Fabrication and Characterization of Carbon-Based Nanomaterial for Energy Storage Applications

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Abstract

Carbon nanomaterials are accepted to be proper and promising (when utilized as energy materials) to pad the danger of environmental change. They have exceptional chemical, mechanical, electrical and thermal properties. This not really settled to give an abstract of new advances towards their union, properties, and a energy storage applications are discussed. A single wall carbon nano tubes (SWCNT) based electrodes are prepared and then these electrodes are investigated for their performance as an electrode. The study is useful as it will lead to the pathway of the utilization of the SWCNT as energy storage material. The study at different scan rates confirmed that the SWCNT based electrodes are highly stable and offer a high charge storage capacity. Electrochemical study of these electrodes proves these to be a suitable candidate for energy storage applications.

Keywords: Carbon nano tube; Electrode; Electrochemical studies; Energy storage; Nanomaterial

1. Introduction

Today, electric energy use becomes significantly because of quickly expanding request in arising economies and in human existence. Be that as it may, the limited measures of normal assets, the significant expense of petroleum derivative and ecological mindfulness are driving endeavors to discover elective solutions to the world's energy needs. In the end, all sustainable energy frameworks should be founded on restricted utilization of petroleum products and more prominent utilization of environmentally friendly power. Then again, the creation of power is profoundly concentrated, and frequently happens a significant distance away from end buyers. This delocalized power creation and the trouble of settling the force network have caused stockpile request unevenness [1].

As needs be, create, communicate, convert and store energy in sensible and brilliant manner. For example, electrical energy storage (EES) is an efficient methodology at present a work in progress, and it empowers power to be created from irregular energy sources and be put away for use when it is required. Truth be told, the storage of electric energy has as of late become a need attributable to the rise of applications like hybrid electric vehicles and numerous different sorts of convenient electrical gadgets. The huge development of electric or hybrid electric vehicles has likewise advanced the pressing and expanding interest for cutting edge energy storage technologies [2-7]. Consequently, critical headway in empowering productive and sustainable energy use requires a pressing improvement of storage techniques to satisfy developing energy needs and to adjust supply and utilization while staying away from asset depletion and long haul harm to the climate.

Enormous scope research endeavors have been made in different locations all throughout the planet to foster an assortment of electrical energy storage gadgets. Subsequently, numerous potential methods have been presented for energy storage frameworks and gadgets, for example, flywheels [8], power devices [9], batteries [10, 11], electrochemical capacitors and customary capacitors [12, 13]. Among these gadgets, batteries, electrochemical capacitors (ECs, called electrochemical twofold layer capacitors, or ultra-capacitors) and traditional capacitors are the three principle electrochemical energy storage technologies because of their viable force/energy abilities, portability with light weight, high effectiveness and minimal expense. Each anyway offers various qualities and applications with intrinsic benefits, remembering for execution, cost and reliability. To more readily comprehend their disparities, a Ragone plot can be attracted to represent their individual exhibitions. The Ragone plot is regularly used to diagram a gadget's trademark power density (W/kg) corresponding to its energy density (Wh/kg) as displayed in Figure, the slanting lines exhibit the energy charge/discharge times.

