Research Article

PAPER BATTERY-A PROMISING ENERGY SOLUTION FOR INDIA

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ABSTRACT

This paper gives a thorough insight on this relatively revolutionizing and satisfying solution of energy storage through Paper Batteries and provides an in-depth analysis of the same. A paper battery is a flexible, ultra-thin energy storage and production device formed by combining carbon nanotubes with a conventional sheet of cellulose-based paper. A paper battery can function both as a high-energy battery and super capacitor , combining two discrete components that are separate in traditional electronics . This combination allows the battery to provide both long-term steady power production as well as bursts of energy. Being Biodegradable, Light-weight and Non-toxic, flexible paper batteries have potential adaptability to power the next generation of electronics, medical devices and hybrid vehicles, allowing for radical new designs and medical technologies.

The paper is aimed at understanding & analyzing the properties and characteristics of Paper Batteries; to study its advantages, potential applications, limitations and disadvantages. This paper also aims at highlighting the construction and various methods of production of Paper Battery and look for alternative means of mass-production.

KEYWORDS: Carbon, Nanotubes , Cellulose , Paper Battery

1. INTRODUCTION

1.1 Need

The basic problems associated with the present Electro-Chemical batteries are: (1) Limited Life-Time: Primary batteries irreversibly (within limits of practicality) transform chemical energy to electrical energy. Secondary batteries can be recharged; that is, they can have their chemical reactions reversed by supplying electrical energy to the cell, restoring their original composition. But, Rechargeable batteries are still costlier than Primary Batteries in the markets of developing countries like India. (2) Leakage: If leakage occurs, either spontaneously or through accident, the chemicals released may be dangerous. For example, disposable batteries often use zinc "can" as both a reactant and as the container to hold the other reagents. If this kind of battery is run all the way down, or if it is recharged after running down too far, the reagents can emerge through the cardboard and plastic that forms the remainder of the container. The active chemical leakage can then damage the equipment that the batteries were inserted into. (3)Environmental Concerns: The widespread use of batteries has created many environmental concerns, such as toxic metal pollution. Metals such as Cadmium, Mercury, Lead, Lithium and Zinc have been identified as highly toxic metals**.** Also, batteries may be harmful or fatal if swallowed. Small button/disk batteries can be swallowed by young children. While in the digestive tract the battery's electrical discharge can burn the tissues and can be serious enough to lead to death.

Fig1. A Leaking Electrochemical Battery

The limitations of Fuel cells are: (1). Cost: Hydrogen-based fuel cells are still extremely costly for general consumer use. Their use is still restricted to rocket launch vehicles. Liquid Hydrogen and Hydrogen Peroxide are essential ingredients that make them costly. (2). Portability & Size: Fuel cells are still not portable in size, which makes it very difficult for use in electronic and medical gadgets.

The limitations of Solar Cells are**: (**1) Versatility: Solar cells can not be used under all situations, like Emergency Power-Backup, Emergency Energy Purge.(2) Adaptability: Solar cells can not be used in all battery-powered equipment. (3). Portability & Size: They are not at all portable or robust.

(4)Need of an Auxiliary back-up battery: The solar cells need an auxiliary back-up battery during failures.

1.2. Literature Review:

There has to be a compromise between the charge producing device (Battery) and a charge storing device(Capacitor). Batteries (whether primary or secondary) cannot possess indefinite recyclability. Same is the case with capacitors. So, if a balance be sought between them in such a way so as to utilize the properties of both, the results would be more rewarding. Owing to this fact and to the miraculous properties of the Carbon nanotubes, there has been a steady and progressive interest in the global scientific community aimed at its utilization in the production of Paper Batteries. Significant works have been carried out independently, notable among which are by Pushparaj et al.[2007] and Yi Cui et al.[2010] in the field of preparing the first prototypes.

