Triboelectric-Based Energy Harvesting Face Mask Using Recyclable Materials

Brady Miller, Samantha Barker and Reza Rashidi
Department of Mechanical and Electrical Engineering Technology, State University of New York, Alfred State College
Alfred, NY, USA
e-mail: rashidr@alfredstate.edu

***Abstract*— This paper presents the development of a face mask that includes a triboelectric nanogenerator utilizing movements due to pressure changes when speaking to power an embedded temperature sensor. The triboelectric nanogenerator (TENG) produces electricity using common materials including printer papers, ball-point pen inks, and sheets of polytetrafluoroethylene (PTFE). The pen ink is painted onto the paper containing arrays of 2 cm long slots that are 200 µm in width. The paper with holes is placed on the top of a PTFE layer followed by another layer of ink-covered paper without holes. This layer-on-layer device is inserted into the front of the face mask. When the wearer speaks, the acoustic energy travels through the slots and vibrates the PTFE and inked-paper layers. Electrons are transferred from the ink to the plastic through these forms of movement. The electricity generation is due to the transfer of electrons between the negative and positive mediums, which electrically charges each side of the TENG. The electricity generated is transported to a thermistor located near the chin and ear and embedded in the mask band to sense the temperature of the wearer's skin. Testing was conducted using a Bluetooth speaker to create soundwaves that initiated the triboelectric effect. The song that was used to test was "Back in Black" by the band AC/DC. The mask generated a peak-to-peak voltage of 1.72 V and 2.48 V at 70 dB and 80 dB, respectively.**

Keywords-triboelectric nanogenerator; TENG; paper; PTFE; recyclable materials; face mask; thermistor.

I. INTRODUCTION

Sustainability has become an ethical standard in engineering as the world drives towards creating more eco-friendly energy options from sources, such as solar, wind, hydro, geothermal and fuel cells. However, these modern alternative energy sources require high-tech and expensive equipment for effective fabrication. This greatly impacts the widespread availability for such energy sources and therefore prevents the majority of the population from using these types of energy. The high costs of alternative energy sources gatekeeps alternative energy from lower income communities [1], resulting in the continued reliance of current energy sources that are harmful to the environment. Moreover, the size of these alternative energy methods has restricted its applications. Since the use of portable devices has risen so greatly in the past few decades, energy consumption has also greatly increased; therefore, the need for portable-sized energy harvesters is at an all-time high. In recent years, the push for generators on a micro scale has greatly increased [2]. Energy harvesters have been used to power various systems and devices, such as wearable devices [3], wireless sensor networks [4], buildings [5], tactile sensors [6], biomedical devices [7], and roadway applications [8]. Most of these harvesters utilize vibration as the most available energy source in many environments, such as vehicles [9] and human body [10]. This type of energy source can be converted into electrical energy using triboelectric [11], piezoelectric [12], electrostatic [13], and electromagnetic [14] methods. Various energy harvesting devices have been demonstrated by this group [15][16][17].

Triboelectric nanogenerators (TENGs) are a form of energy harvesters that use motion frequency for self-generation. TENGs function through pairs with one side abundant in positive charges and the other being abundant in negative charges. Some positively charged materials include silicon oxide [18], stainless steel and aluminum [19]. Some negatively charged materials include silicon [18], polyvinyl chloride (PVC) [20], and polyvinylidene difluoride (PVDF) [19]. The triboelectric effect occurs when these two sides touch at a high frequency. There are two main motions that are looked at when using the triboelectric effect: sliding motion and tapping motion. At the point of contact, a chemical bond is formed between the two surfaces, called adhesion, and electrons are transferred from the negative half to the positive half to equalize their electrochemical potential. TENGs are effective energy harvesters for applications that require high voltage and low current. This research intends to use a voltage drop across a thermistor to calculate a temperature reading of the wearer. This focus requires the need for higher voltages as opposed to current, making triboelectric a desired choice. The requirement for the nanogenerator to be small enough to fit into a face mask also promotes the decision on the use of triboelectric. TENGs are an effective method of alternative energy harvesting because of their wide variety of applications, such as bicycles [21], clothing [22], and portable power sources [23]; however, these applications are primarily focused on bodily movement. TENGs may also be used to harvest energy through the vibrations of acoustic frequency [19][24].

