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TOWARDS A CMOS-COMPATIBLE ACCELEROMETER USING SELF-POWERED TENG SYSTEM

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ABSTRACT

This paper exhibits an accelerometer based on a MEMS triboelectric nanogenerator (TENG) system. Unlike traditional mesa-scale TENGs, this device is fabricated using standard, scalable to high-volume manufacturing and CMOS-compatible processes. Compatibility with CMOS technologies opens a door for the creation of various integrated self-powered sensors and communication systems with electronic components. The presented self-powered accelerometer can measure the acceleration with direct voltage measurements from TENG output, where no external power is needed. The device exhibits linear behavior when sinusoidal base excitation is applied at each frequency.

KEYWORDS

Triboelectric generator, accelerometer, self-powered, MEMS, Polyimide.

INTRODUCTION

With the world-wide evolution in internet of things (IoT) the energy needs are growing drastically. With the increase of power need, research on different power harvesting schemes is spreading. One of the most promising ways of harvesting energy from mechanical energy was found to be the triboelectric energy harvesters. This type of energy harvesting has many advantages such as the low cost of the materials, high generated voltage, ease of fabrication, and material durability [1]. Depending on the type of motion that the generator is subject to, a suitable generator mode is used. For instance, an in-plane motion is used in generators that has sliding electrode, rotational motion is used in generators with rotary disc-shaped electrode, and a perpendicular motion is used in contact-separation triboelectric generators.

Contact-separation triboelectric generators has upper conductive electrode, dielectric layer, lower conductive electrode, and a gap between them. When one of the conductive electrodes hit the dielectric layer, charges are formed due to the difference in electron affinity difference in both layers. Once separated, voltage difference is produced between the conductive layers because of these charges.

Contact-separation triboelectric generators were used as accelerometers by Zhao et. Al for the range 1.07 – 1.25 m/s^2 [2]. A better range for acceleration measurement was achieved by accelerometer built by Liu et al. were the accelerometer provided linear output when tested in the range 1-11m/s^2 [3].

In this work, a micro-machined contact-separation triboelectric generator is used for sensing the acceleration. This triboelectric generator is made using CMOS-compatible processes and it is the smallest triboelectric generator with 2mm square sides and a thickness of 1 µm. The introduction is followed by fabrication process, experimental setup, and discussion.

FABRICATION PROCESS

The contact-separation TENG is made of a triboelectric pair (a dielectric material and a conductive material) separated by an air gap from a conductive layer. The device's schematic is shown in Fig. 1, and the mask layout design is shown in Fig. 2.

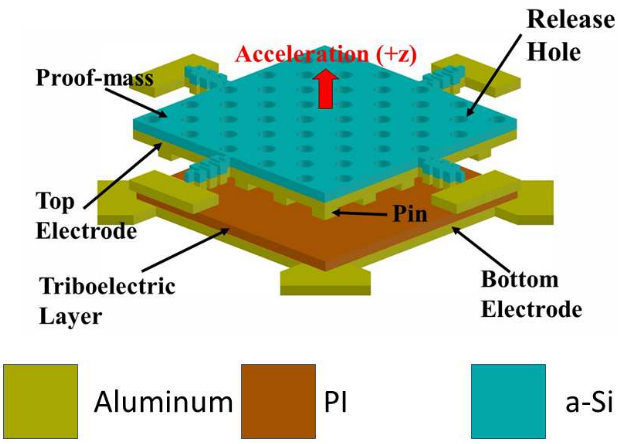

Figure 1MEMS-TENG device schematic.

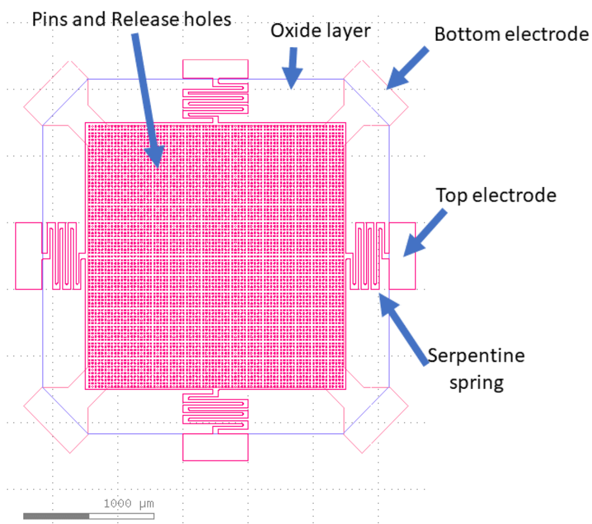

Figure 2 MEMS-TENG layout showing the MEMS design.

This device was fabricated in a clean room on 100mm Si wafer with an insulating thin film aluminum nitride layer. The triboelectric pair was fabricated by sputtering and patterning aluminum followed by coating and patterning of polyimide. Then, a thin silicon oxide film is deposited by the PECVD method and patterned to create a gap between the polyimide and top electrode. Aluminum sputtering and patterning is repeated to fabricate the top electrode. Then, a layer of amorphous silicon (a-Si) is deposited on top as a proof mass and a structural layer. Finally, the devices are released by etching the silicon oxide sacrificial layer using vapor hydrofluoric acid (vHF) etching. The dimensions of the device are listed in Table1.

Table 1. MEMS-TENG accelerometer dimensions.

