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14. ABSTRACT For years researchers have been attempting to design more effective means of harvesting and utilizing energy in a portable form. One well known form of energy with a lot of potential uses is electric energy. Electric energy can provide light, operate machinery, or generate heat. Portable electrical energy devices can allow for many new applications in the present day world. In this project, the group will design and fabricate a portable device that can effectively produce electricity, store it efficiently, and then implement it towards a practical everyday use. Our means of doing this is by designing a novel, flexible energy device based on a supercapacitor concept. The special
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Design and Fabrication of a Flexible Supercapacitor Energy Device

Technical report for Tuskegee University EENG0492 – Engineering Design and Analysis

April 27, 2015

Lamont Henderson, David Billingslea and Johnathan Williams

1. Introduction

A supercapacitor is a relatively new concept in technology currently being fabricated in order to meet the rising demand for rapidly charging and discharging energy storage devices. Capacitors are similar to batteries, in that they both store electrical energy; yet use a different process in accomplishing that same task. In terms of energy storage, batteries utilize chemical reactions to create a polar differential between its two terminals; capacitors on the other hand use an applied electric field or voltage across its parallel plates to build a charge between the two conducting plates, otherwise known as electrodes [1]. Supercapacitors are built upon a similar principle to that of regular capacitors, but have significantly higher capacitance values. What makes a supercapacitor so effective is that it has a second layer of capacitance located between each electrode and the electrolyte/dielectric on both sides, indicating it has a higher energy density and can store more charge along the surface area of its parallel plates [1].

Researchers have predicted that further advancements in supercapacitor technology could possibly have a greater impact on society than the battery has ever managed to do so [2]. Although the energy storage capabilities of batteries are recognized as one of the most significant scientific contributions in history, supercapacitors have the potential to render them obsolete. Since batteries rely on chemical reactions to produce power, there is finite number of times they can be charged and discharged before decomposing and subsequently releasing harmful chemicals into the environment [2]. However, supercapacitors can be charged or discharged a higher number of times at a faster rate and still perform at maximum efficiency while leaving minimal environmental footprint.

The purpose of this design project is to fabricate such a device that will be able to do all of the above. The methodology of our design process is to implement carbon nanotube infused plastic material to help create a flexible and ultra-light supercapacitor.

2. Design Project Tasks Timeline

The following tables provide us a timeline to follow. The timeline is important because it allows us to stay on task. If we stay on schedule and adhere to the deadlines listed, we will finish our project on time. Table I shows the January 2015 timeline. We formed our groups, selected a design topic, chose a project advisor, and drafted an abstract. Table II shows our plan of action for February 2015. We have spent the majority of that time designing and fabricating our device

Bank, and power a load	Week 1							Week 2							Week 3							
PLAN OF ACTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Prepare Final Demonstration	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Prepare Final Report	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Final Presentation																						x
Final Demonstration																						x
Final Report Due																						x

3. Design Procedure Block Diagram

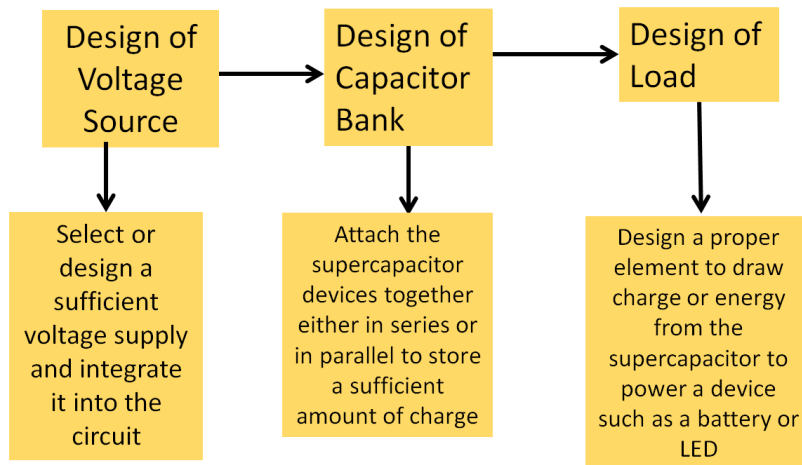


Figure 1. Block Diagram of Design Procedure

3.1)