While the applications of TENGs are still growing, the development of paper-based nanogenerators has allowed for an easily accessible, inexpensive method for alternative energy harvesting [25]. Further research has drifted towards the implementation of other low-cost materials into TENG fabrication, such as papers [20][24], pencil graphite [26], pen ink [27], and PTFE. The combination of these low-cost and easily accessible materials will allow for the wider distribution and use of alternative energy harvesting methods. This is particularly important for applications that demand low-cost, recyclable devices. The implementation of these recyclable materials allows for simple, environmentally friendly, and sustainable applications. Paper is also a flexible material that provides ample movement necessary for TENG applications. This flexibility has allowed for further TENG development in which paper may act as both a structure component of the application and a functioning half of the triboelectric pair [24][27]. Face masks are a disposable supply that require low-cost components. The masks in the market currently focus on protecting others from coming in contact with any germ or virus. In addition, face masks can be designed to trap water droplets produced from respiration [28] in order to control the spread of infected particles.

This paper proposes a face mask that utilizes low-cost, paper-based TENG to generate electricity from the vibrations caused by breath and speech [29] and to power an embedded temperature sensor within the mask itself. To best of our knowledge, this is the first time that a self-sustained, temperature monitoring face mask design using triboelectric nanogenerators fabricated with recyclable materials is demonstrated. In the paper-based TENG, pencil graphite and pen ink can act as conductive electrodes to facilitate the transfer of charges. These materials are thin and easily manageable when being applied to a TENG layer. However, the pencil graphite was determined by sources to be unreliable when deformation occurs to the paper layer [27]; therefore, pen ink is a much more desirable conductive electrode for this TENG application. The paper layer is painted with a layer of pen ink to form one half of the triboelectric pair, and it will be used in an application to address a resultant issue of the current COVID-19 pandemic. The pen ink used in this paper is a more cost-effective solution compared with the silver nanowire [20], evaporated silver [25], or copper [24] coatings used on a soft paper as an electrification layer generating triboelectric charges upon contacting with a mating membrane.

Previous self-powered mask designs were established to deactivate virus-infected particles [30]; however, these claims were only validated through simulation. The proposed TENG design for the face mask in this paper has been developed and tested for the next step of the mask development. The mask design, while keeping people safe from spreading the virus, will be able to read the wearer’s temperature. This ability will allow an early detection of a user that may contract the virus. This is particularly more important for the environments where a contagious or deadly virus, such as COVID-19 exists, and mask wearers may want to monitor their body temperature without touching another device. A consideration for this design will be that the addition of the triboelectric generating layers will give the mask an added layer of bulk and protection from the spread of diseased particles. While the temperature sensor, and wiring will give the mask an added weight plus material that could cause a discomfort to the user if not implemented correctly. The added size and weight of the materials have been considered to prioritize user comfort. This paper will focus on only the mask design and its triboelectric energy harvester.

The rest of this paper is organized as follows: Section II describes the design, working principle, flow simulation, and fabrication and assembly of the device. Section III presents the testing method and tools, testing results, the discussion on the results, and the future work. Finally, the conclusions are discussed in Section IV.

II. DESIGN AND FABRICATION

A. Nanogenerator Design

Ballpoint pen ink was determined to be a more stable conductive material than pencil graphite [27]. Therefore, it was the best option to use for easily accessible materials. A layer of ballpoint pen ink was painted onto an A4 style standard sheet of paper. All the ink from seven traditional ballpoint pens was used on the sheet of paper. Once the pen ink was applied, a small painting brush was used to smooth out any uneven spots of the ink and make the layer uniform. This layer acts as the conductive electrode for the paper TENG. The entire sheet of paper being covered in pen ink eases the machining process with the laser cutter itself. Since the laser uses a grid patterned metal as a template for cutting, a full sheet eliminates potential error in cuts that could be off centered or not perfectly symmetrical.

A laser-cutting method was used to create the design with a pattern of slots cut into the ink-painted paper, as shown in Figure 1. The pattern consists of four columns. The two central columns consist of sixty-eight rows each. The column centered in the topmost portion of the shape contains sixteen slots. The column centered in the lower portion of the shape contains eight slots. The placement of the columns is designed to properly utilize available surface area while maintaining uniformity and the ability to catch the vibrations from breath and speech. The distance between each row is evenly distributed.

