]. This study advances the state of the art by characterizing an AlN MEMS vibration-to-electricity transducer. Notably, the device is capable of generating voltage without the need for batteries. It has been specifically designed for use in conservation and preventive conservation within the field of cultural heritage. This application is critical for monitoring vibrations in compliance with regulations [2] or detecting mechanical shocks to protect or evaluate artifacts of historical and artistic significance. The results highlight the potential of the proposed MEMS for low-power, long-term applications, emphasizing its suitability for vibrational sensing technologies [3].

MEMS Process

The oscillatory behavior of the microsystem, based on a cantilever design, and the piezoelectric response of the AlN element in the MEMS are modeled (see Fig. 1) using a lumped-parameter system consisting of a mass (M), a spring (X), and a damper (C), which represent inertia, stiffness, and mechanical losses, respectively. For a given time-dependent motion z(t), a relative displacement y(t) occurs between the frame and the mass M due to inertia. The mass-spring-damper system, as a second-order system, enables the determination of the natural frequency f_n. The AlN acts as the transducer, capable of generating a variable voltage output and, in the presence of a load, a current I(t).

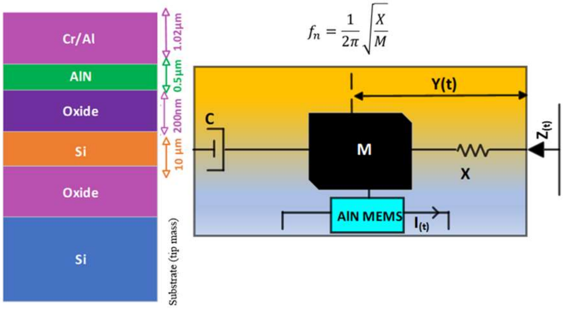

Fig. 1. Electromechanical model of the MEMS and its fabrication process

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The fabrication of the piezoelectric cantilever-type AlN MEMS resonator involves an 8-step process, using an SOI wafer with a 0.5 µm device layer, a 1 µm buried oxide layer, and a 400 µm handle layer. Key dimensions, process steps, and film thickness values are shown in Fig. 1 and Tab. I respectively.

Methodology and Results

The measurement setup (see Fig. 2) is based on an APS 129 ELECTRO-SEIS® shaker for MEMS characterization. An automated system enables the measurement of the MEMS voltage output as a function of the applied z(t) excitations imposed by the vibrating platform. Signal post-processing was performed using MATLAB® routines. Fig. 3 shows the Frequency Response Function (FRF) obtained during the calibration process. The input to the shaker is a sine wave with a frequency linearly varying from 60 Hz to 70 Hz and a constant acceleration of approximately 0.5 m/s² (Root Mean Squared, RMS). The spike indicates the resonant frequency of the microsystem. Fig. 4 presents the calibration diagram of the MEMS device. The results show a maximum voltage of approximately 85 mV at 0.5 m/s². It is worth noting that the sensitivity is about 180 mV/m/s².

Conclusion

In this study, an AlN-MEMS device was characterized for kineto-electric conversion, with a focus on applications in the field of cultural heritage conservation. The device effectively detects low-frequency, weak-intensity vibrations and generates voltage, reducing the need for batteries and minimizing power consumption.

Tab. 1: Characteristics of the MEMS layers

MEMS Layer	Young's Modulus [N/m²]	Thickness [m]	Width [m]	Length [m]
Metal (Al)	0.68E+11	1.00E-6	800E-6	8000E-6
Metal (Cr)	1.49E+11	0.02E-6	800E-6	8000E-6
AlN (Piezo)	2.80E+11	0.50E-6	800E-6	8000E-6
Silicon layer	1.69E+11	10.00E-6	800E-6	8000E-6
Substrate (tip mass)	1.69E+11	400.00E-6	800E-6	800E-6

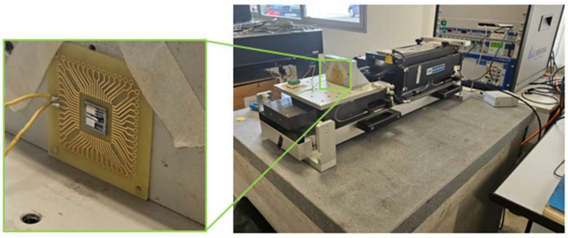

Fig. 2. Experimental Setup and the bonded MEMS

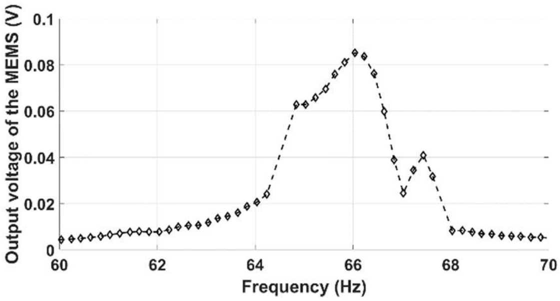

Fig. 3. FRF of the MEMS output with respect to a sweep sine input excitation

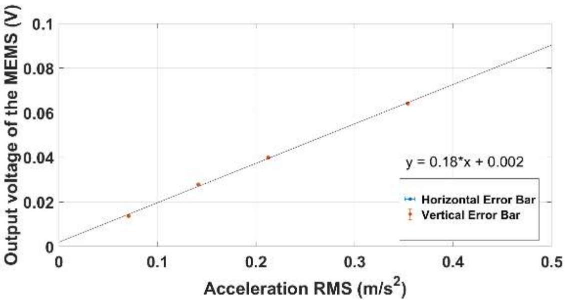

Fig. 4. Calibration diagram of the fabricated MEMS device

The results showed a resonant frequency between 60 Hz and 70 Hz and a sensitivity of approximately 180 mV/m/s², with a maximum output voltage of 85 mV at 0.5 m/s². These features make the device suitable for real-time monitoring of vibrations in situ or during transportation of historical artifacts and structures.

Acknowledgements

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