Fabrication of Micro Scale Triboelectric Microphone

CNF Project Number: 2929-21
Principal Investigator(s): Shahrzad Towfighian
User(s): Mohammad Alzgool

Affiliation(s): Mechanical Engineering, Binghamton University

Primary Source(s) of Research Funding: National Science Foundation Grant #1919608

Contact: stowfigh@binghamton.edu, malzgoo1@binghamton.edu, mmalzgool14@gmail.com

Primary CNF Tools Used: YES Asher, Unaxis PT770, OEM AlN sputtering, AJA sputter deposition, Heidelberg DWL-2000 Mask writer, Oxford PECVD, Oxford 81 etcher, PT770 etcher, DISCO dicing saw, SÜSS MA6-BA6 contact aligner, YES polyimide curing oven, PRIMAXX vapor etcher

Abstract:

We were previously able to fabricate the smallest triboelectric generator and we used it for switching a MEMS parallel-plate switch and as an accelerometer. The generator was utilized as a vibration sensor by connecting it to a MEMS-switch, this switch operates once the frequency or acceleration of vibration surpasses a threshold, the operating modes are called frequency sensitive mode and acceleration sensitive mode. Nowadays, we are trying to fabricate a microphone that operates by using the mechanical structure and the triboelectric property of polyimide and aluminum with a back-etched wafer with aluminum nitride-aluminum layer as our diaphragm. The back-plate consists of polyimide and aluminum. The polyimide is thick and is a substitute for the amorphous silicon that we used in previous design as a proof mass. The motivation of this project comes from the promising results acquired from the MEMS triboelectric accelerometer which gave high signal-to-noise ration and the high and linear response of the output voltage.

Research Summary:

There are many advantages of triboelectric generators over piezoelectric generators such as lower cost, high flexibility, and superior electrical output. The operation of triboelectric generators depends on contact of a metal and a dielectric material with different affinity to electrons, the contact will result in charged conductive plates and separation with high impedance in between the plates will result in high voltage.

The triboelectric generator fabricated in this project was connected to a MEMS switch with a summer electronic circuit to apply DC voltage to the system (Figure 1). The triboelectric generator in this work is responsible for the AC voltage supply which is generated as a response to outside vibration excitation. When the vibration exceeds certain amplitude or frequency the switch closes as a result of the dynamic behavior of the MEMS switch which is characterized in previous works.

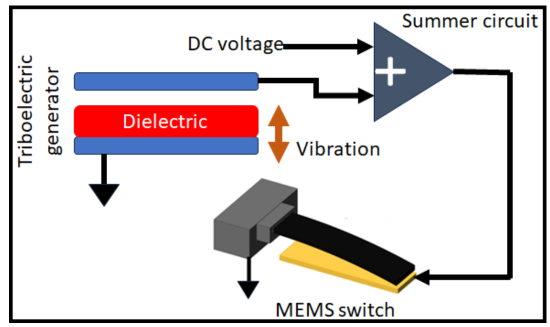

Figure 1: Experimental setup schematic.

Fabrication:

The fabrication process for triboelectric generator starts with aluminum nitride insulation, aluminum is sputtered and patterned for bottom electrode, polyimide spin-coating, curing, and patterning is carried out. This will result in the bottom layer of the generator. Then, the gap is created by silicon oxide layer which is patterned to create top layer anchors. And top layer is created by sputtering aluminum and depositing amorphous silicon for proof-mass.

Nowadays, we are trying to change the fabrication process so that polyimide layer is part of the top electrode and to have a hole under the bottom electrode to create a microphone. A triboelectric microphone as we envision will have a back-etched silicon wafer as sound inlet, a membrane of aluminum nitride which vibrates with input, a small gap between the membrane and the back-plate, and a back-plate of polyimide-aluminum pair. The design of membrane and the back-plate is carried out with frequency mismatching in mind to guarantee contact between them as sound is received.

The fabrication process starts with 500 nm deposition of aluminum nitride followed by 100 nm sputtering of titanium nitride-aluminum to create the diaphragm. Both layers are patterned using ICP-RIE PT770 etcher. Then, 1.0 μm sacrificial layer for the gap is deposited using PECVD and etched using oxford 81 RIE. Then, the inlets are made by back-etching the wafer which is done by depositing 100 nm aluminum nitride which is patterned with back-side-alignment. The aluminum nitride is used as a hard-mask for back etching which is done using Unaxis PT770 for > 1000 loops. For the top layer, we start with spin-coating and curing of polyimide (HDmicron PI 2574). Then, aluminum is sputtered on top and patterned with PT770. Patterned aluminum can be used as a hard mask for polyimide patterning which is done by RIE machine oxford 81 with CF_4-O_2 recipe. Finally, the wafer is diced and wire-bonded for testing.

