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LIST OF ABBREVIATIONS

1. NiCd - Nickel cadmium
2. NiMH - Nickel – Metal Hydride
3. SLI - Starting, Lighting, Ignition
4. RFID - Radio Frequency Identification
5. RH - Relative Humidity
6. RT - Room Temperature
7. CVD - Chemical Vapour Deposition
8. DNA - Deoxyribonucleic acid

CHAPTER 1

INTRODUCTION TO ORDINARY BATTERY

An electric battery is a device consisting of one or more electrochemical cells that convert stored chemical energy into electrical energy. Each cell contains a positive terminal, or cathode, and a negative terminal, or anode. Electrolytes allow ions to move between the electrodes and terminals, which allows current to flow out of the battery to perform work. Figure 1.1 shows the structure of a typical battery.

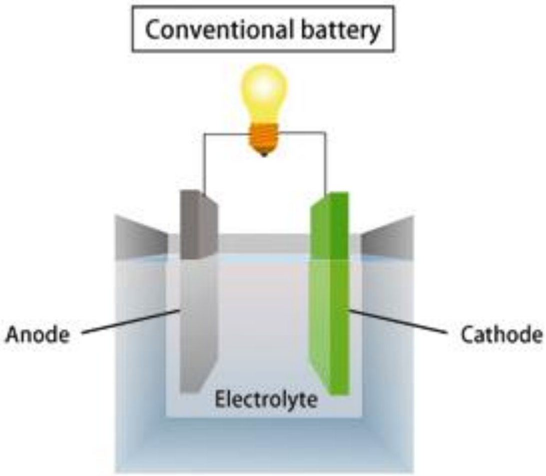

Figure 1.1 Typical battery structure [1]

Batteries convert chemical energy directly to electrical energy. A battery consists of some number of voltaic cells. Each cell consists of connected in series by a conductive electrolyte containing anions and cations. One half-cell includes electrolyte and the negative electrode, the electrode to which anions (negatively charged ions) migrate; the other half-cell includes electrolyte and the positive electrode to which cations (positively charged ions) migrate. Redox reactions power the battery. Cations are reduced (electrons are added) at the cathode during charging, while anions are oxidized (electrons are removed) at the anode during discharge.

Primary (single-use or "disposable") batteries are used once and discarded; the electrode materials are irreversibly changed during discharge. Common examples are the alkaline battery used for flashlights and a multitude of portable devices. Secondary (rechargeable batteries) can be discharged and recharged multiple times; the original composition of the electrodes can be restored by reverse current. Examples include the lead-acid batteries used in vehicles and lithium ion batteries used for portable electronics. Batteries come in many shapes and sizes, from miniature cells used to power hearing aids and wristwatches to battery banks the size of rooms that provide standby power for telephone exchanges and computer data centers.

Disposable batteries typically lose *8* to *20* percent of their original charge per year when stored at room temperature (*20°–30 °C*). This is known as the "self-discharge" rate, and is due to non- current-producing "side" chemical reactions that occur within the cell even when no load is applied. The rate of side reactions is reduced for batteries are stored at lower temperatures, although some can be damaged by freezing.

The disadvantages of regular batteries are

• Internal parts may corrode and fail, or the active materials may be slowly converted to inactive forms.

• The active material on the battery plates change chemical composition on each charge and discharge cycle, active material may be lost due to physical changes of volume; further limiting the number of times the battery can be recharged.

• Fast charging increases component changes, shortening battery life-span.

• If a charger cannot detect when the battery is fully charged then overcharging is likely, damaging it.

• NiCd cells, if used in a particular repetitive manner, may show a decrease in capacity called "memory effect". The effect can be avoided with simple practices. NiMH cells, although similar in chemistry, suffer less from memory effect.

• Automotive lead–acid rechargeable batteries must endure stress due to vibration, shock, and temperature range. Because of these stresses and sulfation of their lead plates, few automotive batteries last beyond six years of regular use. Automotive starting (SLI: Starting, Lighting, Ignition) batteries have many thin plates to maximize current. In general, the thicker the plates the longer the life. They are typically discharged only slightly before recharge.