Previous designs of flexible energy-storage devices have been based on separated thin-electrode and spacer layers, proving less-than-optimum in performance and handling because of the existence of multiple interfaces between the layers. Pushparaj et al. demonstrated the fabrication of ‘electrode-spacer-electrolyte’ integrated nanocomposite units to build a variety of thin flexible energy-storage devices. The robust integrated thin-film structure allows not only

good electrochemical performance but also the ability to function over large ranges of mechanical deformation, record temperatures and with a wide variety of electrolytes.

The attempt to integrate the components on to a single unit was revived by Yi Cui et al. with a much simpler and more promising approach. In this paper, they integrated all of the components of a Li-ion battery into a single sheet of paper with a simple lamination process. Although a paper-like membrane has been used as the separator for other energy storage systems including super capacitors, it was the first demonstration of the use of commercial paper in Li-ion batteries, where paper is used as both separator and mechanical support.

Another significant attempt to exploit the properties of Paper batteries was made by Dr. Mangilal Agrawal, Lousiana Tech University. Having done much work with biosensors and bio-capacitors, he successfully demonstrated how the relative proportion of CNT and Paper could be used to customize the voltage output of the Paper Battery. Since the field is so promising and potent, there has been a huge amount of work done over CNTs and Paper Batteries. However, the entire work in literature is neither lucidly arranged nor easily accessible. This paper is solely aimed at analyzing and accumulating the available works on Paper Batteries and then evaluating their properties, applications, advantages and disadvantages in depth. The paper also throws some light on the production methods of CNTs and on the work that is being carried out in Indian scenario.

2. PAPER BATTERIES-BASICS:

2.1 Definition

A paper battery is a flexible, ultra-thin energy storage and production device formed by combining carbon nanotubes with a conventional sheet of cellulose-based paper. A paper battery acts as both a high-energy battery and super capacitor, combining two discrete components that are separate in traditional electronics.

Paper Battery=

Paper (Cellulose) + Carbon Nanotubes

Cellulose is a complex organic substance found in paper and pulp; not digestible by humans. A Carbon NanoTubes (CNT) is a very tiny cylinder formed from a single sheet of carbon atoms rolled into a tiny cylinder. These are stronger than steel and more conducting than the best semiconductors. They can be Single-walled or Multi-walled.

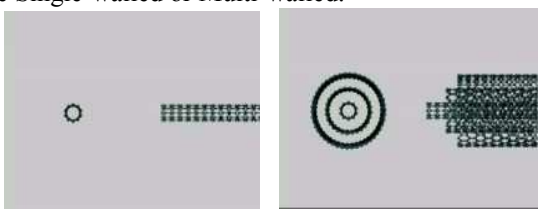

Fig2. Types of CNTs

2.2 Properties of Paper Batteries:

The properties of Paper Batteries are mainly attributed to the properties of its constituents.

2.2.1 Properties of Cellulose:

- High Tensile strength; Low Shear Strength
- Biodegradable
- Biocompatible
- Excellent Porosity & Absorption Capacity
- Easily Reusable and Recyclable
- Non –Toxic

2.2.2 Properties of Carbon Nanotubes:

- Ratio of Width: Length: $1:10^7$
- High tensile Strength (Greater than Steel).
- Low Mass density & High Packing Density.
- Very Light and Very Flexible.
- Very Good Electrical Conductivity (better than Silicon).
- Low resistance (~33 ohm per sq. inch).
- Output Open Circuit Voltage(O.C.V): 1.5-2.5 V (For a postage stamp sized Specimen)
- The O.C.V. of Paper Batteries is directly proportional to CNT concentration.
- Stacking the Paper and CNT layers multiplies the Output Voltage; Slicing the Paper and CNT layers divides the Output Voltage.
- Thickness: typically about 0.5-0.7mm.
- Nominal continuous current density: 0.1 mA/cm^2/ active area.
- Nominal capacity: 2.5 to 5 mAh/cm^2/ active area.
- Shelf life (RT): 3 years.
- Temperature operating range: -75°C to +150°C.
- No heavy metals (does not contain Hg, Pb, Cd, etc.)
- No safety events or over-heating in case of battery abuse or mechanical damage
- No safety limitations for shipment, packaging storage and disposal.