Dimension	Value
Bottom layer thickness	200 nm
Polyimide thickness	5 µm
Oxide layer thickness (Gap)	2µm
Top layer aluminum thickness	120 nm
Top layer a-Si thickness	1 µm
Top electrode area	4 mm^2
Spring width 1	20 µm
Spring width 2	40 µm

EXPERIMENTAL SETUP

The device was mounted on a B&K shaker (4809) driven by a B&K power amplifier (2706) and a DAQ (USB 6366). The shaker was characterized using a Doppler laser vibrometer focused near the center of the shaker's stage where input voltages that keep the acceleration values constant were found. Then, these voltages and frequencies drove the shaker while TENG accelerometer output was monitored. The experimental setup is shown in Fig. 3.

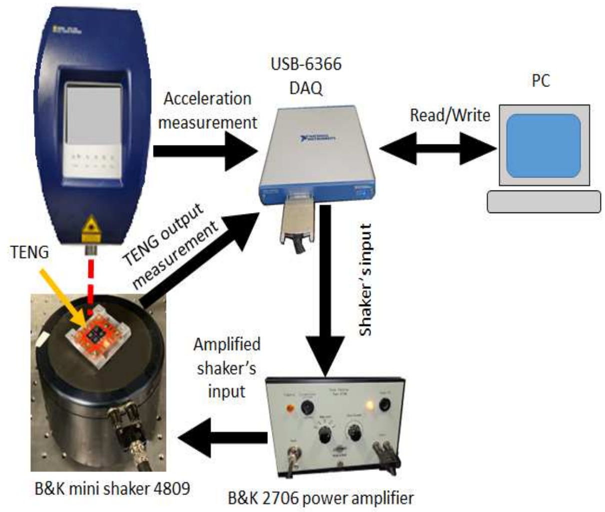

Figure 3. Accelerometer characterization experimental setup. The accelerometer is packaged on a PC Board and mounted to the shaker table.

The input frequency is varied in the range of 0-8 kHz by applying sinusoidal signal with acceleration values from 2 to 10 g, the output of the TENG accelerometer is recorded, and the root mean square of the generated voltage is used to quantify the accelerometer's response.

RESULTS AND DISCUSSION

As the input frequency is varied in the range of 0-8 kHz and the acceleration magnitude is varied from 2 to 10 g, the RMS of the output of the TENG accelerometer is shown in Fig. 4. The TENG accelerometer output shows a linear relationship between the acceleration and the generated voltage at each frequency, which is very important for sensor application.

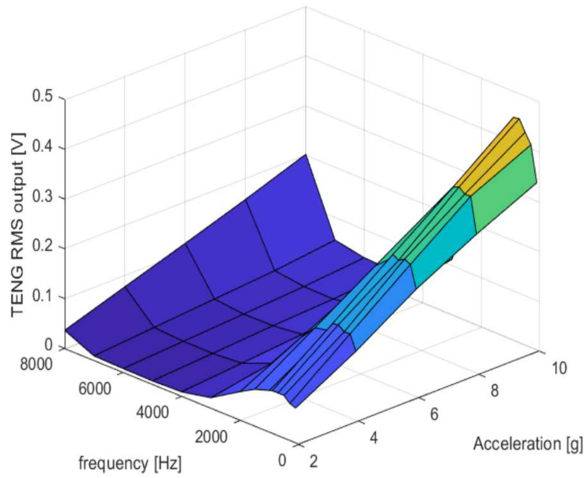

Figure 4. MEMS-TENG accelerometer measured output. The output voltages are the RMS of values of generated voltage against input acceleration for a range of frequencies.

The accelerometer's sensitivity ranges from 6.144 mV/g to 68.39 mV/g for the maximum voltage generated, shown in Fig. 5, with the maximum occurring at 700 Hz, at the natural frequency of the TENG.

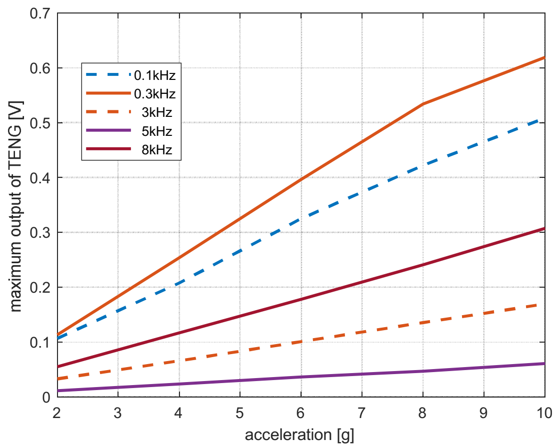

Figure 5. RMS of accelerometer output voltage as a function of acceleration at various frequencies.

A previous work for triboelectric accelerometer with polyimide was reported by Zhao et al. [2] where the generated voltage peaked at 3.3 V for acceleration range 0.11-0.13 g, but the device was ~600 times larger in area than our proposed device. The sensitivity for the device reported in this paper is 4-45 mV/g. The presented miniaturized self-powered accelerometer can be used for shipment monitoring devices and for measuring impact in sport helmets.

CONCLUSION

In this paper, we presented a self-powered micro-machined triboelectric accelerometer operating in contact-separation mode. The accelerometer was tested by sinusoidally exciting the base in the range of 2-10 g with frequency ranging from 0 to 8 kHz, and it provided output up to 683.9 mV at 10g and 700 Hz which is the natural frequency of the accelerometer. The accelerometer output is linear at each input frequency with sensitivity ranging from 6.144 mV/g to 68.39 mV/g.

This accelerometer is made of the smallest MEMS-triboelectric generator which is fabricated using CMOS-compatible microfabrication processes in a cleanroom with 2mm × 2mm ×1μm top electrode made of conductive aluminum layer and amorphous silicon proof-mass.

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