Harvesting energy from triboelectric devices

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Abstract — In the present days, new technologies in the area of energy are being investigated and developed, with the purpose of discovering new or improving already existing ways of obtaining clean energy, without harnessing the environment. Many are promising, others still have the potential to become practical and be useful. One of this technologies resides on the triboelectric effect. In this work, we will talk about this effect and its details and advantages, as well as our own experiment in our laboratory Science College of Porto University. Several triboelectric materials were tested and evaluated. Through methods in circuit eletronics, and with LabView analysis, we reached a power density between Nylon 6.6 and PTFE of about $0.16 W/m^2$, with respective load resistance of 100Ω. The power density and current behavior were as expected, and the results were reasonable given the parameters of the experiment. A glove application was also tested, giving an average potential difference of about 0,52V.

I. INTRODUCTION

The massive development of the world electronic technology follows a general trend of miniaturization, portability, and functionality. The next few decades will be about building functionality on existing electronics, which inevitably involves developing a range of sensors including but not limited to navigation, motion, chemical, biological, and gas sensors. The near future development is about electronics that are much smaller than the size of a cell phone, so that each person on average can have at least dozens to hundreds of such small electronics. New technologies that can harvest energy from the environment as sustainable self-sufficient micro/nanopower sources are newly emerging fields of nanoenergy, which is about the applications of nanomaterials and nanotechnology for harvesting energy for powering micro/nanosystems. New areas on nanoenergy generation through energy harvesting are emerging for applications to power micro/nano-systems. The goal is to build self-powered technologies with ultra small size, hypersensitivity, multi-functionality and low consumption. The general characteristics of such power sources include availability, efficiency and stability. As a solution, nanogenerators (NGs) have been developed to take advantage of ever present environmental energy such as the motion of the waves or the simple walk of a person.

The triboelectric nanogenerator (TENG) is a device that converts mechanical energy into electricity using the coupling effects between triboelectrification and electrostatic induction through the contact separation or relative sliding between two materials that have opposite tribo-polarity. The triboelectric effect is a contact-induced electrification in which a material becomes electrically charged after it is contacted with a different material through friction. Triboelectric effect is a general cause of every day's electrostatics, and probably one of the few effects that have been known for hundreads of years. Although this is one of the most frequently experienced effects that each and every one of us inevitably uses every day, the mechanism behind triboelectrification is still being studied. After two different materials come into contact, a chemical bond is formed between some parts of the two surfaces (adhesion), and charges move from one material to the other to equalize their electrochemical potential. The transferred charges can be electrons or may be ions/molecules. When separated, some of the bonded atoms have a tendency to keep extra electrons and some a tendency to give them away, possibly producing triboelectric charges on surfaces.

Traditional triboelectric generator is a mechanical device that produces static electricity or electricity at high voltage by contact charging. The most popular ones are the Wimshurst machine and Van de Graaff generator, which were invented in ~1880 and 1929, respectively. Both machines use the accumulated static charges generated by triboelectrification; the tribo-charges are transferred from a rotating belt to a metal brush by the corona discharging (e.g., the electric-field-induced arching of air); once the accumulated charge density reaches a critical value, discharging over two opposite electrodes occurs (Figure 2). It appears that the traditional triboelectric generator is a high voltage source, and there is no current unless there is a discharging.

Fig. 1- Wimshurt machine

Fig. 2- Van der Graaf generator

Figure 3 shows a triboelectric series, which basically is a loose ranking of a material´s polarity when charged with a given material. The ranking of a material may easily change position in the series depending on several factors such as surface roughness, force of contact, work function, charge backflow, charge breakdown (of air), etc. These variables, which affect the magnitude of the charge generate, only add to the confusion of understanding the tribocharging mechanism and make the triboelectric series chart a relative comparison of materials and not an exact science.