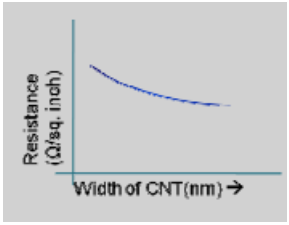

Fig3. Variation of Resistance with Width of CNT

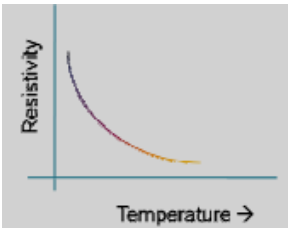

Fig4. Variation of Resistivity with Temperature

2.2.3 Additional Properties acquired by Paper Batteries:

- Output Open Circuit Voltage(O.C.V): 1.5-2.5 V (For a postage stamp sized specimen)
- The O.C.V. Of Paper Batteries is directly proportional to CNT concentration.

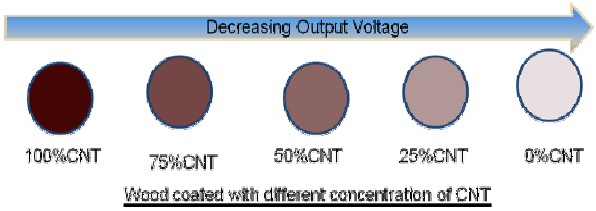

Fig 5. Variation of O.C.V with CNT Concentration

Stacking the Paper and CNT layers multiplies the Output Voltage.

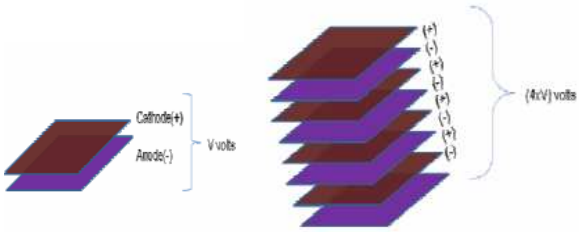

Fig6. Variation of O.C.V with stacking

Slicing the Paper and CNT layers divides the Output Voltage.

For length, l = V volts

For length,(l/2) =(V/2) volts

2.3 Construction and Working

A very brief and concise explanation has been provided.

- Cathode: Carbon Nanotube (CNT)
- Anode: Lithium metal (Li^+)
- Electrolyte: All electrolytes (incl. bio electrolytes like blood, sweat and urine)
- Separator: Paper (Cellulose)

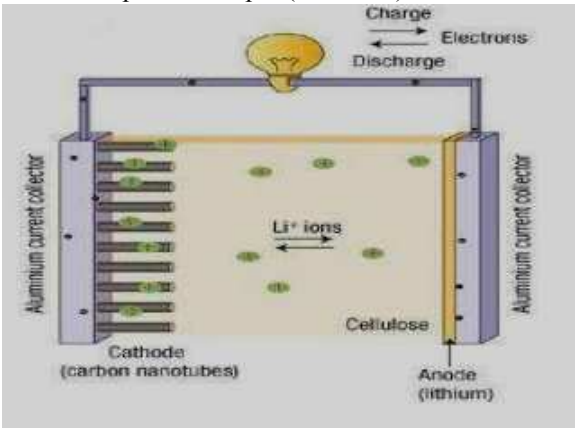

Fig7. Schematic of a Paper Battery

The **process** of construction can be understood in the following steps:

- Firstly, a common Xerox paper of desired shape and size is taken.
- Next, by conformal coating using a simple Mayer rod method, the specially formulated ink with suitable substrates (known as CNT ink henceforth) is spread over the paper sample.
- The strong capillary force in paper enables high contacting surface area between the paper and nanotubes after the solvent is absorbed and dried out in an oven.
- A thin lithium film is laminated over the exposed cellulose surface which completes our paper battery. This paper battery is then connected to the aluminum current collectors which connect it to the external load.
- The working of a paper battery is similar to an electrochemical battery except with the constructional differences mentioned before the procedure.