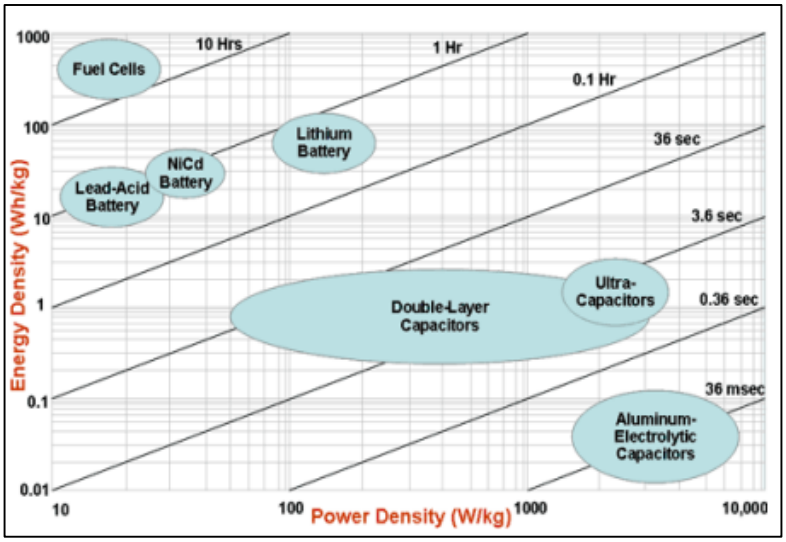

Fig. 1 Ragone plot for electrochemical energy storage devices: fuel cells, batteries, conventional capacitors and electrochemical capacitors [14]

SUPER CAPACITORES

Supercapacitors likewise called ultracapacitors and electric twofold layer capacitors (EDLC) are capacitors with capacitance esteems more prominent than some other capacitor type accessible today. Capacitance esteems coming to up to 800 Farads in a solitary standard case size are accessible. Supercapacitors have the most noteworthy capacitive density accessible today with densities so high that these capacitors can be utilized to applications regularly held for batteries. Supercapacitors are not as volumetrically productive and are more costly than batteries however they do enjoy other upper hands over batteries settling on the favored decision in applications requiring a lot of energy storage to be put away and conveyed in explodes repeatedly.

The main benefit supercapacitors have over batteries is their ability to be charged and released ceaselessly without debasing like batteries do. This is the reason batteries and supercapacitors are utilized related to one another. The supercapacitors will supply capacity to the framework when floods or energy blasts since are required. Supercapacitors can be charged and released rapidly while the batteries can supply the mass energy since they can store and convey bigger sum energy over a more drawn out slower timeframe [15].

HYBRID CAPACITORS

Hybrid capacitors arose as a clever answer for beat the limitations of EDLCs and pseudocapacitors, joining both previously mentioned charge storage instruments in a solitary gadget [16]. This can be cultivated using composite or hybrid materials formed by an EDLC-type and a pseudocapacitor-type part as electrodes, the alleged composite or symmetric hybrids. Hybrid capacitors can likewise be classifed as hilter kilter hybrids when two or three two electrodes with various storage components: in one of the electrodes, just an electrostatic cycle happens, while in the other electrode redox reactions or a blend of nonFaradaic and Faradaic measures happen. At long last, the third sort of hybrid capacitors is battery-type hybrid capacitors, where one of the electrodes is a material containing Li+ ions to empower Li+ intercalation/deintercalation likewise to battery instrument.

A comparison of the SWCNT and MWCNT is described below for a better understanding of these materials in Table 1.

Table 1: Properties of single walled and multi walled nanotubes

Property	SWCNT	MWCNT	Units
Specific gravity	0.8	<1.8	g/cm^3
Elastic-modulus	~1.4 x 10^3	~0.3–1 x 10^3	GPa
Resistivity	5–50 x 10^{-6}	5–50 x 10^{-6}	Ω cm
Thermal-conductivity	3000	3000	W/m-K
Magnetic susceptibility	22 × 10^6	22 × 10^6	EMU/g
Thermal stability	550–800 (air) 2800 (vacuum)	550–800°C (air) 2800 (vacuum)	°C
Mechanical Strength	50–500	10–60	GPa

2. Electrochemical capacitors, applications and challenges

Electrochemical capacitors are energy gadgets that store and delivery electric energy through nanoscopic particle detachment at the electrochemical interfaces between an electrode and 5 a fluid electrolyte [17, 18]. Lately, ECs have drawn in expanding