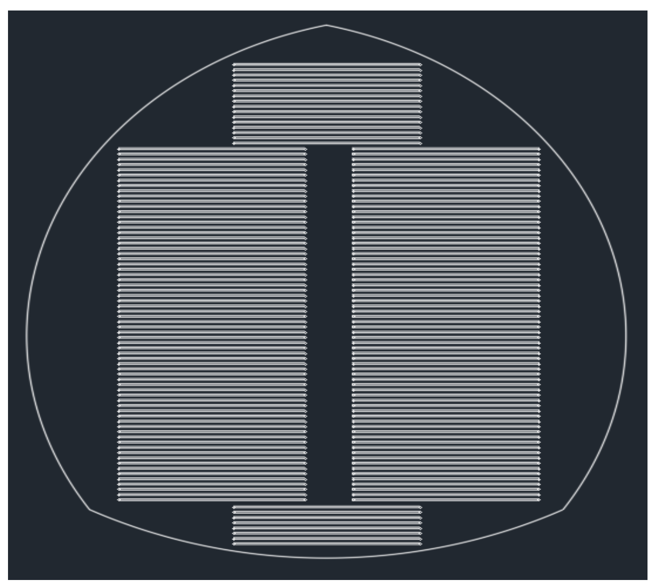


Figure 1. AutoCAD design of paper with slots for laser cutting.

Prior research indicated that the highest output occurs when 20% of the surface area is void and the hole diameter is 200 μm [24]. Through calculation, this design was determined to contain 19.92% void-to-surface area ratio.

The slots are distributed in an evenly spaced pattern to ensure consistent energy harvesting.

B. Working Principle

The diffraction of sound waves is the desired form of energy creation and harvesting. The closeness of the slots directs the acoustic waves through them. The wave interference creates an outbound resultant wave that is of some amplitude compared to the incoming waves. Resultant waves will cause an increase in the number of waves feeding through the two layers of the triboelectric pair. As the number of waves increase between the layers of the pair, vibrations will occur therefore allowing the transfer of electrons to occur. Increasing the frequency and amplitude of the waves will directly increase the resultant waves allowing for more energy to be created. Diagram of sound wave interference is depicted in Figure 2.

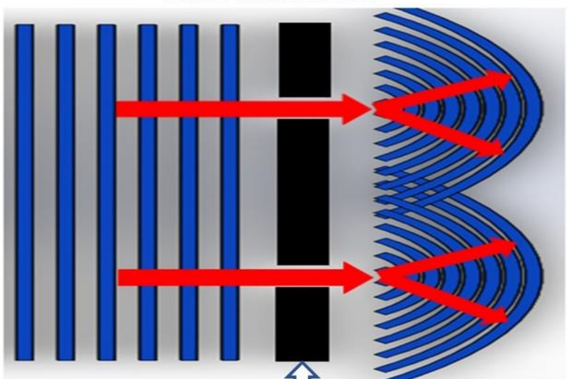


Figure 2. Diagram of sound wave interference.

The triboelectric pair of materials for the TENG design is paper and PTFE [31]. The enlarged view shown in Figure 3 gives the layout layer by layer of the TENG. Printer paper is covered with a layer of ball point pen ink, it is then machined by the laser cuter to create the slits. The layer is placed on the top of a PTFE plastic layer. Directly under this plastic layer is another layer of pen ink spread across paper. These layers are solid and do not contain any slits. The pattern of slots in the paper will allow vibration to move the triboelectric pairs and generate energy to power an indicator LED.

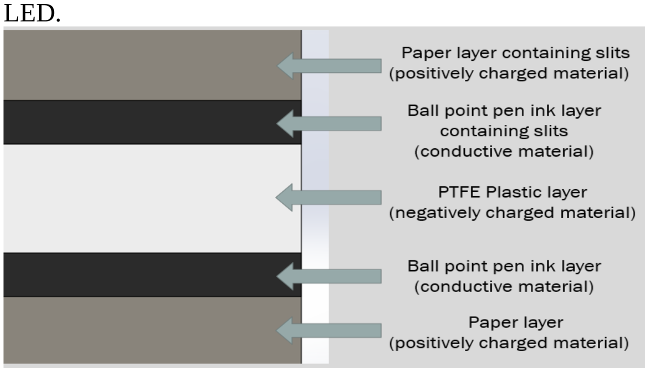


Figure 3. Material layers of the TENG.

C. Flow Simulation

A flow simulation in SolidWorks was performed to determine the pattern of air flow within the TENG. This simulation was used to determine the likelihood of vibration within the TENG to produce optimal transfers of charges. As shown in Figure 4, the velocity contours give a representation of how the air is going to move through the slots of the TENG. As the air flows through the slots, a wave effect is produced within the TENG. This wave effect will allow the layers of the triboelectric pair to vibrate against each other, which will facilitate the triboelectric effect to occur. The figure shows the direction of the voice and breath from the wearer. These two waveforms contact the slits in the paper layer that interferes and creates a resultant wave that vibrates the layers together. The resultant vibrating wave is shown affecting the contours between the layer with slits and the plastic layer. The vibrations continue through the paper layer and affect the contours past the plastic layer into the second layer of paper.

