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Design and Development of Triboelectric Blue Energy Harvester

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Abstract*: Numerous energy sources like vibration, rotation, spinning, human motion and energy from water wave are being explored for harvesting energy. In this work, Tribo-electric Blue Energy Harvester (TeBEH) has been developed in which water waves i.e. blue energy is used as an energy source. It is preferred due to its enormous and environmentally friendly source of energy. The most of the portion of energy from water wave remains unexplored because absence of efficient advancements. Despite the fact that the conventional water wave based electromagnetic generators are well studied and developed, however, triboelectric nanogenerator has numerous advantages ranging from minimal cost to simple device fabrication. There is a lot of kinetic energy in ocean waves which can be harvested. The structure is made up of acrylic box with copper and aluminum as electrodes in combination with triboelectric material as a dielectric for triboelectrification. Gold nanoparticles (Au-NPs) were grown and embedded in polydimethylsiloxane (PDMS) layer to enhance surface charge density in triboelectric layers. The various combinations of tribo-material with electrodes are used to trap the optimized energy. It has been observed that the maximum electric potential of Vpp= 5.10 Volts / Vrms = 2.16 Volts was harvested for (Cu-Au-PDMS)-Cu layer.

***Index Terms*: Blue Energy Harvester, Nanoparticles, Polydimethylsiloxane, Triboelectrification**

I. INTRODUCTION

Energy crises are one of the top ten problems of the world and becoming critical due to the gradual depletion of fossil fuels. Looking for other sorts of alternative sources toward the economic advancement of our society has pulled in increasing attention to make the systems power autonomous like wireless sensor system[1], healthcare and portable devices. Renewable and environmentally friendly energy sources include vibration energy[2,3,4,5], solar, water, wave and wind energy. Particularly, due to less reliance on ambient weather, climatic condition, and the plenteous reserve over other sources, water wave harvesting is one of the foremost promising energies for large-scale applications[6,7]. Harvesting such a broadly dispersed energy from water is a challenge due to limitations in current advanced technologies[8,9].As the electromagnetic and electrostatic harvesters are heavy, costly, easily corroded, and inefficient to work at ocean wave frequency[10,11,12,13.] TeBEH provides us with wide material selection and is additionally developing as promising mechanical energy harvesting system in light of their novel figure of benefits. Triboelectric nanogenerator used in TeBEH is device which converts the externally mechanically triggered energy into electricity. The process is done by the combination of electrostatic induction and triboelectric effect. In 2012 Prof. Zhong Lin Wang's with his group firstly developed TENG at Georgia institute of technology[14].

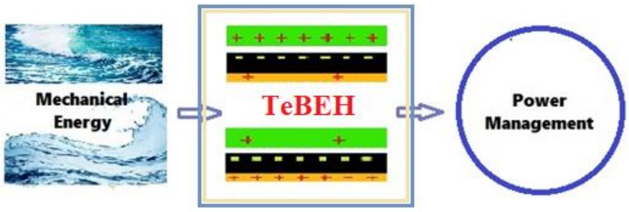

Fig. 1:- The system architecture for the triboelectric energy harvester.

Fig. 1 shows the structural details which consists of water wave as the source of mechanical energy, the triboelectric nanogenerator and the power management system. Qiongfeng Shia et.al proposed a buoy ball triboelectric nanogenerator which is self-powered. Because of its high adaptability it is not only used for sensor nodes but also in array for wide applications [15]. Xiya Yang, presented a water tank type triboelectric nanogenerator made of polytetrafluoroethylene to harvest energy from water wave. The short circuit current and the open circuit voltage is found to have opposite trends with the increment in contact frequency [16]. Tao Jiang et.al developed the spring based triboelectric in which spring stores the energy generated during water wave impact from waves and transforms this lower frequency impact into the higher one[17]. Yuanjie So, Xiaonan et.al proposed surface modification techniques has been applied in hybrid design to increase the surface charges which shows increase in the energy conversion efficiency[18,19]. From the above cited brief literature review, it is found that triboelectric materials and structure modification are the key parameters. Triboelectric generator using a deformative material with nanoparticles is proposed in this work. Out of various types of working modes for triboelectric layers, the working principle of bellows-assisted triboelectric blue energy harvester is the same as that of common contact separation mode.