• Battery life can be extended by storing the batteries at a low temperature, as in a refrigerator or freezer, which slows the side reactions. Such storage can extend the life of alkaline batteries by about *5%*; rechargeable batteries can hold their charge much longer, depending upon type. To reach their maximum voltage, batteries must be returned to room temperature; discharging an alkaline battery at *250 mA* at *0 °C* is only half as efficient as at *20 °C*. Alkaline battery manufacturers such as Duracell do not recommend refrigerating batteries.

• When a battery is recharged at an excessive rate, an explosive gas mixture of hydrogen and oxygen may be produced faster than it can escape from within the battery, leading to pressure build-up and eventual bursting of the battery case. In extreme cases, battery acid may spray violently from the casing and cause injury. Overcharging—that is, attempting to charge a battery beyond its electrical capacity—can also lead to a battery explosion, in addition to leakage or irreversible damage. It may also cause damage to the charger or device in which the overcharged battery is later used. In addition, disposing of a battery via incineration may cause an explosion as steam builds up within the sealed case.

CHAPTER 2

INTRODUCTION TO PAPER BATTERY

A paper battery is an ultra-thin, flexible energy storage device that is used as a battery and also as a good capacitor. It is created by combining two things: nano composite paper and nanotubes (nano composite paper made from cellulose and nanotubes made from carbon). Nanocomposite paper is a hybrid energy storage device made of cellulose, which combines the features of super capacitors and batteries. It takes the high-energy storage capacity of the battery and high-energy density of the super capacitor producing the bursts of extreme power. This combination allows the battery to provide long-term steady power production. Non-toxic, flexible paper batteries have the potential to power the next generation of electronics, medical devices and hybrid vehicles, allowing for radical new designs and medical technologies. A sample of paper battery is shown in Figure 2.1 .

Figure 2.1 A sample paper battery [2]

A carbon nanotube material is a cylinder shaped material, made of carbon. These tubes have different structures that differ in thickness, length, type and number of layers. Carbon nanotubes are characterized into different types based on their structure. They are single walled carbon nanotube, double-walled carbon nanotube, triple-walled carbon nanotube and multi-wall carbon nanotube. Structural view of single walled carbon nanotube is shown in Figure 2.2 .

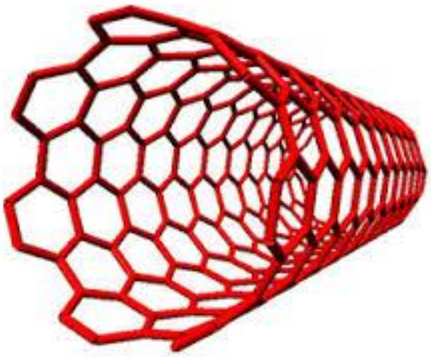

Figure 2.2 Structural view of carbon nanotube [3]

Paper batteries may be folded, cut or otherwise shaped for different applications without any loss of integrity or efficiency. Cutting one in half halves its energy production. Stacking them multiplies power output. Early prototypes of the device are able to produce *2.5 volts* of electricity from a sample the size of a postage stamp. The devices are formed by combining cellulose with an infusion of aligned carbon nanotubes that are each approximately one millionth of a centimeter thick. The carbon is what gives the batteries their black color. These tiny filaments act like the electrodes found in a traditional battery, conducting electricity when the paper comes into contact with an ionic liquid solution. Ionic liquids contain no water, which means that there is nothing to freeze or evaporate in extreme environmental conditions. As a result, paper batteries can function between -*75* and *150 °C*.

CHAPTER 3

MANUFACTURING OF PAPER BATTERY

One method of manufacturing begins with growing the nano tubes on a silicon substrate and then impregnating the gaps in the matrix with cellulose. Once the matrix has dried, the material can be peeled off of the substrate, exposing one end of the carbon nano tubes to act as an electrode.