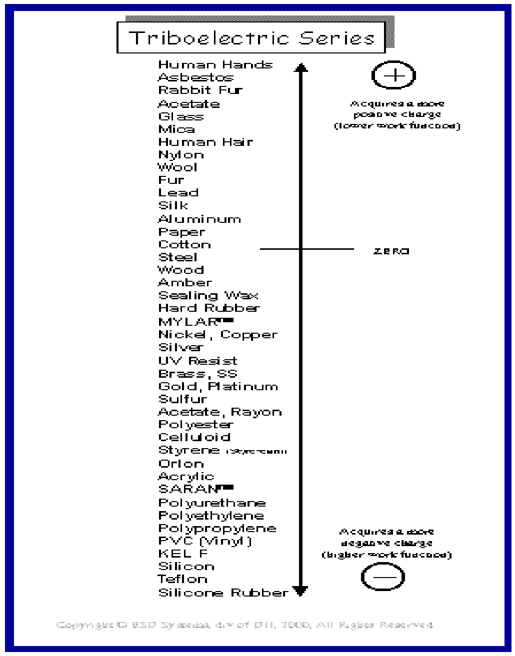

Fig. 3- Triboelectric series of some materials

II. Theory - procedure

In this section we will summarize the theoretical procedure to follow, and the experimental setup used in the experiment.

We had several materials to use, but we only used two of those, which would be the ones that presented bigger triboelectric polarity. From the materials we had in hand, Nylon 6.6 presented the greatest electronic affinity, so we just had to vary the other materials and find the best pair to execute our experiment. The other materials were PVC, PTFE, FEP, Cu and Cellulose. From the triboelectric series we can see that PTFE (polytetrafluoroethylene) presents the biggest polarity comparing to others. To confirm this, we tested each material by connecting the tip of both films to an oscilloscope and measuring the potential difference. It was confirmed that PTFE and Nylon 6.6 were the best pair of materials.

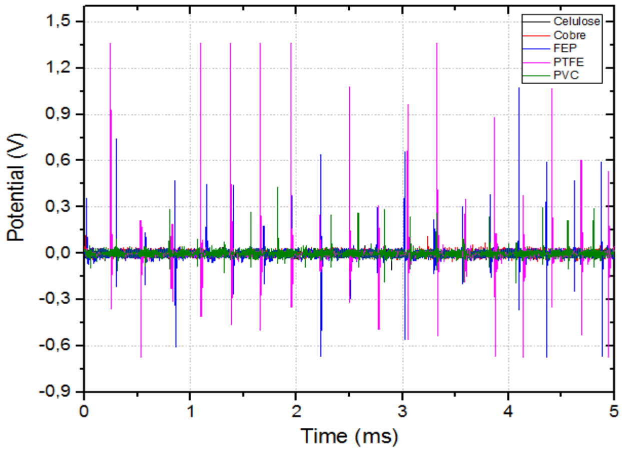

Fig.4 – Results for the materials tested in the triboelectric effect

A. Experimental setup

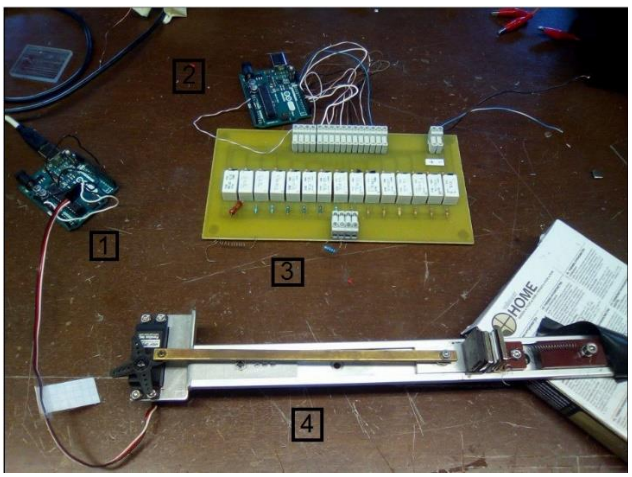

Fig.5 – Experimental setup used in our experiment. 1- Arduino board used to control the step motor; 2 Arduino board used to change the resistor and connected to LabView; 3- printed circuit board; 4- Rotary step motor

B. Open-circuit

In order to reveal the pair of materials we used the setup shown previously in the open-circuit configuration, since we just needed to measure the potential difference for each pair of materials.