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Fig. 2 schematically shows the common contact separation mode. When there is mechanical triggering to TeBEH due to water waves, initially the triboelectric layer on one side of acrylic blocks collides and gets in contact with Cu electrodes on acrylic box inner sides, which generates positive charges on the Cu and negative charge on the triboelectric layer. As the water wave impact is periodic the triboelectric layer and Cu separates by producing inner dipole moment between the Cu electrode and triboelectric layer. This continues the flow of free electrons from the Cu electrode[20] attached with the triboelectric layer to the Cu electrode on acrylic inner sides by balancing electric field, which produces positive charges on top Cu electrode due to electrostatic induction till the maximum separation. Again, when two surfaces come close to each other, free electrons drives back to Cu electrode on triboelectric layer leading to the formation of a complete cycle[17].

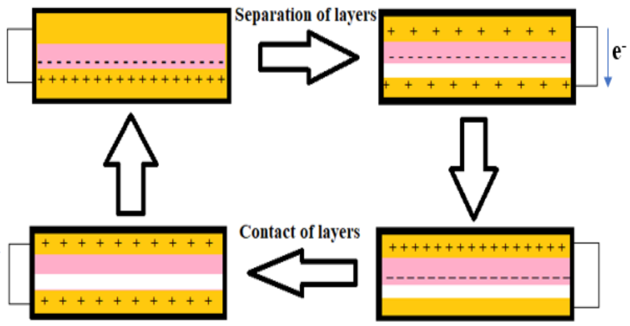

Fig. 2:- Working principle of Tri-bioelectric layers.

The triboelectric materials have wide choices varying from the most positively charged material which is polyurethane to the most negatively charged material which is silicon rubber in addition with some neutrally charged materials. This as a whole is known as triboelectric series*21*.In this work, we have used the impacting materials from the reviewed literature which consists of Aluminum and copper as electrodes with Kapton and PDMS as triboelectric layers. Material modification was done to obtain the increased charge by incorporating nano-particles. As the energy conversion efficiency is given by,

$\eta = (E_{out} / E_{in}) * 100$ % -----eq (1)

Where Eout & Ein being the output and input energy of the device respectively. Though determining the input energy is difficult, but it is same for all the devices. Thus, we can find the improved performance of the devices. Similarly, in this work the improved performance is found by voltage ratio of the output open circuit voltage by providing the same mechanical triggering to the devices.

II. EXPERIMENTAL SECTION

A. Material and chemicals

Acrylic sheet was used for making the outer structure of the triboelectric nanogenerator. The Aluminum and copper tape were used as electrodes with PDMS and Kapton as a triboelectric material. PDMS and its curing agent with hexane (Sigma) is used to make a thin PDMS layer. The chemicals used for making the doped PDMS layer using nano-particles were chloroauric acid and trisodium citrate dehydrate (TCD) whereas Chloroauric acid [HAuCl4] was used as a seed material.

B. TeBEH design

TeBEH outer structure was fabricated using acrylic sheet of dimension 6.9cm*5.9cm*5.9cm. The internal tribo-layer set were fabricated using copper and aluminum as electrodes with one among Kapton, PDMS, gold nano-particles embedded PDMS as triboelectric layer.

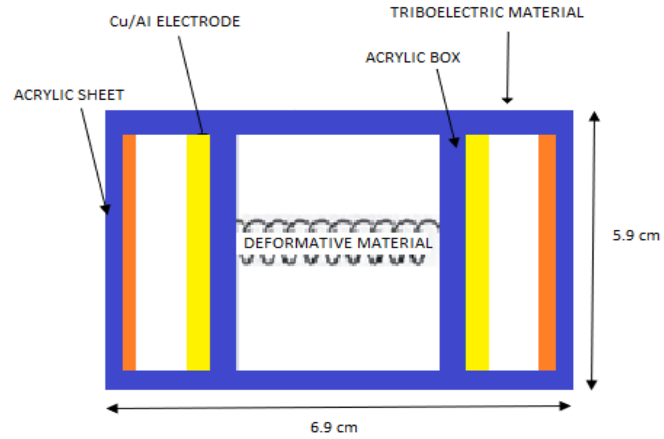

Fig. 3: - TeBEH structure with 2-sets of one Tribo-layer and one electrode.

