Study of Triboelectric Micromechanism for Three Dimensional Energy Harvesting

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Abstract. Capturing mechanical energy from the surroundings is a potential strategy to power different sensor nodes and devices. In past few years, Triboelectric effect has been recently utilized in energy harvesting devices as a method to convert mechanical energy into electrical energy. One of the major limitations of the triboelectric mechanism based devices is that they are only responsive to stimulation in a single direction. This limitation hinders the application of triboelectric mechanism devices in various practical situations. In this paper, we present a novel design for triboelectric mechanism based devices which is sensitive to excitation in multiple directions.

1. Introduction
With the growing energy needs and energy requirements, generating green and sustainable energy is an important challenge. To power sensors and various devices, harvesting mechanical energy from various sources in environment is a potential solution. Recently, triboelectric mechanism has become a popular approach for mechanical energy harvesting owing to its high power output, easy fabrication and wide choice of materials [1, 2]. It has also been utilized to realize sensors for different applications including vibration sensing [3], chemical [4] and tactile sensing [5]. One of the major limitations of the triboelectric mechanism based devices is that they are only responsive to stimulus in a single direction. This limitation hinders the application of triboelectric mechanism devices in various practical situations. To improve the utility of triboelectric based energy harvesting devices and sensors, it is important that these devices they are responsive to the mechanical stimulations. This paper presents a novel device design for triboelectric mechanism based devices which are sensitive to mechanical stimulations in three dimensions. This design will enable the triboelectric mechanism based devices to harvest energy from multiple directions and hence increasing their applicability in different practical scenarios.

2. Device design
2.1. Device configuration
For three dimensional (3D) energy harvesting, the device should be able to generate electrical output for both in-plane and out-of-plane mechanical stimulations. For 3D energy harvesting using
triboelectric effect, a device design is proposed and fabricated as shown in figure 1. The triboelectric energy harvesting device comprises of two parts: top and bottom. The bottom part comprises of Si substrate etched with through holes. The top part consists of PDMS micropillars which are then assembled to be inserted through the holes in Si substrate. PDMS layer and the copper film coated Si substrate comes in contact with each other when mechanical force is applied on the device.

![Figure 1](image1)

**Figure 1.** (a) Schematic of the device. (b) View of the device with pillars inserted inside holes.

2.2. **Working principle**

The device works on the principle of generating surface charges using triboelectric effect as the triboelectric layers come in contact with each other. The schematic for the working mechanism 3D energy harvester is shown in figure 2. The surface area of the PDMS layer can be divided in two parts: flat surface area and pillar surface area as shown in figure 2a. The device design results into difference in interaction between PDMS layer and Cu film, for different mechanical stimulus. When normal force is applied on the top elastic PDMS film, it presses the film towards the Cu film in the normal direction leading to the deformation of the PDMS layer. It comes in contact with Cu film in both flat area and pillar area resulting in generation of surface charge in the contacted regions as shown in figure 2b. When the shear force is applied on the PDMS film, the film undergoes shear deformation. PDMS pillars come in contact with inner sidewalls of the etched holes. Due to the contact area between PDMS pillars and Cu film on inner sidewalls, triboelectric surface charges are generated as shown in Figure 2c. The aforementioned mechanism enables the device to harvest energy from both in-plane and out-of-plane mechanical stimulation.

![Figure 2](image2)

**Figure 2:** (a) Schematic depicting the flat and pillar contact area. (b) and (c) Shows the triboelectric charging when normal and shear forces are applied, respectively.

3. **Fabrication**

3.1. **Bottom part fabrication**

For the bottom part fabrication Si wafer was deposited with 2 μm thick silicon dioxide (SiO2) using PECVD (figure 3a). The wafer was then coated with photoresist and patterned using lithography followed by etching of SiO2 layer using reactive ion etching (RIE). Thereafter, deep reactive ion etching (DRIE) is used to etch away Si. As the device is DRIE etched, the sidewall angle is a tilted at an angle. The photoresist layer is then stripped and SiO2 is etched away. To create through holes, the samples are background up to 300μm. Then the samples are coated with 100nm thick Cu film from both the sides of the samples as shown in figure 3a. The Cu layer on Si serves as a triboelectric layer to generate surface charges and also an electrode to power the external load connected to device.