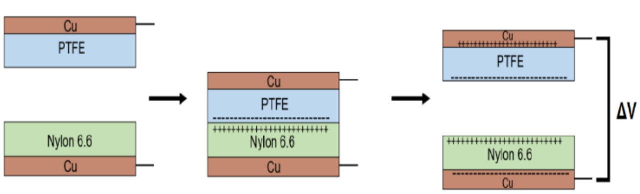

Fig.6 - Open-circuit setup for potential difference measurements [3]

C. Short-circuit

The second part of the experiment was to measure the current that flows through the configuration of the materials. For that purpose, we used a “small” load resistance (~10 Ω), small compared to the resistances we used in the resistor. This way, we get an accurate measurement of the total current that flows through the configuration.

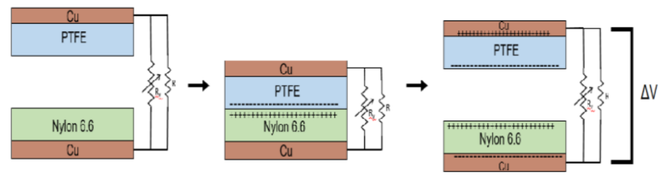

Fig.7 - Short-circuit setup for current measurements [3]

III. Experimental procedure

The triboelectric materials were in a film form, with one side being a copper plate, working as our electrode, and the other the material. As we can see in Figure 4, the mechanism to obtain contact between the two parts consists of a rotary step motor and a fixed spring, each one with magnets to enable contact. Both Nylon and PTFE are attached to each side of the mechanism and also connected to the oscilloscope, and during the collision we can see the respective potential difference generated. The motor is controlled by an Arduino device connected to the computer. In the short-circuit configuration, we also used another Arduino to control a printed circuit board that contained several resistances, ranging from 100Ω up to 1GΩ. This Arduino was also connected to the computer, and to a LabView program, in order to ease the process.

IV. Application

Our professor suggested us to use this principle and apply it in a every day situation, in order to obtain energy from random sources without having deliberately to obtain them in the regular way. We thought initially in applying this principle in road bumps, since it is well frequented, and by objects (vehicles) of substantial weight. Since this wasn´t very pratical for us, we decided instead to test this in human skin, more specifically between a piece of nylon and human skin, where the contacts were placed in a glove.

V. Results

A. Nylon 6.6 – PTFE

Our results can be seen in the following images.

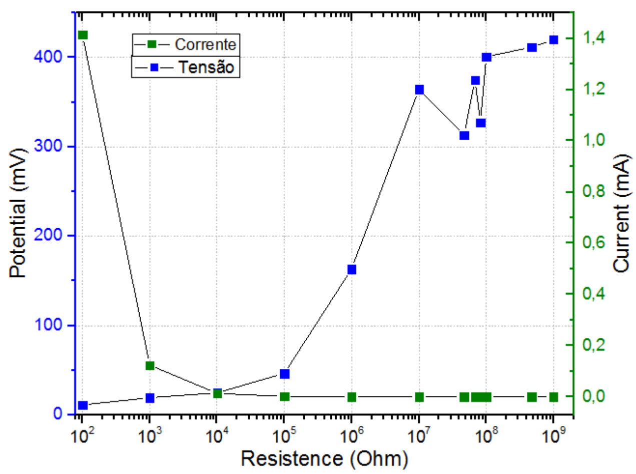

Fig.8 – Potential difference and current dependence on the resistance used.

As expected, the potential difference, PD, tends to increase with the load resistance, if we ignore 2 points and follow the general trend of the graph. Current, however, decreases very rapidly with the resistance, as we also expected. With these data, we can predict that the power density (W/cm^2) will also decrease drastically with increasing load resistance.