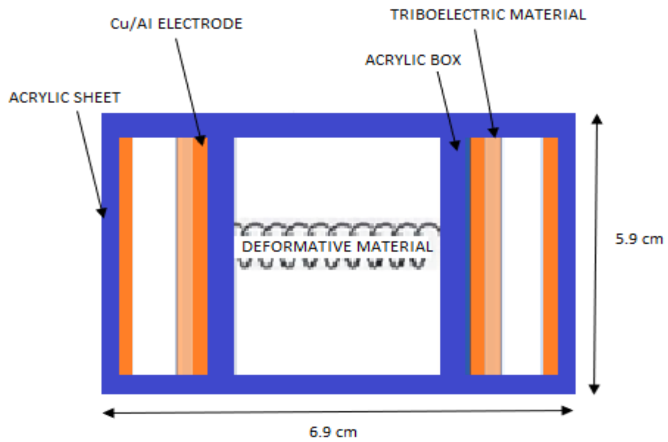

Fig 4: - TeBEH structure with 2-sets of a Tribo-layer in between two electrodes.

Fig.3 TeBEH structure shows with 2-sets formed by one tribo-layer and one electrode whereas fig. 4 shows TeBEH structure with 2-sets formed by one triboelectric layer and two electrodes. The separation gap in tribo-materials is maintained less than 5mm.

C. TeBEH Structure Modification:

Triboelectric material: The PDMS layer was prepared using the of mixture of Sylgard 184 prepolymer, with its curing agent and hexane in ratio 10:1:1.5. The nanoparticles are separated by the citrate anions. In this project, gold nanoparticles were made using citrate method which were then embedded in PDMS to make an even layer[22,23].

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Synthesis of Gold Nanoparticles by Citrate method :In this method stock solution was prepared of 1.0 mM hydrogen tetrachloroaurate and 1% trisodium citrate.

From the stock solutions of 20 mL of 1.0Mm hydrogen tetrachloroaurate was taken into a 50 mL flask and was kept and boiled on a hot plate with a magnetic stirrer. 2 mL of a 1% solution of trisodium citrate, Na3C6H5O7.2H2O was mixed. The gold solution was developed gradually as the citrate reduces gold (III). The gold elements at macro-scale is gold colored but as these elements reaches the nano-scale the colour changes from red to dark purple. The formation of gold nano-particles can be observed by the colour change in between red to purple as seen in fig. 5(a) and the nanoparticle detection is done by the reflection of beam of laser through the synthesized solution as shown in fig. 5(b) and fig. 5(c). When the laser light passes through the gold solution which is the 1.0 mM solution of hydrogen tetrachloroaurate, the laser light will not transmit through this solution. But when it transmits through the synthesized gold nano particles solution, a clear laser beam can be observed due to polarization. Hence this visual test can determine presence of nano-particles in the solution[24].

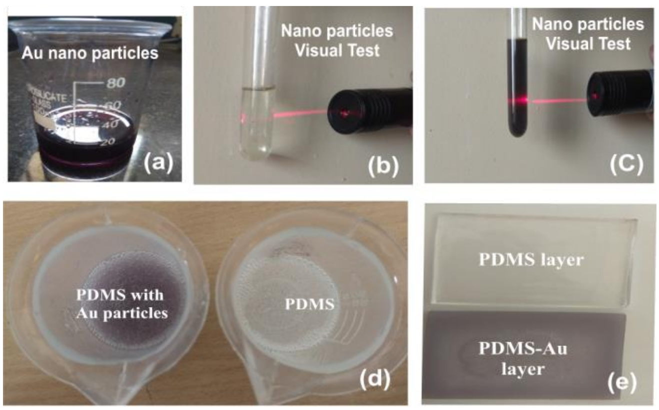

Figure 5 : (a) Synthesized Au-NPs by citrate process. (b) Visual test for nanoparticle detection by the reflection of beam of laser through gold solution (c) Visual test for nanoparticle detection by the reflection of beam of laser through gold nanoparticles solution (d) PDMS solution with and without gold nanoparticles (e) PDMS layer with and without embedded Gold nanoparticles.

Now a 3ml volume of the nano-particle solution is used in the PDMS mixture to form a thin layer of Au-NPs embedded PDMS as shown in fig 5 (e). Using the spectrometer (Aimil) the graph of absorbance with respect to wavelength was plotted and the peak was obtained at 522nm for absorbance of the nanoparticle's solution which matches with the range of reported paper[25].