3. ADVANTAGES OVER EXISTING BATTERIES:

1. Biodegradable & Non Toxic: Since its major ingredients are of organic origin, it is a biodegradable and non toxic product.
2. Biocompatible: They are not easily rejected by our body's immune system if implanted into human body.
3. Easily Reusable & Recyclable: Being cellulose based product it is easily recyclable and reusable, even with the existing paper recycling techniques.
4. Durable: It has a shelf life of three years (at room temperature). Under extreme conditions it can operate within -75° to +150°C.
5. Rechargeable: It can be recharged upto 300 times using almost all electrolytes, including bio-salts such as sweat, urine and blood.
6. No Leakage & Overheating: Owing to low resistance**,** it does not get overheated even under extreme conditions. Since there are no leaky fluids**,** so even under spontaneous or accidental damage, there is no leakage problem.
7. Very Light Weight & Flexible.
8. Easily Moldable Into Desired Shapes & Sizes.
9. Customizable Output Voltage:
   - By varying CNT concentration.
   - By stacking & slicing.

4. APPLICATIONS

With the developing technologies and reducing cost of CNTs, the paper batteries will find applications in the following fields:

1. In Electronics:

- in laptop batteries, mobile phones, handheld digital cameras: The weight of these devices can be significantly reduced by replacing the alkaline batteries with light-weight Paper Batteries, without compromising with the power requirement. Moreover, the electrical hazards related to recharging will be greatly reduced.
- in calculators, wrist watch and other low drain devices.
- in wireless communication devices like speakers, mouse, keyboard ,Bluetooth headsets etc.
- in Enhanced Printed Circuit Board(PCB) wherein both the sides of the PCB can be used: one for the circuit and the other side (containing the components)would contain a layer of customized Paper Battery. This would eliminate heavy step-down transformers and the need of separate power supply unit for most electronic circuits.

2. In Medical Sciences:

- in Pacemakers for the heart
- in Artificial tissues (using Carbon nanotubes)
- in Cosmetics, Drug-delivery systems
- in Biosensors, such as Glucose meters, Sugar meters, etc.

3. In Automobiles and Aircrafts:

- in Hybrid Car batteries
- in Long Air Flights reducing Refueling
- for Light weight guided missiles
- for powering electronic devices in Satellite programs

4. PAPER BATTERY:INDIAN SCENARIO

Unfortunately, not much work has been carried out India, except for a few notable ones.The work is carried out as a joint research project of the Kalasalingam University in Krishnankovil, India; the Indian Institute of Technology ,Mumbai; and IMRAM Tohoku University in Japan, assisted by India's Department of Science and Technology. Kalasalingam University's G. Hirankumar brought optimized cathode materials (CNT) to Tohoku University's laboratories for three months of joint development.

Research is ongoing.

5. LIMTATIONS & DISADVANTAGES OF PAPER BATTERIES:

It would not be logical only to ponder over the miraculous properties and applications of Paper Batteries .Things need to be discussed at the flip side as well. Following are some of them:

- Have Low Shear strength**:** They can be 'torn' easily.
- The Techniques and the Set-ups used in the production of Carbon Nanotubes are very Expensive and very less Efficient. These are:
  (i)Arc discharge
  (ii)Chemical Vapour Deposition (CVD)
  (iii) Laser Ablation
  (iv)Electrolysis
- When inhaled, their interaction with the Microphages present in the lungs is similar to that with Asbestos fibers, hence may be seriously hazardous to human health.