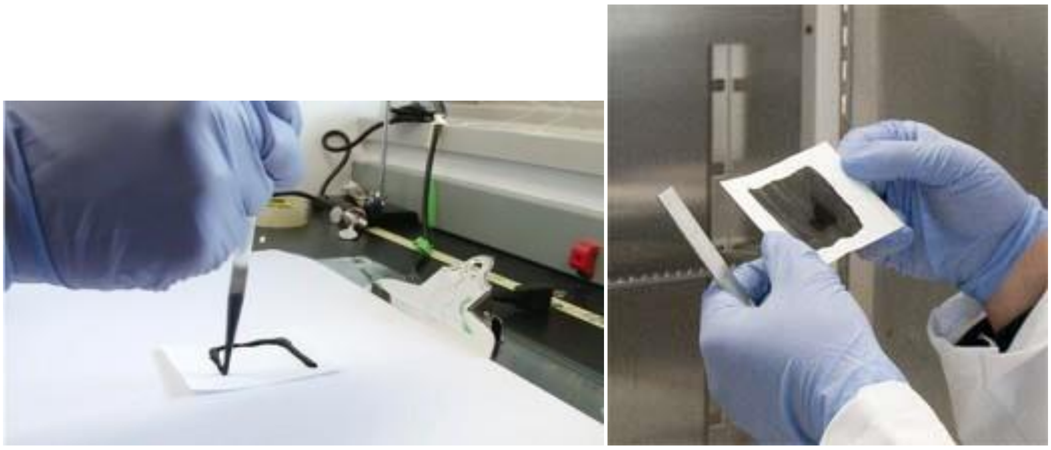

Figure 3.1 Imposing carbon ink on paper [4]

When two sheets are combined, with the cellulose sides facing inwards, a super capacitor is formed that can be activated by the addition of the ionic liquid. This liquid acts as an electrolyte and may include salt-laden solutions like human blood, sweat or urine. The high cellulose content (over *90%*) and lack of toxic chemicals in paper batteries makes the device both biocompatible and environmentally friendly, especially when compared to the traditional lithium ion battery used in many present-day electronic devices and laptops. Specialized paper batteries could act as power sources for any number of devices implanted in humans and animals, including RFID tags, cosmetics, drug-delivery systems and pacemakers. A capacitor introduced into an organism could be implanted fully dry and then be gradually exposed to bodily fluids over time to generate voltage. Paper batteries are also biodegradable, a need only partially addressed by current e-cycling and other electronics disposal methods increasingly advocated for by the green computing movement.

3.1 Development

The creation of this unique nano composite paper drew from a diverse pool of disciplines, requiring expertise in materials science, energy storage, and chemistry. The researchers used ionic liquid, essentially a liquid salt, as the battery's electrolyte. The use of ionic liquid, which contains no water, means there's nothing in the batteries to freeze or evaporate. This lack of water allows the paper energy storage devices to withstand extreme temperatures. It gives the battery the ability to function in temperatures up to *300 °F* and down to *100* below zero. The use of ionic liquid also makes the battery extremely biocompatible; the team printed paper batteries without adding any electrolytes, and demonstrated that naturally occurring electrolytes in human sweat, blood, and urine can be used to activate the battery device.

Cellulose-based paper is a natural abundant material, biodegradable, light, and recyclable with a well-known consolidated manufacturing process. These attributes turn paper a quite interesting material to produce very cheap disposable electronic devices with the great advantage of being environmental friendly. The recent revolution of thin-film electronic devices such as paper transistors, transparent thin-film transistors based on semiconductor oxides, paper memory open the possibility to produce low cost disposable electronics in large scale. Common to all these advances is the use of cellulose fiber-based paper as an active material in opposition to other ink- jet printed active-matrix display and thin-film transistors reports where paper acts only as a passive element (substrate). Batteries in which a paper matrix is incorporated with carbon nanotubes, or biofluid - and water-activated batteries with a filter paper have been reported, but it is not known a work where the paper itself is the core of the device performance.