Results:

The pull-in for the beam used in this work happens at 2.1 V statically. Dynamically, the generator provides AC voltage up to 0.6 V peak to peak. In frequency sensitive mode of operation, the pull-in happens at different frequencies depending on the applied DC voltage, at 1.6 V it happens at 10.6 kHz, and at 1.7 V it happens at 8.9 kHz as shown in Figures 2 and 3.

For amplitude sensitive mode, the acceleration was raised gradually in 10 seconds period while measuring the response of the beam, it was noticed that there is an amplitude of oscillation that provides AC voltage that is enough to close the switch. This experiment is shown in Figure 4.

Conclusions and Future Steps:

The triboelectric generator previously fabricated was useful for vibration measurements, it can operate a switch in different modes by using the dynamic of the switch and the generator. The output of the generator increases with the excitation amplitude and, thus, can drive the switch to close in amplitude sensitive mode once a threshold is past. And because the switch has natural frequency that changes with DC voltage, the frequency of the vibration that causes the switch to close can be tuned.

Currently, we are working on fabricating a triboelectric microphone by adding a back-etch to the fabrication process and swapping the position of the polyimide from bottom to top so that it will act as a dielectric and a proof-mass layer.

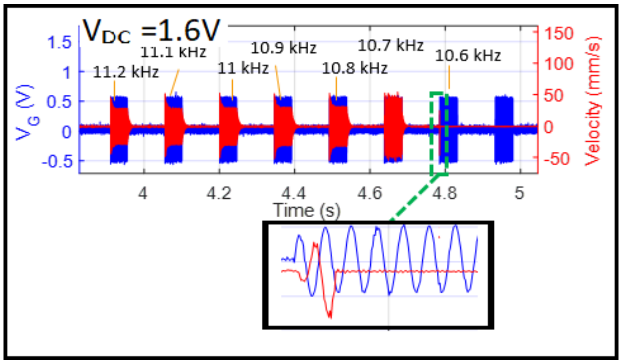

Figure 2: Frequency sensitive vibration sensor at V_{DC} = 1.6 V.

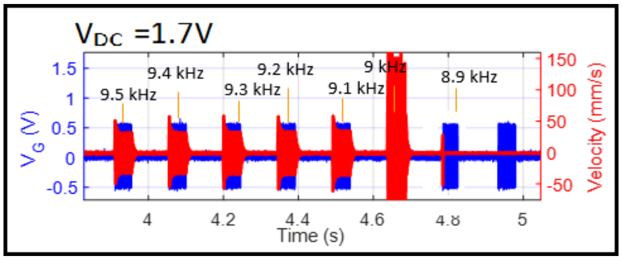

Figure 3: Frequency sensitive vibration sensor at V_{DC} = 1.7 V.

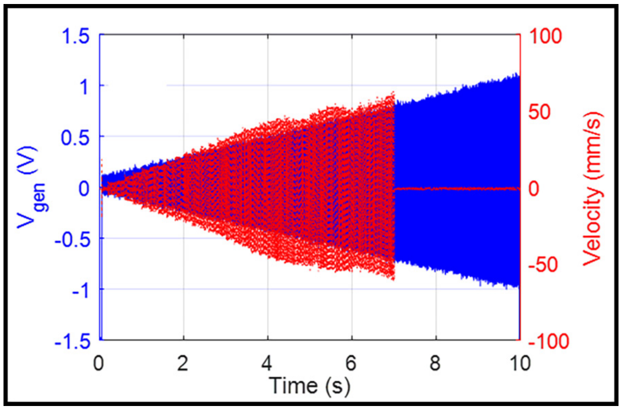

Figure 4: Acceleration sensitive vibration sensor.

References:

[1] Alzgool, M., Tian, Y., Davaji, B., and Towfighian, S. (2023). Self-powered triboelectric MEMS accelerometer. Nano Energy, 109, 108282.

[2] Mousavi, M., Alzgool, M., Davaji, B., and Towfighian, S. (2023). Event-driven MEMS vibration sensor: Integration of triboelectric nanogenerator and low-frequency switch. Mechanical Systems and Signal Processing, 187, 109921.