A Wideband Triboelectric Energy Harvester

Lokesh Dhakar [1, 2], Huicong Liu[1, 3], F. E. H. Tay[2, 4] and Chengkuo Lee[1]

[1] Department of Electrical and Computer Engineering, National University of Singapore, Singapore
[2] NUS Graduate School for Integrative Sciences and Engineering, Singapore
[3]Robotics and Microsystems Center, Soochow University, P. R. China
[4] Department of Mechanical Engineering, National University of Singapore, Singapore

E-mail: elelc@nus.edu.sg

Abstract. Contact electrification or triboelectric charging has mostly been seen as a negative phenomenon in various engineering applications. In electronic applications, static charge build-up may even destroy some of the components. In this paper, we demonstrate a cantilever based design using triboelectric charging mechanism for energy harvesting applications. The voltage output of triboelectric energy harvester (TEH) continuously increases with increased mass applied force and proof mass loading on the cantilever. The voltage output increases from 0.4V to 1.8V as the excitation acceleration increases from 0.4g to 1.8g. The design has been shown to demonstrate wide bandwidth characteristics. The FWHM increases from 3.76 to 12.64 Hz as the acceleration increases from 0.4g to 1.8g. The peak power output is found to be 0.18μW at 1.4g.

1. Introduction

Green energy is gaining increased importance in today's world when earnest efforts are being made by society and governments to decrease the dependency on non-renewable energy resources. Energy harvesting devices have emerged as one of the most promising solutions to serve smaller energy needs e.g. powering low power electronic devices and wireless sensors [1]. Vibrations in environment provide an important source of energy which can be tapped using energy harvesting devices. Traditionally, three approaches have been used in energy harvesting devices: electrostatic, electromagnetic and piezoelectric [2][3][4]. Recently, tribolelectricity has been demonstrated as a potential mechanism for energy harvesting [5]. But the area of utilizing triboelectric mechanism for vibration based energy harvesting is mostly unexplored. This paper presents a triboelectric energy harvester (TEH) design working on the principle of contact electrification. According to contact electrification theory, two dissimilar materials get charged when they are contacted and separated. The triboelectric charging process for different materials is well studied for different metals and polymers [6]. Different materials have different tendency to attract electrons which is a property of material also known as electronegativity. According to the tendency of a material to attract electrons, the materials can be arranged in a 'triboelectric series'[6] which lists different materials in the order of relative polarity of contact charge acquired. The materials with a tendency of acquiring a positive charge are placed at top of the series whereas materials with a tendency to acquire negative charges are placed at lower positions in the series. There have been some published works in past couple of years demonstrating the principle of triboelectric energy harvesting [7][8].

Traditional resonant energy harvesting devices based on electrostatic, electromagnetic and piezoelectric mechanisms have confronted problem of narrow operational bandwidth. This paper proposes an energy harvesting design based on triboelectric contact and separation method which solves the narrow bandwidth problem. Wide operation bandwidth(BW) is obtained by use of incorporating spring hardening effect in the device [9][10].

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2. Design and fabrication of triboelectric energy harvester

The schematic of the proposed device using triboelectric mechanism is shown Figure 1. The fabricated top part is assembled on a cantilever end which vibrates when mechanically excited by vibrations. The source of vibration can be human motion , wind flow or machine vibrations[11]. The fabricated bottom part is assembled right below the top part. The top part makes contact with the patterned bottom part and then releases due to vibrational motion of cantilever. As making contact and releasing is essential part in process of triboelectric mechanism, the proposed device is designed to take advantage of BW widening phenomenon using a stopper [9]. In the presented design, the bottom part serves as a mechanical stopper for the cantilever which significantly increases the operating BW of TEH.