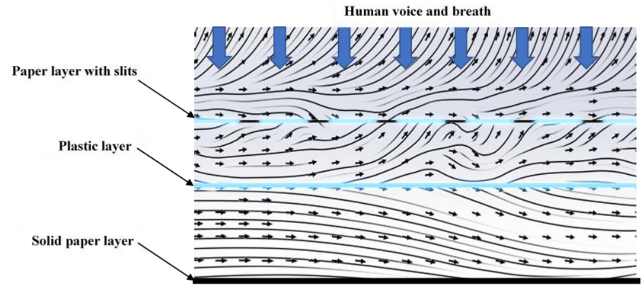


Figure 4. SolidWorks flow simulation of the design with the TENG highlighted in blue. The blue arrows represent the direction of the incoming human voice and breath. The layers of the TENG itself is depicted in a close-up view. The small black arrows in the figure itself represent the movement of the air contours intertwined between the layers of the TENG.

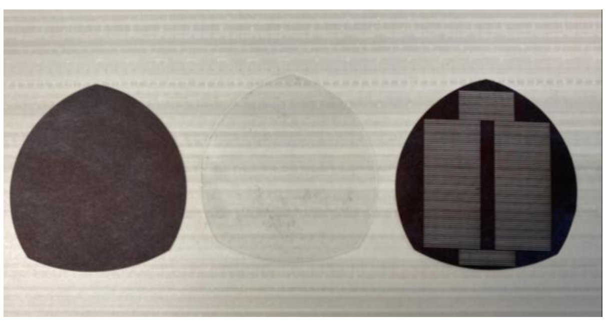
The external velocity representing a human's breath was set as an input of 1.3 m/s. As the contours travel between the layers of the TENG, a wave is created. Since the slots of the material are placed closely together, the waves that travel through will interfere with each other; this interference creates resultant waves, which maximizes the number of waves between the layers. This resultant wave is the main source of movement needed to create the transfer of electrons between the two triboelectric pairs.

D. Fabrication and Assembly

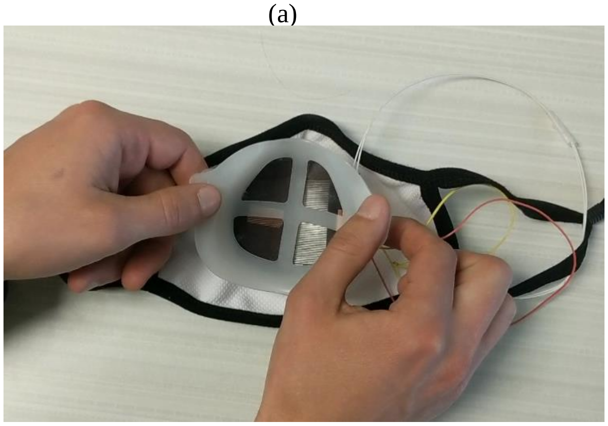
The nanogenerator consists of two sections of paper with measurements of 8 cm width, 6 cm in length, and 0.01 mm thickness. A piece of PTFE plastic was cut to the same measurements as the paper. An evenly distributed layer of ink was spread across an A4 sheet of printer paper. The pen ink cartridge was removed from the barrel of the pen and the ink flowed freely from the cartridge onto the paper. Using a small paint brush, the ink was spread evenly across the surface until the entire sheet was coated. Having a full sheet of paper coated in ink allowed for easier machining with a Fusion 40 carbon dioxide laser cutter. The laser cutter uses a grid system to align and cut material and using a full sheet of paper eliminates potential error in cuts that could be off

 ISBN: 978-1-61208-918-8

centered or not perfectly symmetrical. The full sheet of paper promotes stability and accuracy during the cutting procedure. Using AutoCAD, the design template for the slot configuration was uploaded to the laser cutter. This data was uploaded in different cuts; each row of slots was one separate cut; the next cut was the perimeter of the nanogenerator itself. The laser cutter allows the user to change the cutting speed and power of the laser for each job that is uploaded to it. The following job settings are specific to the Fusion M2 40 Epilog Laser only. The jobs associated with the cutting of the slots had a power setting of 15% and a speed of 50%. Cutting time was approximately six minutes for all cuts to be finished. The speed of the process could be lower than six minutes with an increase to the cutter speed, but this setting was utilized to assure the material was cut all the way through. A plastic insert was also cut using the solid configuration of the paper inset. Although PTFE is not harmful to the human respiratory system [30], another layer of normal filter material can be added to the inner side of the face mask to avoid any potential hazard. Figure 5(a) shows different layers of the triboelectric nanogenerator fabricated using common printer paper and PTFE plastic and the laser-cut configuration of the TENG paper inserts.