There are several arbitrary choices for the voltage source. In Figure 1 we will select or design a proper voltage source that can provide enough power to the entire supercapacitor circuit. One option includes using a regular battery as displayed in Figure 2. The battery utilizes chemical reactions to produce voltage. A second option is to choose solar cells. Figure 3 shows a detailed schematic of the constituents of a solar cell. Essentially a solar cell is a diode that absorbs solar energy in the form of photons from sunlight. The diode proceeds to convert the

solar energy into electrical energy so that it can be harvested and eventually used as a power supply. The final option is to use piezoelectric devices such as the special crystals shown in Figure 4. What makes these crystals so unique is their ability to produce voltage when one applies pressure to their surface. In the case of Figure 4, when the crystal is squeezed, it produces a voltage of 2.758V.



Figure 2. Double A 1.5V Battery

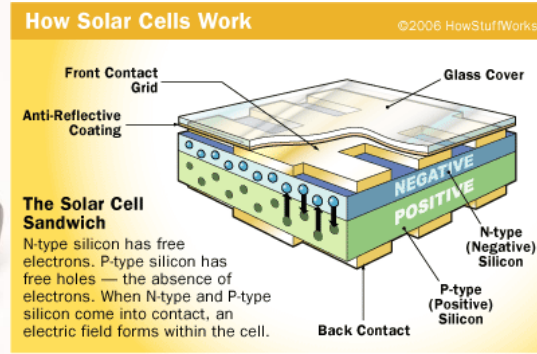


Figure 3. Solar cell



Figure 4. Piezoelectric crystal producing voltage

3.2)

The third step is to design the capacitor bank itself. This is accomplished by stacking the supercapacitor devices together in parallel or series. We want the supercapacitors to have sufficient capacitance and be able to serve as an adequate voltage supply. The supercapacitor device will have the topmost layer as the conducting electrode with the electrolyte attached immediately after. This pattern repeats itself to the nth degree until we have a satisfactory supercapacitor structure.

3.3)

The final stage for our project is to attach a load to the end of the circuit. We want the load to be powered by the supercapacitor, which will serve as a voltage supply. The load needs to be able to draw enough current from the supercapacitor bank in order to be turned on so that we can plot its Voltage-Current (IV) characteristic curve. If all goes well, the supercapacitor

bank will be a packaged and lone-standing voltage source that can effectively power or charge a variety of electronic components including LEDs, diodes, or an empty battery.

4. Description of Fabricated Supercapacitor Devices

For the past couple of weeks, we have been in the microelectronics laboratory designing, fabricating, and testing several different types of polymer based supercapacitor devices. We are now attempting to create a supercapacitor bank; a device with numerous supercapacitor devices attached together either in series or parallel. The capacitor bank structure will have a single electrode on the very end of both sides. All of the supercapacitor electrodes utilize CNT (Carbon Nanotube) material as the conductors of electricity. Figure 5 and Figure 6 show the Carbon Nanotube material on the nanoscale. A carbon nanotube is a cylindrical shaped structure composed entirely of carbon atoms that when unfolded, reveal numerous hexagonal patterns. These patterns represent the bonds between each individual carbon atom. The atomic structure of carbon nanotubes not only gives the capacitor great flexibility, it also allows a greater conductivity of electricity. A black CNT/PVA (polyvinyl alcohol) liquid was poured onto a petri dish to form a casting. While the PVA/CNT substrate is still hydrated and wet, liquid CNT mixed with a small amount of acetone will be dropped on top. This process forms the outermost electrodes for our capacitor bank. We repeat this pattern of dropping liquid CNT and hydrating the PVA/CNT casting with water to ensure as much CNT remains on the surface as possible. More CNT sticking onto the surface will result in a larger amount of stored energy. For the dielectric material, a mixture of PVA and phosphorus was poured to form a second casting. The casting will solidify into a lightweight and extremely flexible plastic material. It will serve as the electrolyte insulating material between the CNT electrodes. We want the PVA and phosphorous dielectric to be as thin as possible to ensure the supercapacitor can hold a charge well into the milli Farad (mF) range for a 1cm^2 area. Figure 7 and Figure 8 show a sample of how the innermost electrodes will be composed of acetone/CNT liquid drops on top of the plastic PVA/Phosphorus dielectric. We plan to “sandwich” the CNT and electrolyte solid between the PVA/CNT electrodes. This will complete our supercapacitor bank design. Figure 9 and Figure 14 provides another view of our supercapacitor sample.