consideration, basically because of their high force density, long life-cycle and ability to connect the force/energy hole between batteries/power modules (which have high energy density) and customary capacitors (which have high force density) as depicted in Figure 1.1. In contrast with basic working systems, batteries and power devices produce their put away energy through chemical reactions, while ECs create by using electrostatic detachment between electrolyte ions and high-surface region electrodes [18, 19]. Not at all like batteries or power devices, are irrelevant chemical charge move reactions and stage changes associated with charging and releasing, so the charge-release interaction won't really be restricted by chemical energy in the electrode. Thus, the charging and releasing rates are a lot quicker than the electrochemical redox reactions inside batteries, ultimately prompting higher force density in ECs. They have been as of now displayed with an almost limitless cycle-ability, and with a high cycle productivity. In addition, ECs can not just capacity successfully at amazingly high and low temperatures (common working temperature goes from - 40 to 70 °C), yet additionally contain no dangerous or harmful materials, and their waste materials are handily discarded, contrasted with batteries.

Low energy density As examined previously, ECs experience the ill effects of restricted energy density (up to around 5 Wh/kg) contrasted with batteries (regularly 50 Wh/kg). For example, economically accessible ECs can give energy densities of just 3 - 4 Wh/kg, which restricts the utilization of ECs to a couple of moments, commonly inside the scope of 1 - 30 s.

High self-release (Internal resistance) Another test that should be met for ECs to satisfy their guarantee is in working on their inclination to self-release. In down to earth utilization of EC gadgets, there is a decrease in voltage on an open circuit because of an inside resistance. Self-release is characteristic for all electrochemical energy storage frameworks, including batteries and capacitors. Notwithstanding, it happens at higher rate for ECs since ECs have no component to thermodynamically and dynamically settle voltage not at all like batteries. Therefore, the voltage of ECs can be effortlessly upset by some depolarizing interaction from the inward resistance. This self-release trademark keeps an eye on more inconvenient in ECs than batteries, and prompts lower force and energy density. Subsequently, oneself release conduct of ECs is an unreliability factor in energy storage and should be addressed.

High cost The costs of crude materials keep on being significant difficulties for EC commercialization. The principle cost of an EC emerges from its electrode materials, and when EC utilize natural electrolytes, their cost is a long way from insignificant. Besides, the assembling cost is likewise controlled by fabrication strategies for genuine items. Along these lines, the improvement of assembling is needed to plan streamlined EC's design as well as versatile, cost-compelling fabrication techniques.

3. Synthesis and characterization methods

3.1 Electrode fabrication methods

For the plan of EC structures, the main EC part is the electrode. The advancement of EC electrodes has commonly started from endeavors to upgrade the design of the interface response between the electrodes and the electrolyte and to prompt somewhat minimal expense in fabrication techniques. Critical advancement concerning procedures for manufacturing nano-organized electrodes has been accomplished, which has extraordinarily worked on their rformance. Until this point in time, an assortment of techniques have been presented for manufacturing EC electrodes, including cast-covering, electro-affidavit [21, 22] and vacuum filtration [23, 24]. In the cast-covering procedure, electrodes are manufactured from directing particles of carbon powder (e.g., AC) alongside a fluorine-containing polymer (PTFE) restricting specialist, which are combined as one through a dissolvable to deliver a glue or slurry material. This strategy is now notable and is utilized in the creation of business ECs. A promising fabrication strategy for carbonbased electrodes is electrophoretic statement (EPD). Another strategy is vacuum filtration, which frames a slight film as an electrode.

3.2 Characterization techniques

Cyclic voltammetry (CV) is an electrochemical investigation method whereby the current of an electrochemical cell is plotted against its voltage at a decent greatness of pace of progress in the voltage (filtering rate). This strategy isn't just the typical method of estimating material capacitance but at the same time is the technique frequently utilized in the examination of faradaic reactions. In principle, an EDLC doesn't include a faradaic response. Practically speaking, be that as it may, EDLC conduct incorporates faradaic parts because of the redox response or the particle energy at the electrode/electrolyte interfaces, and CV can give understanding into these cycles. An unadulterated capacitor of steady capacitance has a rectangular CV plot; for instance, at voltages adequately high to start a redox response, the current expansions in a dramatic design. Similarly, the state of the voltammetry plot shows the intricacy of the electrochemical cycles at play in the EDLC [25, 26].