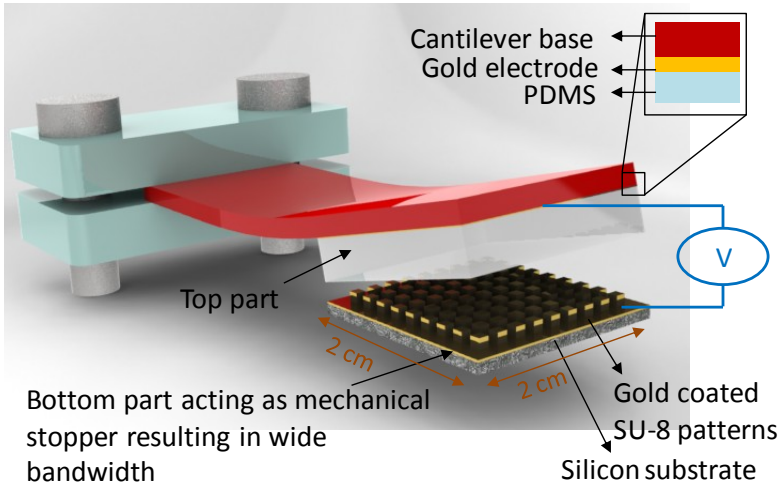


Figure 1. Schematic of the cantilever based triboelectric energy harvester.

The process flow for the fabrication of top and bottom parts as shown in Figure 1 is described in Figure 2. For the bottom part fabrication, pillar arrays are formed on Si wafer using negative photoresist SU-8 by photolithography. After the formation of pillar arrays on Si wafer, 100 nm gold layer is deposited on top of SU-8 pillar arrays using thermal evaporation technique which serves as the bottom electrode. Contacts are made from the bottom electrode using conductive silver paste and heating it at 120˚C for 20 minutes so that solvent evaporates and hardens the silver paste.

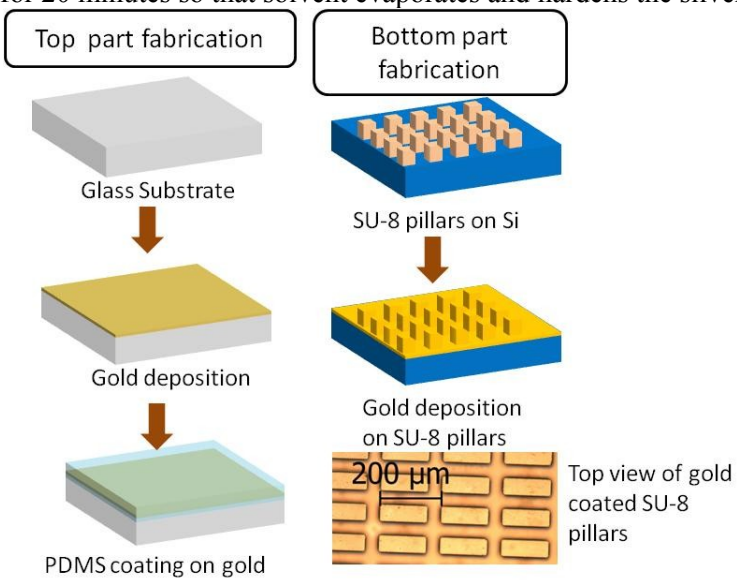


Figure 2. Process flow for the fabrication of top and bottom parts.

For the top part fabrication, 100 nm gold layer is deposited on glass which serves as the top electrode for TEH. Thereafter, a PDMS layer is spin coated using SYLGARD® 184 silicone elastomer kit. PDMS layer is then cured at 80˚C for 2 hours. This top part is then assembled on an Aluminum cantilever which can vibrate to provide the contact and separation motion for top and bottom parts. As shown in Figure 1. The top part moves with the cantilever and the bottom part remains fixed on a support.

3. Experiments and results

TEH was characterized by mounting it on an electromagnetic shaker and exciting at various frequencies and accelerations with different mass loadings. The output voltages and accelerations are recorded using a data acquisition system.

3.1. Characterization at different accelerations

TEH was characterized at different excitation accelerations to study the effect on output voltage. The acceleration was increased in steps of 0.2g from 0.4g to 1.8g. The peak output voltage continuously increased from 450 mV at 0.4g to 1845 mV at 1.8g. During the testing, distance between the top part and bottom part is kept constant. Due to constant distance, the impact force of top part to bottom part increases as the acceleration is increased. Therefore as the impact force increases, the output voltage of TEH continuously increases as shown in Figure 3.