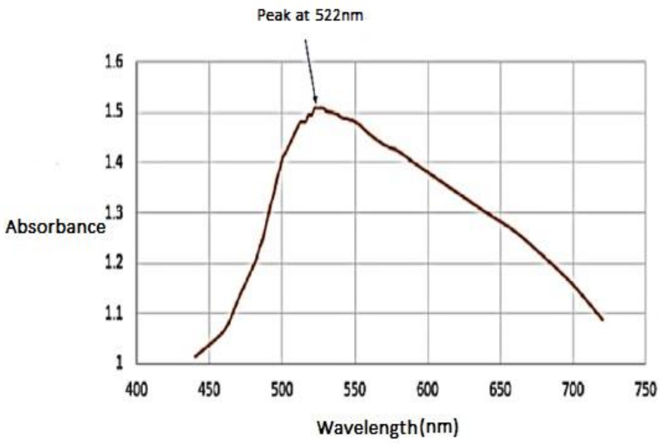

Fig. 6:- Plot for Wavelength Vs Absorbance for sample of gold Nano-particles by citrate method.

III. RESULTS AND DISCUSSION

For testing of the TeBEH device the following combination were made for the materials.

(i) Device 1 (D1): Aluminum and Kapton
(ii)Device 2 (D2): Copper and Kapton
(iii) Device 3 (D3): Copper and Cu-PDMS
(iv) Device 4 (D4): Copper and Gold embedded Cu-PDMS

Fig. 7 shows the above designs which were used for testing of TEBEH performance to obtain efficient **o**utput.

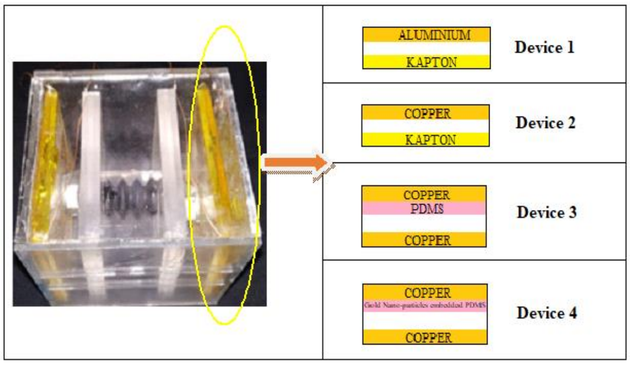

Fig. 7:- TeBEH designs used for testing the performance of the device.

The devices were tested by using the setup as shown in the fig. 8 which includes a shaker with an accelerometer, the TeBEH device and a digital storage oscilloscope ADS2202CA.

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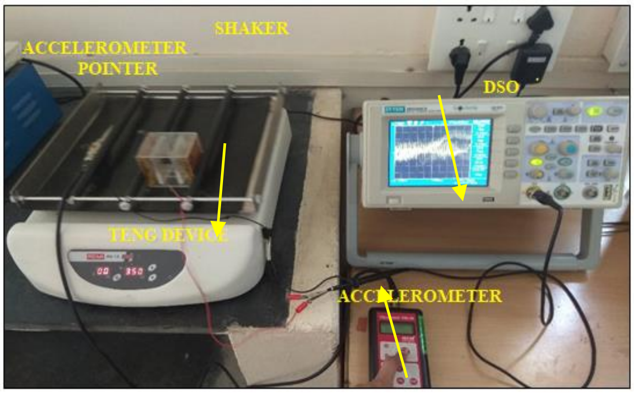


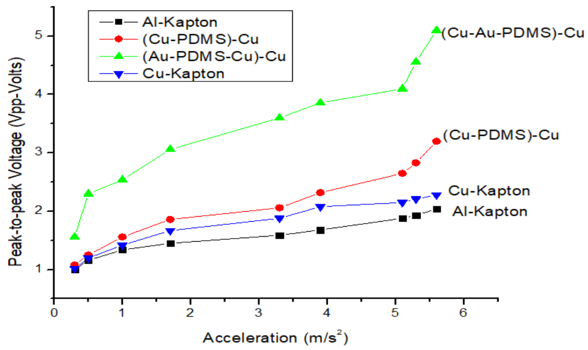
Fig. 8:- Setup for testing the TeBEH devices.

A. Device testing: The TeBEH devices were tested for measuring the parameters like RMS voltage and peak to peak voltage. The shaker was used at different rotation per minutes (RPM) to produce water waves like effect in laboratory. The accelerometer was used to measure the acceleration at different RPM. The fig. 9 shows the variation of voltage at different acceleration and RPM for the TeBEH devices. Table 1 below experimental results in tabular form.