The group continued to experiment with new methods in designing flexible and polymer based supercapacitors. Both Figure 15 and Figure 16 were fabricated by using the regular deposition method of spreading CNT onto a PVA electrolyte membrane. Unfortunately, we required a another method of dispersing CNT onto the dielectric layer. A second technique that was used in the formation of the outermost electrodes was allowing the black PVA and CNT to sit and dry at room temperature to form a casting. Afterwards, the liquid CNT and acetone was then dropped uniformly in rows on top of it. By letting the PVA and CNT material dry first, we avoid the risk of excessive CNT drops eating through the PVA/CNT substance. We also used the spin coat method by utilizing the spin coat machine shown in Figure 13. This technique was used on the black PVA/CNT shell by dispersing PVA/Phosphorus electrolyte onto the substrate. We

then added CNT/acetone drips on the opposite side to form the conductive electrodes. Figure 10 shows a completed supercapacitor sample fabricated through spin coating. By spin coating the substrate with the PVA electrolyte, we were able to make a supercapacitor with a thinner dielectric between the electrodes. We were also able to give the CNT electrodes a larger surface area on the supercapacitor. As a result the supercapacitor has the ability to store a greater charge in the milli Farad (mF) range. Both figures 11 and 12 display our test results from the spin coated supercapacitor.

Since the spin coating method provided most favorable results, we continued to use that technique to make more supercapacitor devices. A PVA/CNT electrode was cut into larger shapes to provide a greater surface area CNT to cover. Immediately, the sample was then placed on a spinning chuck apparatus where it received several drops of PVA electrolyte. The device then rotated the electrode for a set amount of time to allow an even coating over its surface. This entire method was repeated three times each for both electrodes before the two are “sandwiched” together to form a completed and newly fabricated supercapacitor. Afterwards we replicated this process and continue “stacking” one supercapacitor on top of the previous one. Eventually we constructed a newly formed supercapacitor bank. Unfortunately, the supercapacitors created through spin coating were unable to power an LED, prompting us to try another method.

Throughout the course of our project, the chief obstacle we faced was depositing Carbon Nanotubes onto a flexible substrate. In the early stages of our experiment, we concocted a heterogeneous solution composed of CNT and Acetone. Knowing that acetone evaporates at room temperature, we deposited this aqueous solution with hopes of forming a solid pure CNT uniform region. After deposition of the CNT/Acetone mixture onto the flexible surface, we found that the acetone jeopardized the integrity of the substrate, thereby creating holes and fractures. Upon further investigation, we also discovered that the seemingly uniform CNT region formed thin, brittle flakes, with weak adhesion to the surface. A better technique of depositing CNT onto the electrolyte membrane was necessary. A couple of weeks ago we mixed .8g of CNT with 9ml of PVA (polyvinyl alcohol) and dripped isopropyl alcohol onto it. This gave us a CNT “buttery” mixture that when dispersed onto the dielectric, produces a solid smooth layer that sticks to the electrolyte, does not flake off, and is bendable, which provides the capacitor with greater durability. We were able to determine that using this CNT “Butter” to form the conducting electrodes allowed the capacitors to store around 2.2V when an external 3V from a DC power supply was applied to the capacitor itself. With further electrical testing, we discovered to our satisfaction that these supercapacitors were able to power an LED for several seconds. Figure 17 shows the result of utilizing this CNT “Butter” mixture to form a supercapacitor. At that moment, we had just fabricated a fully functional, polymer and CNT based supercapacitor device that could serve as an independent power supply.