(a)



(b)

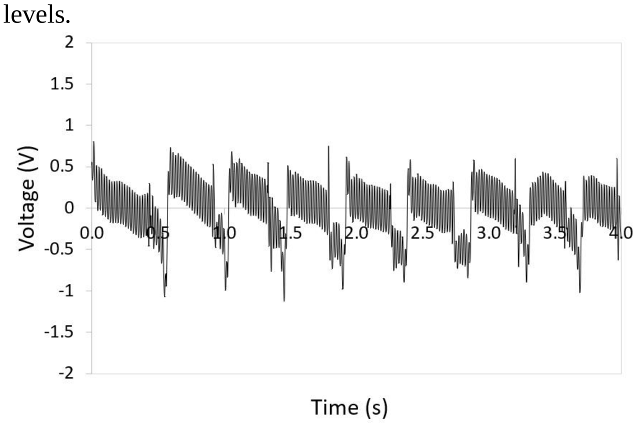
Figure 5. a) TENG layers: paper inserts (images left and write) with plastic insert (middle image). b) Assembled TENG in mask frame placed into cloth mask with wires for testing purposes.

Six nanogenerators were cut with the laser. These nanogenerator sets were then connected in series to maximize the voltage output of the assembled TENG. The assembled TENG was then placed into the plastic mask frame where it will sit when placed into the mask. Another plastic frame is placed on top of the assembled TENG to hold it in place. When the TENG is layered between the two frames, it can be placed into any cloth mask. Figure 5(b) shows the assembled TENG within the mask frames and the thermistor placed within a cloth mask.

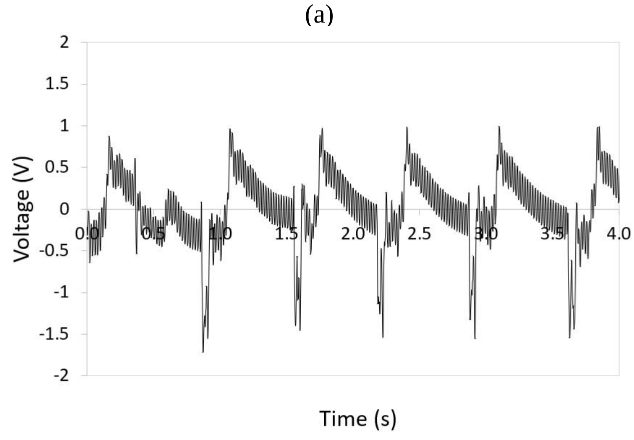
III. RESULTS AND DISCUSSION

The testing procedure involved using a Bluetooth speaker to create acoustic sound waves. Although the type of sound generated by the speaker may not be similar to the one produced by the human, the electronic speaker is the most reliable device generating consistent sound for the proof of concept and testing purposes. The TENG was placed on top of the speaker and music was played from a mobile electronic device. The selected song for this testing process was “Back in Black” by AC/DC. The energy created was recorded using a NI-6003 Data Acquisition Card through the LabVIEW software. The voltage detected directly corresponded to the volume and rhythm of the music.

In order to get the optimum voltage results, different sound intensities were applied to the mask and voltage as a function of time was measured. It was found that sound pressure levels of 70 dB and 80 dB yield the most output. Therefore, these two sound levels were used and the effect was recorded as the voltage outputs. Figure 6 shows the generated voltage as a function of time at two sound pressure levels.



(a)



(b)

Figure 6. Generated voltages of the developed TENG as a function of time at two sound pressure levels of 70 dB (a) and 80 dB (b).