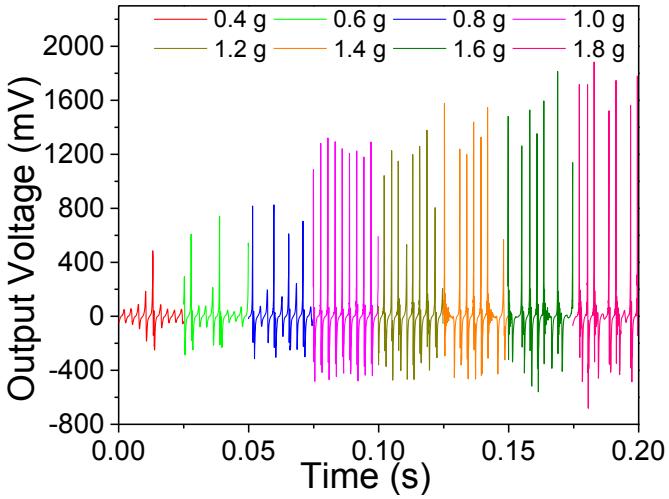


Figure 3. Output voltages at various acceleration levels

3.2. Effect of force and mass loading

The top part which is attached to an aluminum cantilever is loaded with extra proof mass to observe the effect on output voltage. Three different mass loading were used: 1) without any extra proof mass (mass loading = 0 gram) 2) mass loading = 3.2 gram and 3) mass loading = 3.8 gram for which peak voltages were observed to be 1002 mV, 1157 mV and 1570 mV respectively. As the mass loading is increased on the cantilever , the peak output voltage increases as shown in Figure 4.

To quantify the applied force values on TEH, the device was tested using a load cell. In the experimental setup, the top part is attached to a human finger as shown in inset image in Figure 5 and the bottom part is placed on a load cell. The top and bottom part were contacted and separated using the tapping motion of finger. As the top part contacted bottom part, the applied force readings were recorded using the load cell. Corresponding to force values from load cell, the output voltage values from TEH are acquired using LabView DAQ system. The average values of force and peak voltages are plotted in Figure 5. The average peak output voltage continuously increases as the force applied using finger is increased. This result is in accordance to the results obtained by changing the proof mass loadings in cantilever design.

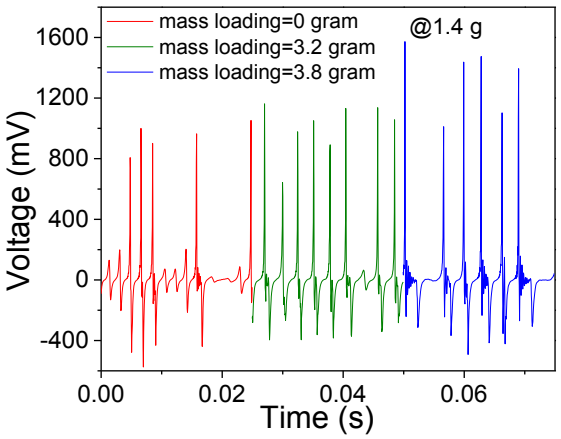


Figure 4. Output voltages at different proof mass loadings

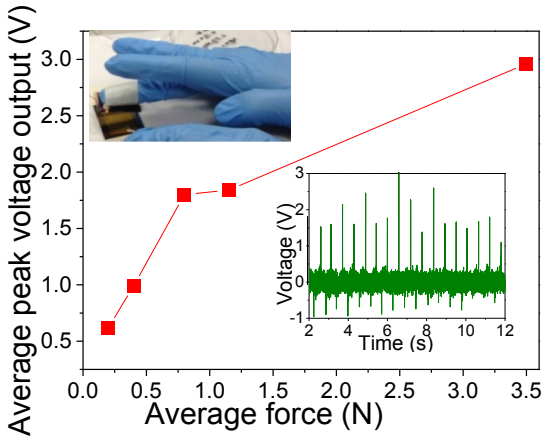


Figure 5. Variation of the peak voltage output with force in finger tapping experiment. The inset graph shows voltage output in time domain.