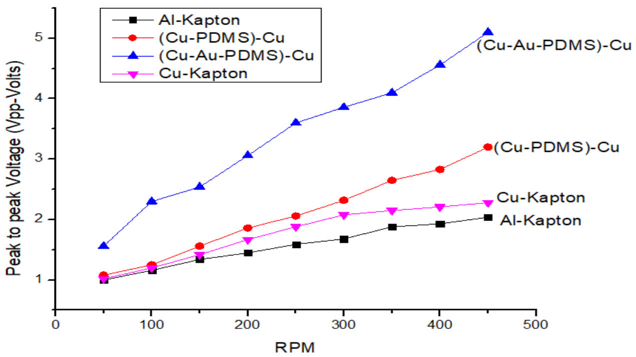
Table 1:- Peak-to-peak voltage of device D1-D4 with respect to acceleration and RPM.

Sr. No.	RPM	Acceleration	Vpp (D1)	Vpp (D2)	Vpp (D3)	Vpp (D4)
1	50	0.3	1	1.02	1.08	1.56
2	100	0.5	1.16	1.2	1.25	2.3
3	150	1	1.34	1.42	1.56	2.54
4	200	1.7	1.45	1.67	1.86	3.06
5	250	3.3	1.59	1.88	2.06	3.6
6	300	3.9	1..68	2.08	2.32	3.8
7	350	5.1	1.88	2.15	2.65	4.1
8	400	5.3	1.93	2.21	2.83	4.56
9	450	5.6	2.04	2.28	3.2	5.1

The fig. 9(a) shows the plot of peak-to-peak voltage(Vpp) with respect to acceleration and fig. 9(b) shows the plot of peak-to-peak voltage(Vpp) with respect to RPM of the shaker. For device (1) at maximum RPM of the shaker at 450 RPM the Vpp = 2.04 Volts and Vrms = 740 Volts, for device (2) the Vpp = 2.28 Volts and Vrms = 720 Volts, for Device (3) Vpp= 3.2 Volts and Vrms = 900mVolts, and for Device (4) Vpp= 5.10 Volts and Vrms = 2.16 Volts.



(a)



(b)

Fig 9:- Characterization of the first two devices. (a) Plot for Peak to peak voltage Vs Acceleration. (b) Plot for Peak to peak voltage Vs RPM.

The highest Vpp = 5.10 Volts which is obtained for the device 4 which consists of the (Cu-Au-PDMS)-Cu. As compared to the other three devices material, the material used for fabricating this device consists of embedded nanoparticles in the triboelectric layer.There is formation of nano-traps which acts like nano-capacitors this leads to the increament in charges in the material layer.Thus we obtain the high output for device 4 with (Cu-Au-PDMS)-Cu layers.

B. Visual Test:

A T-shape of parallel connection of red LEDs was made and powered by the TeBEH devices. The glowing intensity of the LEDs depends on the output voltage of the device. The fig. 10 shows the LEDs powered by device 4 with (Cu-Au-PDMS)-Cu layers. This shows visually that the voltage generated is sufficient to power the array of LEDs.

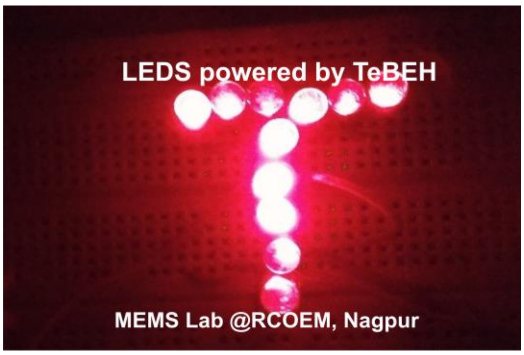


Fig. 10: T-shape LEDs powered by TeBEH.

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IV. CONCLUSION

Tribo-electric Energy Harvester was fabricated for harvesting blue energy using acrylic box as outer layer, and various internal triboelectric layers. The bellows were introduced to translate the frequency from low to high .The performance of devices were measured under the action of vibration shaker at different RPM. The absorbance spectrum has peak at 522 nm, which proves the proper growth of gold particles. The various combination of triboelectric materials were tested.

It was demonstrated that the output voltage of the device increased by 64.31% by embedding gold particles in PDMS as compared to virgin PDMS layer. With reference to visual test , It is claimed that the electric potential harvested by the device is sufficient to drive sensor node to be deployed for water quality monitoring system or other microsystems. The formation of device network and alteration in concentration of nanoparticles can further improve energy level which will be performed in near future.

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