Table1: Comparison of Different methods for producing CNTs

Method	Arc Discharge	CVD	Laser Ablation	Electrolysis
Starting Material	Graphite Electrodes	Hydrocarbon & Metal catalyst	Graphite	Graphite Electrodes
Number of Walls	Multi-walled	Single-walled	Single-walled	Only Multi-walled
Side Products	Produced	None	None	Produced
Production Efficiency	Low	Higher	Very High	Low
Cost	Low	Higher	Highest	Low

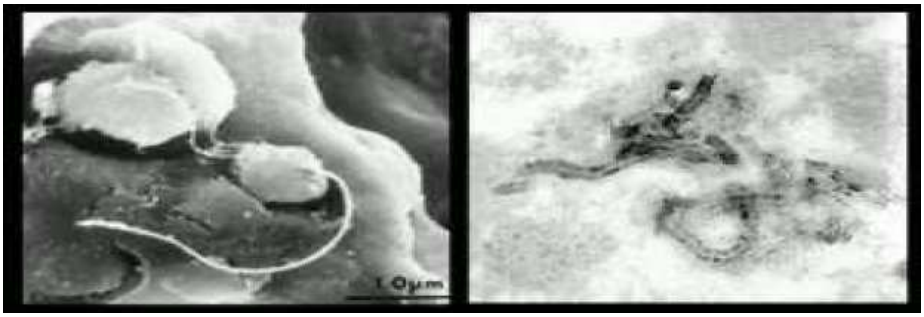

Fig 8. Similarity between the shape of Asbestos fibers (left) & CNTs(right)
Source: 'Museum of Life and Science'

6. RESULTS AND CONCLUSION

One of the major problems bugging the world now is Energy crisis. Every nation needs energy and everyone needs power. And this problem which disturbs the developed countries perturbs the developing countries like India to a much greater extent. Standing at a point in the present where there can't be a day without power, Paper Batteries can provide an altogether path-breaking solution to the same. Being Biodegradable, Light-weight and Non-toxic, flexible paper batteries have potential adaptability to power the next generation of electronics, medical devices and hybrid vehicles, allowing for radical new designs and medical technologies. But India still has got a long way to go if it has to be self-dependant for its energy solution. Literature reflects that Indian researchers have got the scientific astuteness needed for such revolutionary work. But what hinders their path is the lack of facilities and funding. Of course, the horizon of inquisitiveness is indefinitely vast and this paper is just a single step towards this direction.

REFERENCES:

- Pushparaj V. L, Manikoth S. M., Kumar A., Murugesan S., Ci L., Vajtai R., Linhardt R. J., Nalamasu O., Ajayan P. M.."Flexible Nanocomposite Thin Film Energy Storage Devices". Proceedings of the National Academy of Science USA 104, 13574-13577, 2007.. Retrieved 2010-08-08.
- Hu, L. C., J.; Yang, Y.; La Mantia, F.; Jeong, S.; Cui, Y. Highly Conductive Paper for Energy Storage. *Proc. Natl. Acad. Sci.U.S.A.* 2009, *106*, 21490–21494.
- "Beyond Batteries: Storing Power in a Sheet of Paper". RPI. August 13, 2007. Retrieved 2008-01-15.
- "Paper battery offers future power". BBC News. August 14, 2007. Retrieved 2008-01-15
- Katherine Noyes. "Nanotubes Power Paper-Thin Battery". *TechNewsWorld*. Retrieved 2010-10
- Ng, S. H. W., J.; Guo, Z. P.; Chen, J.; Wang, G. X.; Liu, H. K. Single Wall Carbon Nanotube Paper as Anode for Lithium-Ion Battery. *Electrochim. Acta* 2005, *51*, 23–28.
- Hu, L.; Hecht, D.; Gru¨ ner, G. Carbon Nanotube Thin Films: Fabrications, Properties, and Applications. *Chem. Rev.*2010, doi: 10.1021/cr9002962.