3.3 Fabrication and characterization of SWCNT electrodes

Attributable for its potential benefit of astounding electrical conductivity, striking chemical stability, enormous surface region and special structures, an assortment of carbon nanostructures including single walled (SWCNTs) and multi-walled carbon nanotubes (MWCNTs) have drawn a lot of consideration [27, 28]. In the mean time, to manufacture high-execution CNT electrodes with more open pores, much exploration exertion has been resolved to create CNT based electrodes with consistently appropriated and better open pore structures [29-31]. It has gotten truly fundamental to foster a fitting preparing innovation which can cover CNTs with right underlying calculations (e.g., huge surface region, uniform pores) and appropriate for large scale manufacturing. With these considerations, one of promising fabrication strategies for creating CNT covered electrode is the electrophoretic statement (EPD) strategy, which is powerful to control porosity, surface region and density of permeable movies [32].

4. Experimental work

4.1 Synthesis of carbon nano tubes

The SWCNT powder utilized in this work was provided by Nano-C Inc. with a virtue of 97%. The as-gotten tests were first corrosive functionalized utilizing a combination of nitric (HNO3) and sulphuric (H_2SO4) acids with a proportion of 3:1 (Sigma-Aldrich). 10 mL of this combination was then added to 250 mg of the SWCNT powder and saved for 30 minutes to finish the carboxyl functionalization measure [33]. During this interaction the – COOH useful gatherings were added to the imperfections and end locales of SWCNTs. This contrarily spellbinds the SWCNTs and permits them to scatter well in unadulterated water without the utilization of extra surfactants [34].

The utilization of surfactants has been shown contrarily influence the exhibition of CNT electrodes because of the remaining parts of surfactants on the CNT's surface. After the functionalization the blend was weakened with de-ionized water and washed through a channel to eliminate the remaining acidic arrangement from SWCNTs. This cycle was rehashed until the separated SWCNT arrived at a pH of 7, then, at that point more de-ionized water was added and a fluid suspension was created with a grouping of around 0.5 mg SWCNTs/ml H2O.

4.2 Adjustment of pH value

To shift pH upsides of the determined SWCNT suspension, the pH esteem was changed by adding 1M sodium hydroxide (NaOH) or nitric corrosive arrangement (HCl) at room temperature (22 °C). These suspensions were then positioned in a Branson 5210 Ultrasonic cleaner for 6 hours. At last the suspensions were centrifuged at 4000 rpm for 15 minutes to eliminate bothersome particles and agglomerated SWCNT groups. In each progression of the filtration, centrifugation and decantation, the pH esteem was firmly observed utilizing a PHH-830 meter and re-changed if fundamental. Finally, three suspensions with the pH upsides of 4, 7 and 10, separately, were ready and utilized in the EPD processing

Fig. 2 Functionalization processing for SWCNTs

4.3 Electrochemical study

To start with a all the calculations for the weight were done. 5 mg of carbon was mixed to 100 ml of Dimethylformamide. This mixture was then added with a bnder N-methyl-2-pyrolidone (NMP). This solution was then fed to a ultrasonicator for 1 h to achieve a uniform and homogeneous mixture. After the sonication, the solution was coated on a thin graphite sheet and the electrodes were prepared.

5 Results and discussions

5.1 Influence of pH Values of the Suspension to EPD

Each of the three suspensions were ready from a similar example with the convergence of 0.5 mg SWCNTs per 1 ml of water. Then, at that point an additional measure of NaOH or HCI was included request to arrive at various pH esteems in the suspension. It was normal that the higher pH esteem delivered all the more contrarily charged SWCNTs in the suspension, and subsequently SWCNTs are scattered homogenously in higher pH conditions. At long last these examples were handled utilizing the ultrasonic cleaner and bigger agglomerates were sifted through. This example readiness method brought about various appearances and concentrations of SWCNTs in three suspensions. As a rule, the suspension with a lower pH esteem (like pH = 4) contains less charged individual cylinders and more nanotube agglomerates, and the absolute amount of CNTs in this suspension is little.