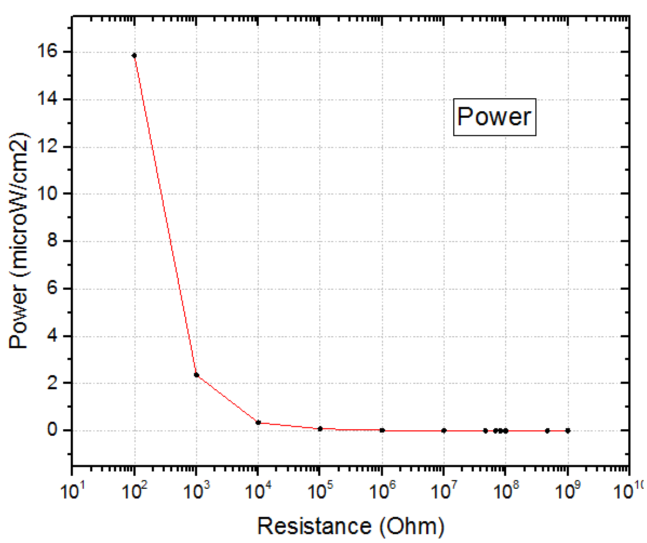

Fig.9 – Power density of our TENG experiment

We estimated the area of our sample to be ~ 5,46cm^2. The sample size and condition were not the best, but we can still clearly see that the sample behaves as expected. The maximum power density was achieved at R_{load}=100Ω, with 16 μW/cm^2 = 0.16W/m^2. This result is close to the one our colleagues from other group achieved, of about ~ 0.1W/m^2. This is acceptable, since the PD depends not only on the resistances and surface area of the samples, but also the force applied by the motor in the collision. Since the step motor is in a simple configuration, one can change the parameters of the setup as best fits, and that´s why this results are good compared to each others, because even with the possible disparities and sample conditions, they don´t differ too much.

B. Application

For our glove application, we used the same principle as for the Nylon-PTFE experiment. We placed our sample in contact with the glove, and the skin of the hand inside the glove in contact with the electrode.

Fig.10 – Image depicting the electrode outside the glove, connected to the skin inside the glove

As for the contact part, we decided just to “clap” our glove into the Nylon sample, generating enough force to detect some PD in the oscilloscope. The data retrieved are presented in the following graph.

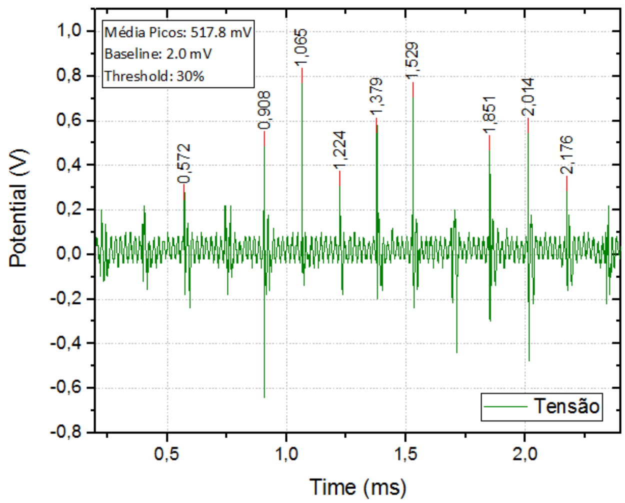

Fig.11 – Data retrieved by the oscilloscope, when clapping the glove to the Nyon sample

We obtained an average PD of 517mV, which is not bad since Nylon and human skin are not the best pair of triboelectric materials, but we also did some effort to make that happen, so we used some force when clapping the glove. If one could apply these concept in a practical way in every day activities, like jobs that require wearing gloves, or even in sports, like boxing, where a punch could deal substancial PD as well as knockout the opponent, we could be staring to a new way of obtain clean energy with low cost. But that is still a bit far away, at least in glove applications, since its not the best pratical way to use this technology.

VI. Conclusion

During this experiment, which lasted about 4 hours, we tested some materials to compare their triboelectric properties and find the best match available in our lab. we used techniques such as short-circuit and open-circuit to perform our measurements. Our results were satisfying, as we observed the expected tendency of decay of power density and current with increasing load resistance in the short-circuit configuration. The maximum obtained power was achieved at $R_{load}=100\Omega$, and value $0.16 W/m^2$.

Our application showed some potential for future applications, yet it still has a long way until it can be used in better pratical ways.

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