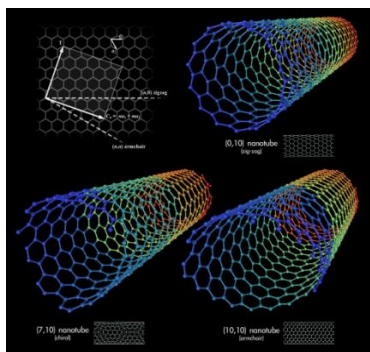


Figure 5. Carbon Nanotubes

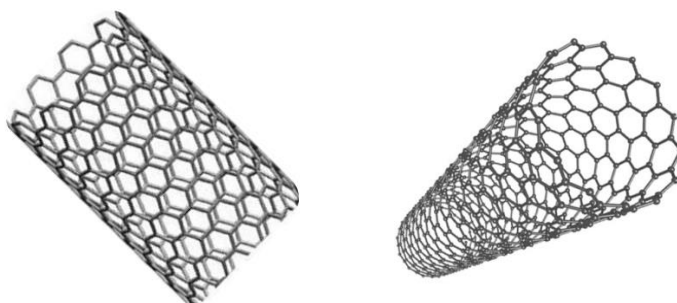


Figure 6. Carbon Nanotubes



Figure 7. CNT Electrodes on PVA/Phosphorus Electrolyte



Figure 8. CNT Electrodes on PVA/Phosphorus Electrolyte



Figure 9. CNT Electrodes on PVA/Phosphorus Electrolyte

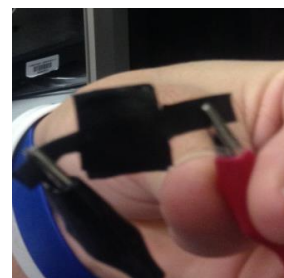


Figure 10. Completed supercapacitor device fabricated through spin coating

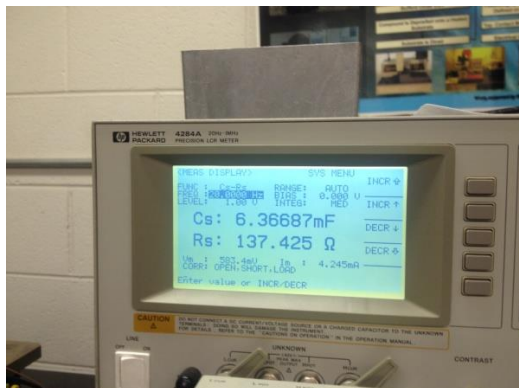


Figure 11. Capacitance values of newly fabricated supercapacitors

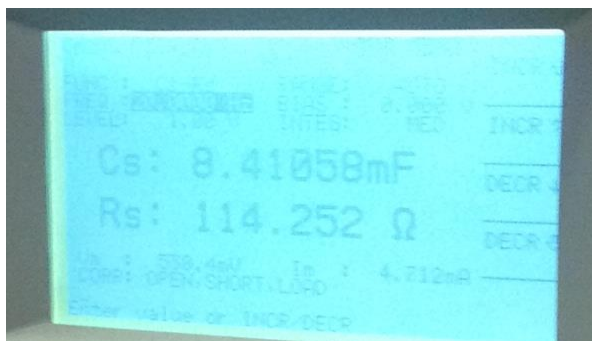


Figure 12. Capacitance values of newly fabricated supercapacitors



Figure 13. Spin coating machine



Figure 14. “Button” Supercapacitor Prototype



Figure 15. “Ugly Duckling” Prototype

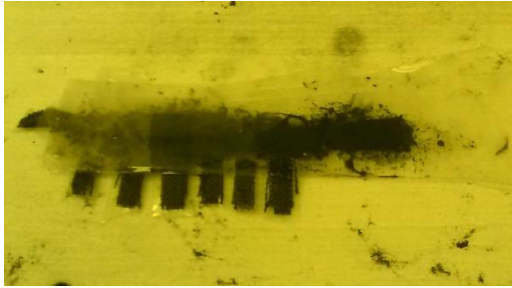


Figure 16. "Snake" Supercapacitor Prototype

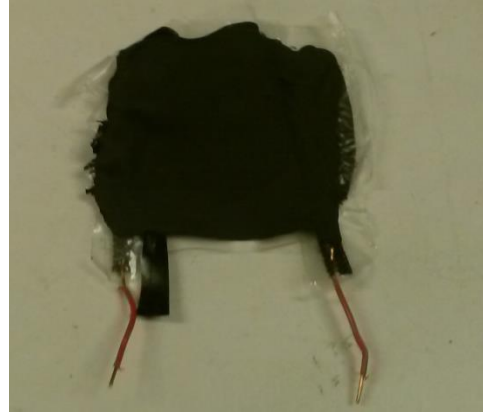


Figure 17. CNT Butter Capacitor Prototype

5. Results