Interestingly, the suspension with a higher pH esteem (e.g., pH = 10) contains not so much agglomerates but rather more individual nanotubes inferable from higher surface charges (Zeta potential) in concurrence with the past examinations [35, 36], uncovers the higher pH esteems work with the better scattering of SWCNTs, which can be credited to a simpler ionization of the carboxylic (COOH) bunch in these suspensions with huge pH esteems. At the point when the pH esteem is expanded by adding hydroxide (OH-), the more carboxylate (- COO-) bunches were acquired on a superficial level, the heavier charging of individual cylinders was accomplished, which prompted the more powerful scattering of SWCNTs. Thus in the wake of sifting, the higher pH suspension has the more noteworthy grouping of scattered SWCNTs in it.

5.2 Electrochemical studies

Fig. 3 shows the result obtained from the cyclic voltametry of prepared electrode. Fig, 3 9a) is a curve between the current and the voltage recorded at different scan rates. It is quite evident that as the scan rate increases the area under the curve grows. The change in the area and shape of the curves is implies that the charging & discharging process of the electrode is actually depends upon the time. Also it is seen that the shape of the curve is not distorted significantly. Such behavior is indicative of good stability of electrode. It also imply to the reversibility of the performance of the electrode. Fig 3 (b) is showing the variation of specific charge as a function of scan rate. The Fig 3 (b) shows that as the scan rate increases, the specific charge capacity of the electrode also goes down drastically.

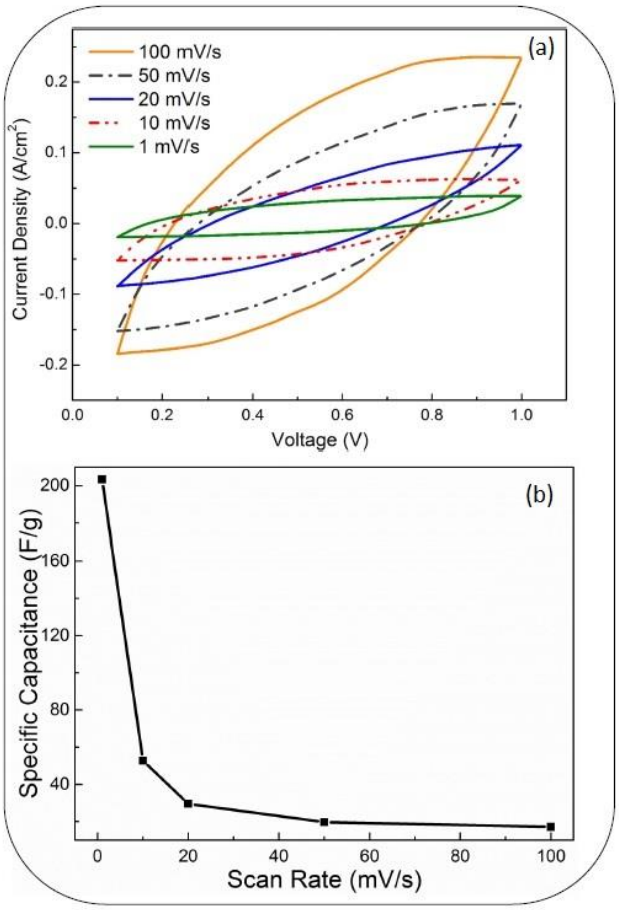

Fig. 3 (a) cyclic voltametry results and (b) specific capacitance as a function of scan rate.

6 Conclusions

The SWCNT covered electrodes were created from functionalized CNT suspensions with different pH esteems. The higher the pH, the more surface region and more-viable pore size conveyance, is prompting a higher explicit capacitance. The electrochemical studies conducted on the synthesized SWCNT show that the specific charge capacity of the electrode is significantly large and the synthesized electrode is also stable and the results are reproducible as well. All these things make the synthesized electrode a suitable candidate for energy storage applications.

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