 ISBN: 978-1-61208-918-8

The graphs shown illustrate a direct change from an instrumental section back to singing at different decibel levels. It is clear that the graphs contain both major and minor vibrational cycles in both sound pressure levels. The minor cycles are within each major cycle. Comparing the graphs of two sound pressure levels implied that the graph of 70 dB level experienced a higher frequency than that of 80 dB level. This is likely because the layers get a better chance to move against each other in 70 dB case. On the other hand, the graph of 80 dB pressure level shows a higher peak-to-peak voltage amplitude than that of 70 dB level. This is likely because of the longer time that the triboelectric harvester layers take to move against each other, resulting in a more travel between layers and so more voltage amplitude.

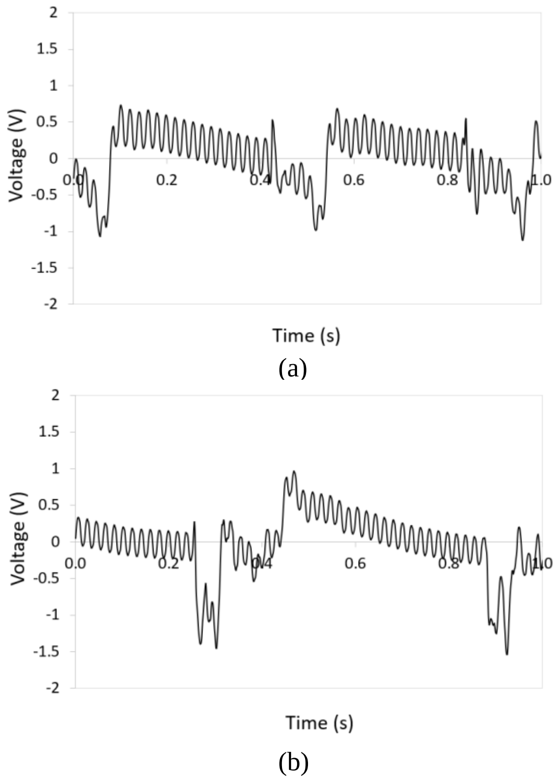


Figure 7. Zoomed graphs of Figure 6 focusing on individual major cycles (generated voltages as a function of time) at two sound pressure levels of 70 dB (a) and 80 dB (b).

TABLE 1. SUMMARY OF VOLTAGE AND FREQUENCY VALUES OF TESTING RESULTS SHOWN IN FIGURES 6 TO 8.

Cycle Type	Parameter	Sound Pressure Level (SPL)	
		70 dB	80 dB
Major Cycles	Peak-to-Peak Voltage (V)	1.72	2.48
	Frequency (Hz)	2.27	1.61
Minor Cycles	Peak-to-Peak Voltage (V)	0.60	0.38
	Frequency (Hz)	51.3	52.2

In order to analyze cycles in each graph, zoomed graphs focusing on individual major cycles were plotted, as shown in Figure 7. It appears that minor cycles in the two sound pressure levels may have different frequencies and voltage amplitudes. In order to look into this, individual minor cycles were developed for both 70 dB and 80 dB sound pressure levels, as shown in Figure 8.

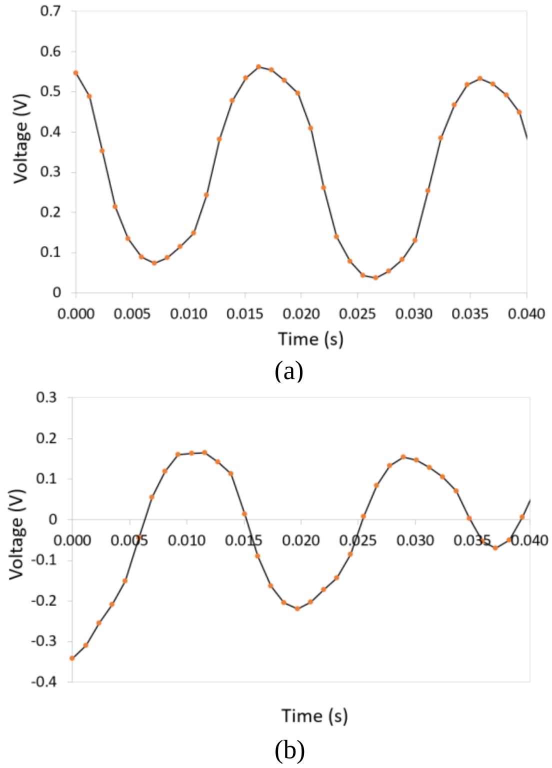


Figure 8. Zoomed graphs of Figure 8 focusing on individual minor cycles (generated voltages as a function of time) at two sound pressure levels of 70 dB (a) and 80 dB (b).