Every group member contributed greatly to the design of a flexible carbon based supercapacitor that can serve as voltage source. We all participated in researching the concept of capacitors, typing the reports, testing our samples in the lab, and fabricating supercapacitors in the clean room. Our joint effort produced favorable results for our project. Several of the capacitors we fabricated were able to store around 2.2V when they are powered by a 5V DC power supply along with also being able to store that voltage for a decent amount of time. After characterizing our capacitors, we have concluded three things. Number one is that the supercapacitors are extremely similar to electrolytic capacitor. The second is that they primarily store voltage through dielectric absorption. And finally, our capacitors have a varying equivalent series resistance or ESR value.

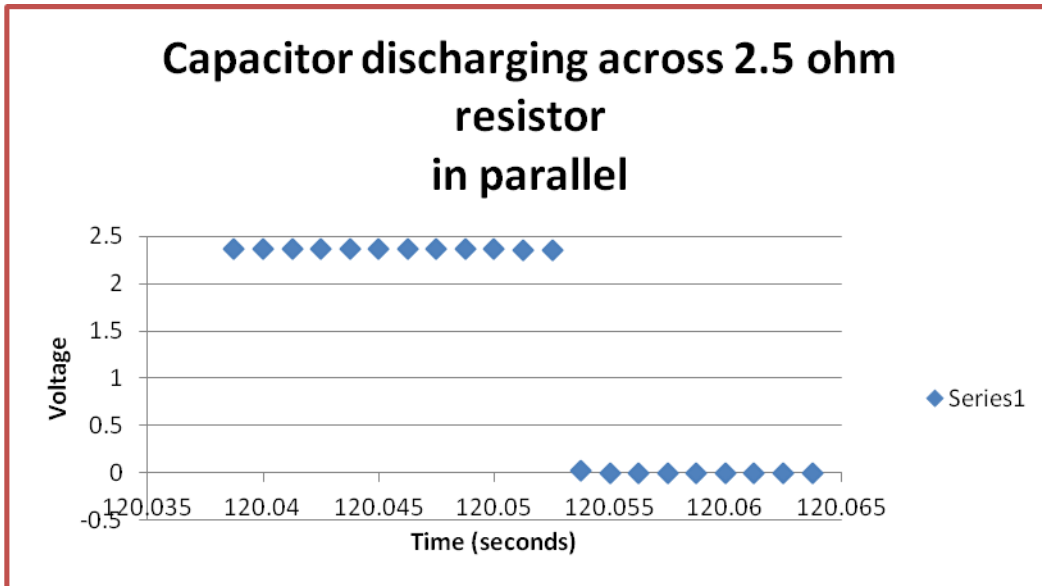


Figure 18 Capacitor Discharging Rate with resistor in parallel.