With the present work, it is expected to contribute to the first step of an incoming disruptive concept related to the production of self-sustained paper electronic systems where the power supply is integrated in the electronic circuits to fabricate fully self-sustained disposable, flexible, low cost and low electrical consumption systems such as tags, games or displays. In achieving such goal we have fabricated batteries using commercial paper as electrolyte and physical support of thin film electrodes. A thin film layer of a metal or metal oxide is deposited in one side of a commercial paper sheet while in the opposite face a metal or metal oxide with opposite *12* electrochemical potential is also deposited. On the other hand, the short current density is highly dependent on the relative humidity (RH), whose presence is important to recharge the battery. The set of batteries characterized show stable performance after being tested by more than *115 hours*, under standard atmospheric conditions room temperature, RT (*25° C*) and *60%* air humidity.

CHAPTER 4
WORKING OF PAPER BATTERY

A conventional battery or Rechargeable battery contains a number of separate components that produce electrons through a chemical reaction between the metal and the electrolyte of the battery. The Paper battery works when the paper is dipped in the ion-based liquid solution; next a chemical reaction occurs between the electrodes and liquid. The electrons move from the cathode to anode to generate electricity. The paper electrode stores energy while recharging within *10 seconds* because the ions flow through the thin electrode quickly. Figure 4.1 shows the working of a paper battery. The best method to increase the output of the battery is to stack different paper batteries one over the other.

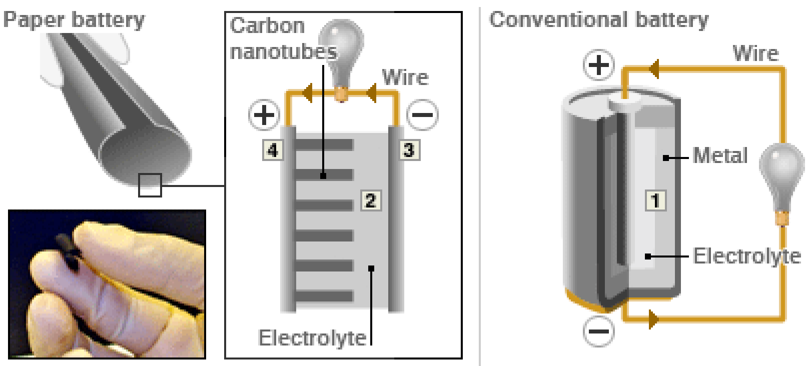

Figure 4.1 Paper battery working [4]

CHAPTER 5
APPLICATIONS OF PAPER BATTERY

The paper battery has many applications ranging from greeting cards to medical devices , its flexibility and paper thin thickness allow it to be utilized in a wide array of products. Additionally, its biocompatibility allows for potential use in medical products and artificial organs. Moreover, stacking sheets of paper batteries could increase the overall power and lead to potential applications in larger electronics.

5.1 MEDICAL

It is used to power artificial cardiac pacemakers which are implanted in a patient's heart. A pacemaker (or artificial pacemaker, so as not to be confused with the heart's natural pacemaker) is a medical device that uses electrical impulses, delivered by electrodes contracting the heart muscles, to regulate the beating of the heart. The primary purpose of a pacemaker is to maintain an adequate heart rate, either because the heart's natural pacemaker is not fast enough, or there is a block in the heart's electrical conduction system.

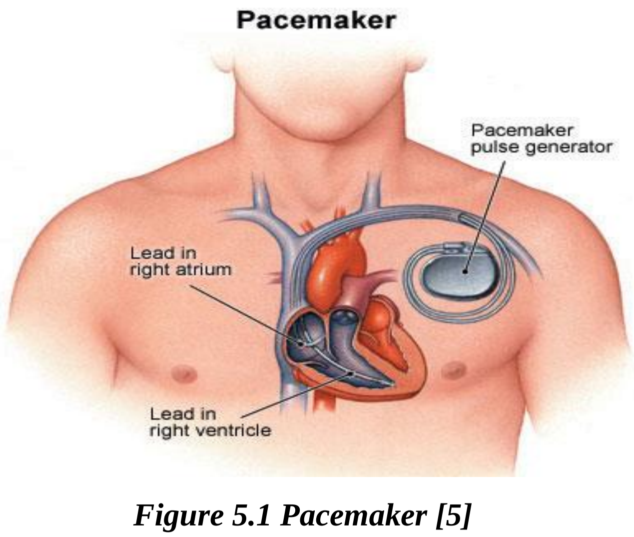

Figure 5.1 Pacemaker [5]