3.3. Wide bandwidth characteristics

One of the main advantages of using cantilever design for triboelectric energy harvesting mechanism is wide BW phenomenon. The bottom part acts as the stopper which obstructs the amplitude of top part attached to cantilever. This results into stiffening of cantilever which means the spring constant of the cantilever increases after contacting the bottom part. The stiffening of cantilever is responsible for widening of the operating BW of TEH as shown in Figure 6. In the experiments, the acceleration is increased in steps of 0.2g from 0.4g to 1.8g. For a constant level of acceleration, the frequency is swept from 10Hz to 40Hz which covers the operating frequency of TEH. The full width at half maximum (FWHM) after Gauss fit of the signals was observed to be increasing from 3.76 Hz to 12.64 Hz for an acceleration level of 0.4g and 1.8g respectively. Therefore, in conclusion the operating BW of TEH increases by more than 300% as the acceleration increases from 0.4g to 1.8g.

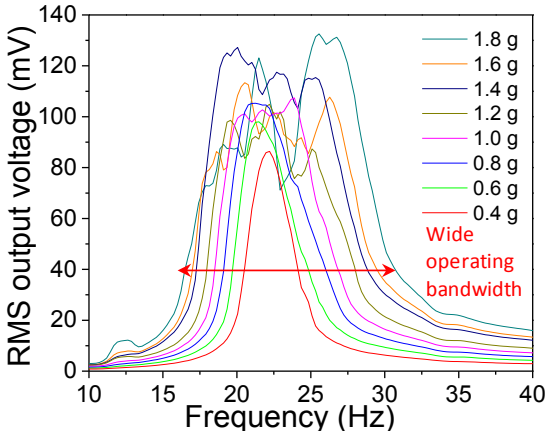


Figure 6. Wide operating bandwidth characteristics of TEH

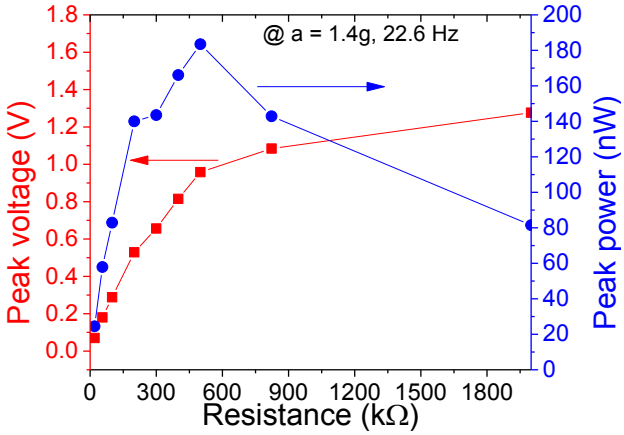


Figure 7. Peak output voltage and power generated by TEH

3.4. Power characteristics

To obtain the power characteristics of TEH, the device was excited at a constant acceleration of 1.4g and frequency of 22.6 Hz. Thereafter, the top and bottom electrodes were connected to a load resistor which is varied from 20 kΩ to 2000 kΩ. The peak output voltage and corresponding power values were measured for different values of load resistances as shown in Figure 7. For the given experimental parameters, the maximum power was obtained to be nearly 180 nW at a load resistance value of 500 kΩ.

4. Conclusion

A novel design for contact electrification (triboelectric mechanism) based energy harvester is proposed and fabricated. TEH is characterized at with three different parameters: acceleration, mass loading and force. The output voltage was observed to be continuously increasing with each of these three parameters. TEH also demonstrated increasingly widened BW characteristics as the excitation acceleration level increased. The maximum FWHM was found to be 12.64 Hz at an acceleration of 1.8g. The peak power was obtained to be 180nW at 1.4g and 22.6 Hz with a load resistance of 500 kΩ. The power output of the presented device can be further improved by optimizing the dimensions of SU-8 pillars in the bottom part.

Acknowledgements

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