3.2. **Top part fabrication**

The top part comprises of the PDMS micropillars. For PDMS micropillar fabrication, the Si samples with etched through holes are attached to a glass slide (figure 3c). These Si chips attached to a glass
slide were used as a mold to fabricate PDMS micropillar structures as shown in figure 3d. The shape of the PDMS pillar replicates the tilted the sidewalls of the Si holes and thus results into circular conical frustum shape as shown in the enlarged view in figure 3d. For the assembly of device, 100µm spacers are cut out to create gap between the top and bottom part. The spacer between the top and bottom part and aligned using manually controlled multi-axis stage to create a gap.

![Figure 3](image)

**Figure 3:** (a) Fabrication of bottom part. (b) Optical image of the bottom part with the cross sectional image. (c) Fabrication of top part. (d) Optical image of the pillars fabricated.

4. Results and discussion

4.1. Output under normal and shear force

As discussed in the previous sections, the device design is responsive to the normal and shear force in different ways. The device was tested for normal and sliding forces applied using human finger. The results due to press and release (normal force) is shown in figure 4a. As the device is pressed, PDMS layer and Cu film both come in contact in the flat contact area and pillar contact area resulting in generation of surface charges due to triboelectric effect. The PDMS surface gets negatively charged whereas the Cu film gets positively charged. As the normal force is released, the PDMS layer starts separating from the Cu film and electric potential at the electrode starts increasing. Thereafter, the PDMS layer again approaches the Cu film leading to decrease in electric potential. The peak voltage measured due to normal force was measured to be 16V. The working mechanism in the sliding mode is similar as the normal mode with the difference that only pillar surface area comes in contact with Cu coated sidewalls due to lateral relative motion. The peak voltage generated using in the sliding mode was measured to be nearly 2V.

![Figure 4](image)

**Figure 4:** Voltage characteristic of the device under (a) normal and (b) shear force applied.

4.2. Energy harvesting

The device was tested for energy harvesting from force in different directions. One of the applications of the small sized device can be in harvesting energy from typing motion on the keyboards or pressing of switches. The peak voltage and current generated due to the normal force application was measured
to be 90V and 0.57µA respectively, by typing motion of the finger as shown in figure 5a. Through the sliding motion, the peak voltage and current generated were measured to be 5V and 0.08µA, respectively. The generated energy was stored in a 1µF capacitor using a full wave rectifier circuit as shown in figure 5e. The capacitor was charged up to 4V using the typing motion of finger for about 40 sec. The energy was then used to light up a red commercial LED as shown in figure 5f. The power output of the devices is limited due to the small size (1cm x 1.2cm of the complete device) but proposed device design can also be used for scaled up devices to improve the power output.

![Figure 5](image.png)

**Figure 5:** (a) Voltage and (b) current generated from the normal force applied on the device. (c) Voltage and (d) current generated due to sliding force applied on the device. (e) Full wave rectifier circuit used to store energy in a 1 µF capacitor. (f) A lit up LED using the harvested energy.

5. Conclusion
This paper presents a novel mechanism based device was designed and fabricated for three dimensional energy harvesting. The mechanism can be used to differentiate between the mechanical interactions in the normal and sliding directions. The device was also demonstrated to harvest mechanical energy from mechanical force in multiple directions. The device was demonstrated to generate a maximum voltage and current of 90V and 0.57µA respectively.

Acknowledgements
This work is supported NRF2011 NRF-CRP001-057 Program ‘Self-powered body sensor for disease management and prevention-orientated healthcare’ (R-263-000-A27-281) from the National Research Foundation (NRF), Singapore.

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