5.2 COSMETICS

It is used for the following cosmetic purposes :

- Anti-aging and wrinkles
- Dark spots / Discoloration
- Skin lightening / Whitening
- Firming and lifting
- Moisturizing

For the above mentioned therapies, the basic mechanism involved is iontophoresis. Iontophoresis is a physical process in which ions flow diffusively in a medium driven by an applied electric field. Iontophoresis is to be distinguished from the carriage of uncharged molecules by diffusive fluxes of other molecules, especially of solvent molecules, for example by electro- osmosis, that is to say by flux of uncharged solvent molecules carried as a cross-effect of iontophoresis. These phenomena, directly and indirectly, constitute active transport of matter due to an applied electric field.

5.3 ELECTRONICS

Paper batteries are used mainly in many electronic devices, such as mobile phones, laptop batteries, calculators, digital cameras and also in wireless communication devices like mouse, Bluetooth, keyboard, speakers and headsets thereby removing the conventional bulky batteries leading to improved design and efficient production.

One important application of the paper battery is its use in powering radio frequency identification devices or RFID . In the past, RFID tags have been used to keep track of cattle and live-stock . However, paper batteries could allow companies to place RFID tags and smart labels on almost all products. For instance, in a grocery store using these RFID tags, the shopping cart could automatically process which items are placed in the cart, charge the customer's credit card and keep track of the store's inventories . Although many supermarkets do not have this technology in store now, with the help of the paper battery to power these RFID tags and labels, this sort of technology could appear in the near future. RFID electronics also appear in road toll collection, animal tracking, passports and airline baggage management; all these potential uses could benefit by having a more powerful and light weight battery, allowing for a longer lasting tag and better data storage.

5.4 MEDIA AND ADVERTISING

Besides tracking devices, paper batteries could also play a large role in media and advertising. For instance a paper battery has enough power to light a small light emitting diode. Therefore, paper batteries could be used in greeting cards to power electronic displays or lights embedded in the card, they could also power any sort of audio device that would play a song or recording upon opening of the card. Other potential applications include using paper batteries to power electronic displays on packaging for items such as cereal boxes. The lightweight and compactness of a paper battery would allow the device to be easily fit into the cardboard design of a cereal box and display videos and play music, attracting more attention, and thus providing better advertising.

5.5 LARGE SCALE ELECTRONICS

Although the compactness of the paper battery is one of its major benefits, the paper battery is not limited to small devices, it has many potential applications in larger devices such as cars, laptops and wind farms. Because the paper battery has the ability to be recharged, it could be used in a typical car battery. By integrating the paper battery into the design of a traditional battery, it is possible to decrease the weight of the battery by up to twenty percent.This would be especially relevant for electric and hybrid cars, since a reduction in weight could potentially increase efficiency. It has also been suggested that the paper battery could power car doors since the paper battery can be formed to fit the curved shape of a vehicle. Additionally, the paper batteries light weight could make them ideal for use in automobiles, aircraft, and even boats. By stacking large sheets of paper batteries on top of each other, it would be possible to increase the voltage and increase the power, thus making the paper battery capable of providing energy for larger machines. Furthermore this pile of paper batteries could also inexpensively help solar and wind farms store what energy they generate. For instance, the flexibility of the paper battery could allow it to be used in solar panels of varying shapes and its ability endure numerous recharge cycles would make it an ideal device to capture the energy from solar power or wind power.

5.6 AUTOMOBILES AND AIRCRAFTS

Paper batteries are used in automobiles and aircraft such as in light weight guided missiles, hybrid car batteries, long air flights reducing refuelling and in satellite programs for powering electronic devices.