Comparing the two graphs indicates that peak-to-peak voltage amplitude in 70 dB pressure level is significantly higher that of 80 dB case while frequency of graph of 80 dB pressure level is slightly higher than that of 70 dB case. It is most likely the paper layers vibrate locally in a way that the contact between layers will stay locally longer. Table 1 summaries the voltage and frequency values in all cases. The highest voltage drop recorded resulted in 2.48 PP-V.

In the next research following this work, a thermistor temperature sensor and LED will be used in conjunction with Arduino coding to track body temperature and act as an indicator for feverish temperatures. The major drawback of the triboelectric nanogenerator used in the facemask is the low current harvested which limits a continuous temperature monitoring. This limitation will be overcome using a tiny battery charger used to store the power generated by the nanogenerator and power the thermistor as needed. In addition, further testing will be performed using the sound generated by human respiration.

IV. CONCLUSIONS

A novel paper-based triboelectric nanogenerator was used to develop the groundwork of a self-powered face mask. This TENG uses low-cost, easily accessible, and recyclable materials to act as the triboelectric pair. These recyclable materials are paper layered in pen ink and PTFE plastic. The triboelectric effect was facilitated within the mask through the vibrations of acoustic frequency. The purpose of this TENG is to power a temperature sensor to indicate feverish body temperatures on the wearer.

Acoustic energy was used to generate vibrations within the layers of the triboelectric pair. Slots were laser-cut into the paper layer to create a void for sound waves to move through. The slots were also placed closely together to generate wave interference and maximize the number of waves travelling in the TENG to create optimal vibrations. These vibrations allowed for the materials to touch and transfer electrons. The triboelectric effect of this design was also enabled through an up-down-and-around sliding motion to mimic the movement of the mask wearer's jaw. The combination of these two motions was able to generate a voltage within the TENG. The produced TENG generated a maximum peak-to-peak voltage of 2.47 V at the sound pressure level of 80 dB.

REFERENCES

[1] T. Dillahunt, J. Mankoff, E. Paulos, and S. Fussell, "It's not all about 'green': energy use in low-income communities," in Proceedings of the 11th international conference on Ubiquitous computing, pp. 255-264, September 2009.

[2] Z. L. Wang, "On Maxwell's displacement current for energy and sensors: the origin of nanogenerators," in Materials Today, vol. 20, no. 2, pp. 74-82, March 2017.

[3] H. Zheng et al., "Concurrent harvesting of ambient energy by hybrid nanogenerators for wearable self-powered systems and active remote sensing," in ACS Appl. Mater. Interfaces, vol. 10, no. 17, pp. 14708–14715, April 2018.

[4] M. H. Anisi, G. Abdul-Salaam, M. Y. I. Idris, A. W. A. Wahab, and I. Ahmedy, "Energy harvesting and battery power based routing in wireless sensor networks," in Wireless Networks, vol. 23, no. 1, pp. 249–266, Jan. 2017.

[5] X. Yue et al., "Development of an indoor photovoltaic energy harvesting module for autonomous sensors in building air quality applications," in IEEE Internet Things Journal, vol. 4, no. 6, pp. 2092–2103, 20 September 2017.

[6] K. Kim, G. Song, C. Park, and K. S. Yun, "Multifunctional woven structure operating as triboelectric energy harvester, capacitive tactile sensor array, and piezoresistive strain sensor array," in Sensors, vol. 17, no. 11, p. 2582, 9 November 2017.

[7] Q. Shi, T. Wang, and C. Lee, "MEMS based broadband piezoelectric ultrasonic energy harvester (PUEH) for enabling self-powered implantable biomedical devices," in Scientific Reports, vol. 6, no. 24946, pp. 1-10, 26 April 2016.

[8] I. Jung, Y. H. Shin, S. Kim, J. Y. Choi, and C. Y. Kang, "Flexible piezoelectric polymer-based energy harvesting for roadway applications," in Applied Energy, vol. 197, pp. 222-229, 1 July 2017.

[9] M. A. Abdullah and J. F. Jamil, "Harvesting energy from the vibration of suspension of a passenger vehicle," in Proc. Recent Adv. Mech. Mech. Eng., pp. 128–133, 2015.

[10] S. Wu et al., "An electromagnetic wearable 3-DoF resonance human body motion energy harvester using ferrofluid as a lubricant," in Applied Energy, vol. 197, pp. 364–374, 2017.