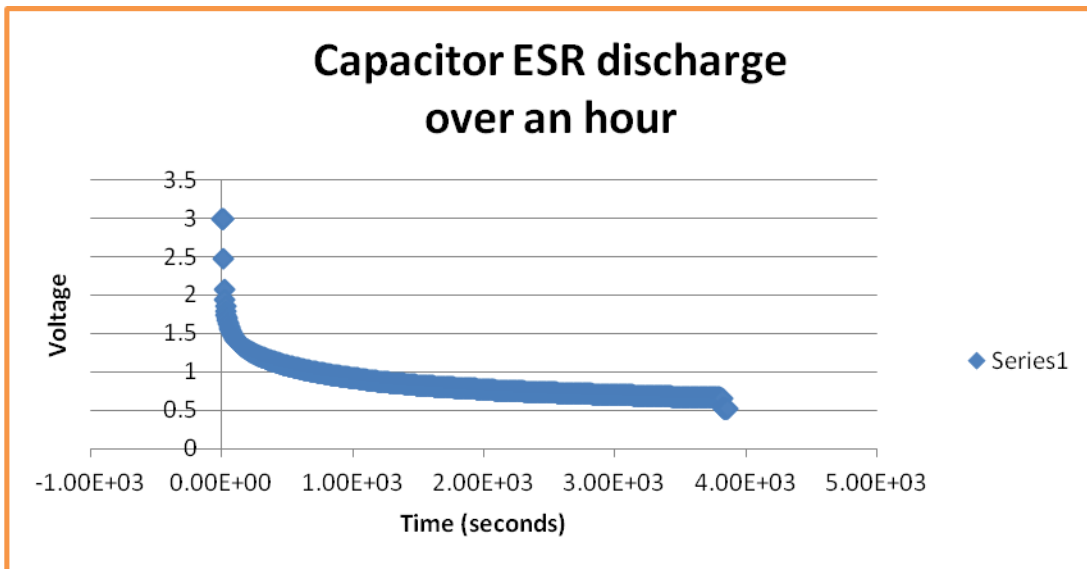


Figure 19 Capacitor Discharging Over Time.

In Figure 18 we were able to chart how a capacitor storing 2.5V can drive current through a 2.5 Ohm resistor and observe how quickly it can discharge. For Figure 19, we were able to plot how effective our capacitors were as stand-alone and packed energy devices. As in, we recorded and plotted its ability to store voltage for an extended period of time. The work we have accomplished so far has certainly brought us closer in completing our device. If we continue to work cohesively together, we are certain that our final project will work exceptionally well.

6. Ethical Considerations

We ensured all work done in the completion of our project followed the rules and standards set by the IEEE Code of Ethics. All appropriate credit and references were duly given to outside sources, professors, and anyone else that contributed to this project. All safety considerations were fully taken into account when handling dangerous equipment or chemicals. There were six rules that applied to our project; (1), (3), (5), (6), (8), and (10).

The IEEE Code of Ethics states that in rule 1 we should to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment. We are fully confident that we abided by every set of procedures and guidelines whenever we worked in the microelectronics laboratory or clean room.

Rule 3 says to be honest and realistic in stating claims or estimates based on available data. In conjunction with this rule we analyzed all of our obtained data and made the appropriately estimated how close we are to our goal.

Another important rule, number 5, states that we should aim to improve the understanding of technology; its appropriate application, and potential consequences. In keeping in line with rule 5, if our project succeeds we would be the first to ever make supercapacitor stacked in series together that can power a device.

Rule 6 says to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations. Again, we completely adhered to this rule by going through the correct steps and methods when working in the clean room or with certain lab equipment.

Rule 8 says to treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression. Needless to say, we treated each other with respect and had little if any difficulties working together in a group.

Finally, rule 10 states to assist colleagues and co-workers in their professional development and to support them in following this code of ethics. For this last rule, everybody in the group helped one another out when someone asked questions. We also helped other groups when they required our advice on a section of their project.

7. Conclusion

We have determined that supercapacitors fabricated through using the CNT “butter mix” and PVA electrolyte mixed with isopropyl gave us the most desirable results. The supercapacitor’s resistance was low enough that current was able to flow through it and provide sufficient power to the rest of the circuit. It stored enough voltage and was easily able to power an LED. As a result, we should able to obtain a quality IV graph of the supercapacitor and later on characterize it.

8. Future Work

Although, we managed to fabricate a stand-alone supercapacitor that could power a load, our product still has a few setbacks. The primary hurdle is that our capacitors run the risk of dehydrating, causing the dielectric membrane to become more rigid and less flexible. This traps the stored electrical energy within the capacitor itself and prevents the ions from leaving the CNT electrodes to travel throughout the circuit. To combat this, it is imperative the group stores the capacitor samples in a hydrated environment. This allows the electrolyte membrane to absorb moisture from its surroundings to increase its flexibility and the ability to release ions in a circuit. We also plan to mass-produce our capacitors and wire them together in parallel and connect them to an LED. Hopefully, several supercapacitors wired together in parallel will produce more current and power the LED for a longer amount of time. Another goal is designing the capacitors with a higher energy density and along with packaging the supercapacitors as stand-alone energy devices. Hopefully, we will have a practical and fully packaged supercapacitor bank design to form a wearable energy scavenging suit.

9. References

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