CHAPTER 6
ADVANTAGES OF PAPER BATTERY

Paper battery is a rechargeable battery that has carbon nanotubes spread over a sheet of cellulose that primarily makes the paper we write on. As the substrate is made of paper which has *90%* cellulose , the battery is completely bio-degradable and biocompatible. There are no traces of mercury , lead , cadmium or any other heavy metals required to keep the device working. So, while disposal of the battery , there won't be any general concerns that exist usually with the conventional batteries.

Unlike lithium-ion batteries which are bulky , these are light and can be delved into any shape as per the size of our device. They offer solution to the problem of risk of explosion and that of corrosion involved while dealing with the batteries used these days. They can be stacked to increase the potential drop across them by still being of same size. Apart from being serving as a power device alone, they can be used as supercapacitors that produce high energy if they are discharged at once without any explosion or harm.

Paper batteries are way better than conventional batteries not only because of the above stated uniqueness they own , but because of the dynamic operation range they withstand. It has no trace of water into its electrolyte, so nothing freezes or evaporates at extremities. The enlarged surface area helps in efficient heat dissipation, thus ensuring the battery doesn't cease to work due to overuse. No wonder that owing to its size and bio-degradability , it is a perfect choice for powering device in pacemakers buried close to the heart. They can take human blood , urine or sweat as electrolyte which makes their use highly lucrative for human health.

CHAPTER 7

LIMITATIONS OF PAPER BATTERY

Before encouraging the widespread use of a new technology, one must always consider the possible ethical concerns surrounding that technology. Some of the major issues regarding paper batteries are the following:

- The Techniques and the Set-ups used in the production of carbon nanotubes are very expensive and very less efficient.

- Nanotoxicology studies have shown that the surfaces of certain nanoparticles have many sharp points, much like asbestos. These sharp points make it difficult for macrophages, or immune cells, to clear foreign particles from the body. Moreover, as the size of these particles decreases, the surface area increases, allowing for better transport across cell barriers and increased ability to react with important cell structures, such as microtubules and DNA. As a result, nanoparticles can have potential harmful health effects, especially if they are inhaled into the lungs. Although direct exposure with nanoparticles or fibers is unlikely in many of these applications, as it will be stored away in part of the electronic, it is important to consider any possible damage to the electronic that would perhaps break the case and expose the nanoparticles to air and the user. More importantly, any adverse health effects create occupational hazards for those manufacturing the paper batteries.

- Batteries with large enough power are unlikely to be cost effective.

- Additionally, the carbon nanotubes could potentially end up in the environment, as paper batteries from smart cards and used temperature monitors are disposed, causing damage to the soil and plants. Ecological studies have shown that the exposure of nanoparticles to largemouth bass fish resulted in lipid damage in the brain. Also, other studies have demonstrated an up regulation of immune system and tissue repair proteins in fish exposed to nanoparticles. Because nanoparticles have been found to have these negative effects on animals in the environment, the use of nanotechnology also raises environmental concerns.

- Theses batteries generate e-wastage, by replacing all the existing batteries with paper battery.

- Since cellulose has low shear strength and can be torn easily.

CHAPTER 8
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 Nontoxic, 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.

In this seminar the functionality of a non-encapsulated thin-film battery using paper as electrolyte and also as physical support is shown. The battery is self-rechargeable when exposed to relative humidity above *40%*. This constitutes the first step towards future fully integrated self- sustained flexible, cheap and disposable electronic devices, with great emphasis on the so-called paper electronics.

The intrinsic properties of paper, such as high solvent absorption and strong binding with nanomaterials, allow easy and scalable coating procedures. Taking advantage of the mature paper technology, low cost, light and high-performance energy-storage devices are realized by using conductive paper as current collectors and electrodes. The concept of using paper as a novel substrate together with solution-processed nanoscale materials could bring in new opportunities for advanced applications in energy storage and conversion. By combining our paper-based energy storage with other types of devices developed, such as bioassays or displays on paper, full paper electronics could be realized in the future.

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