[11] J. He et al., "Triboelectric-piezoelectric-electromagnetic hybrid nanogenerator for high-efficient vibration energy harvesting and self-powered wireless monitoring system," in Nano Energy, vol. 43, pp. 326–339, January 2018.

[12] Y. Liao and H. Sodano, "Optimal power, power limit and damping of vibration based piezoelectric power harvesters," in Smart Materials and Structures 27, no. 7, p. 075057, 2018.

[13] X. Ma and X. Zhang, "Low cost electrostatic vibration energy harvesters based on negatively-charged polypropylene cellular films with a folded structure," in Smart Materials and Structures, vol. 26, no. 8, p. 085001, 20 June 2017.

[14] M. L. Seol, S. B. Jeon, J. W. Han, and Y. K. Choi, "Ferrofluid-based triboelectric-electromagnetic hybrid generator for sensitive and sustainable vibration energy harvesting," in Nano Energy, vol. 31, pp. 233–238, 2017.

[15] R. Hall and R. Rashidi. "Multi-Directional Universal Energy Harvesting Ball," in Micromachines 12, no. 4, p. 457, 2021.

[16] J. Bianconi, J. Hallett, J. Pealo, and R. Rashidi. "A hybrid piezoelectric and inductive rotational energy harvester," in IOP Conference Series: Materials Science and Engineering, vol. 626, no. 1, p. 012004. 2019.

[17] R. Rashidi, N. Summerville, and M. Nasri. "Magnetically actuated piezoelectric-based rotational energy harvester with enhanced output in wide range of rotating speeds." in IEEE Transactions on Magnetics 55, no. 9, pp. 1-8, 2019.

[18] C. Chen et al., "Micro triboelectric ultrasonic device for acoustic energy transfer and signal communication," in Nature Communications, vol. 11, no. 1, pp. 1-9, 2020.

[19] N. Cui et al., "High performance sound driven triboelectric nanogenerator for harvesting noise energy," in Nano Energy, vol. 15, pp. 321-328, July 2015.

[20] C. Wu, T. W. Kima, S. Sung, J. H. Park, and F. Li, "Ultrasoft and cuttable paper-based triboelectric nanogenerators for mechanical energy harvesting," in Nano Energy, vol. 44, pp. 279-287, February 2018.

[21] S. Khalid, I. Raouf, A. Khan, N. Kim, and H.S. Kim, "A review of human-powered energy harvesting for smart electronics: recent progress and challenges," in International Journal of Precision Engineering and Manufacturing-Green Technology, vol. 6, pp. 1-31, 29 July 2019.

[22] S. Wang, L. Lin, and Z. L. Wang, "Nanoscale triboelectric-effect-enabled energy conversion for sustainably powering portable electronics," in Nano Letters, vol. 12, no. 12, pp. 6339-6346, 6 November 2012.

[23] H. Zhang et al., "Single-electrode-based rotating triboelectric nanogenerator for harvesting energy from tires," in ACS Nano, vol. 8, no. 1, pp. 680-689, 2014.

[24] X. Fan et al., "Ultrathin, rollable, paper-based triboelectric nanogenerator for acoustic energy harvesting and self-powered sound recording," in ACS Nano, vol. 9, no. 4, pp. 4236-4243, 19 March 2015.

[25] Q. Zhong et al., "A paper-based nanogenerator as a power source and active sensor," in Energy & Environmental Science, vol. 6, no. 6, pp. 1779-1784, 28 March 2013.

[26] X. S. Zhang, M. Su, J. Brugger, and B. Kim, "Penciling a triboelectric nanogenerator on paper for autonomous power MEMS applications," in Nano Energy, vol. 33, pp. 393-401, March 2017.

[27] K. Xia et al., "Painting a high-output triboelectric nanogenerator on paper for harvesting energy from human body motion," in Nano Energy, vol. 50, pp. 571-580, 2018.

[28] Centers for Disease Control and Prevention, "Considerations for wearing masks," United States of America, 2020.

[29] R. A. Lester and J. D. Hoit, "Nasal and oral inspiration during natural speech breathing," in Journal of Speech, Language, and Hearing Research, vol.57, no.3, pp.734-742, 1 June 2014.

[30] B. Ghatak et al., "Design of a Self-powered Smart Mask for COVID-19," in arXiv:2005.08305 [physics.med-ph], 2020.

[31] D. W. Kim, S. W. Kim, and U. Jeong, "Lipids: source of static electricity of regenerative natural substances and nondestructive energy harvesting," in Advanced Materials, vol. 30, no. 52, p. 1804949, 2 November 2018.