Energy Storage in Carbon Nanotubes

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ENERGY STORAGE IN CARBON NANOTUBES

Abstract

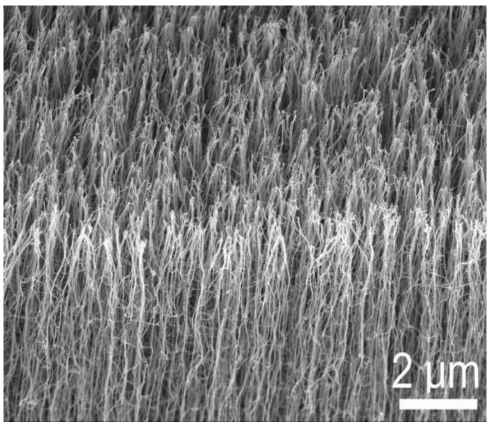
Energy storage in carbon nanotubes is a promising new technology. Carbon Nanotubes with their extraordinary properties in terms of strength, thermal and electrical properties have a big impact on the future of material sciences, electronics and nanotechnology. Owing to their specialized structures and minute diameter, they can be utilized in the creation of ultra-thin energy storage devices which in today's world where electronics is getting smaller could redefine the electronics market and replace capacitors and batteries the way we see them now. This paper deals with various processes of synthesizing carbon nanotubes, enegystorage applications and tries to explain the reasons being the variation of theoretical and practical results.

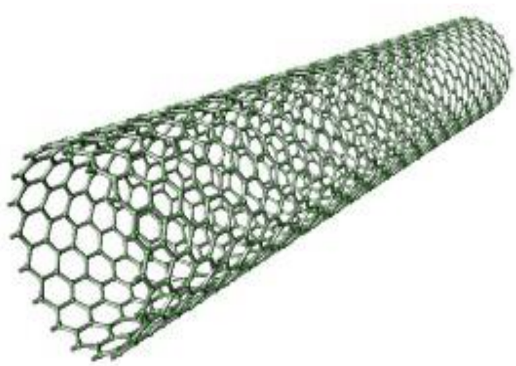
1. Introduction

Carbon nanotubes are hexagonally shaped arrangements of carbon atoms that have been rolled into tubes. These are allotropes of carbon with a cylindrical nanostructure. A CNT is basically single layered graphene rolled up in to a hexagonal tube with a continuous unbroken hexagonal mesh and carbon molecules at the apexes of the hexagons. These are unique tabular structures of nanometer diameter and large (length/diameter) ratios. CNTs have excellent high thermal conductivity and act as perfect electric conductors. Apart from this they have high young's modulus.

CNTs have found a wide range of applications in almost every field with a capability to replace batteries in storing reversible energy. Researchers have found that incorporating nitrogen and iron atoms into the carbon lattice of nanotubes results in nanotubes with a catalytic properties. They have enormous theoretical possibilities but have not lived up to the hype surrounding their development. Researchers have continued to look for ways to use them, however, as successful applications have the potential to be highly lucrative.

The properties of carbon nanotubes depend on how the hexagons of graphene (rolled into a tube) are oriented along the axis of the tube and on the number of walls decides the energy storage capacity of the nanotube.





(a)

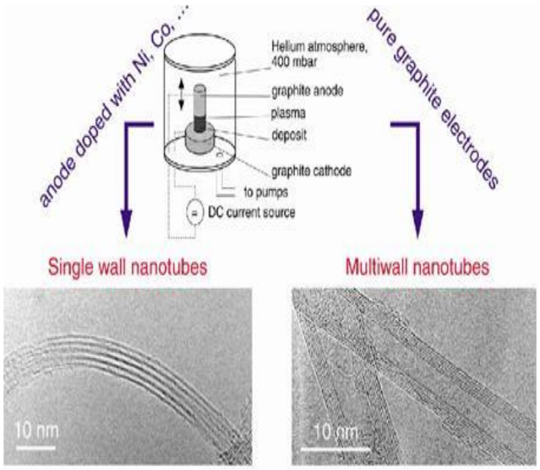
(b)

1.1 Synthesis of Carbon Nanotubes

The MWNTs were first discovered in the soot of the arc-discharge method and this process is generally used in the production of carbon fibers and fullerenes. Are discharge method and laser ablation methods are the simplest and predominant methods of synthesizing CNTs. However CNTs produced by these process contains impurities that are to be separated from the CNT forest.

a) Arc discharge method

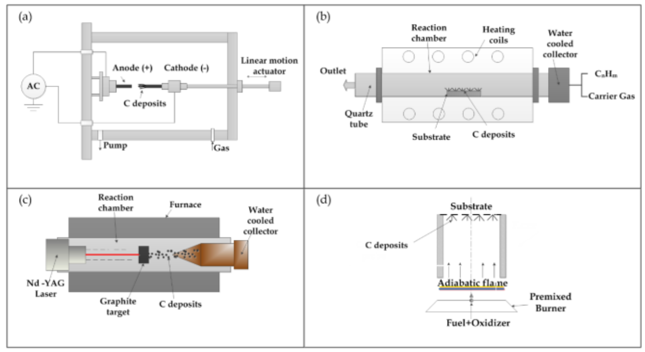
The carbon arc discharge method is initially used for producing C60 fullerenes. In this process two carbon rods placed end to end, are separated by approximately 1mm, in an enclosure that is usually filled with inert gases at low pressure. A supply of Direct current of 50-100 amperes at a potential difference of 20V forms an arc between the two electrodes creating a high temperature discharge between two electrodes. This vaporizes graphite on one electrode and deposit on the other in the form of Carbon nanotube soot.



The variation in the amount of inter gases decides the diameter of the nanotube. Whereas, the variation in the purity of the graphite electrodes decided the number of walls on the carbon nanotube.

b) Laser- ablation:

In 1996, Smalley and co-workers produced high yields (>70%) of SWNTs by laser-ablation
(Vaporization) of graphite rods with small amounts of Ni and Co at 1200 8C. The X-ray.
Diffraction and TEM showed that the synthesized nanotubes were remarkably uniform in diameters and that they formed ropes (or bundles) 5–20 nm in diameter and tens to hundreds of micrometers long. In this process laser is used to vaporize a graphite target in an oven at 1200˚C filled with argon and a pressure of 500 Torr is maintained in the oven. The vaporized graphite is further condensed to collet carbon nanotubes.



2. Energy Storage in Carbon Nanotubes:

Recent researches have been focusing on two main problems energy sources energy storage and impact on environment. The pollution problems associated with the combustion of petroleum related fuels lead to undesired alterations in the Earth’s climate. The scarcity of fossil fuels and global warming have directed attention towards the search of alternative fuels and effective energy storage. There is a demand for high energy density batteries for the effective and portable energy storage.

CNTs are discovered to be the promising means of energy storage due to its high young's modulus, which helps in the mechanical energy storage with a high energy density. However this paper concentrates on how hydrogen is stored in the carbon nanotubes.

2.1 Mechanical Energy storage

Carbon Nanospring stores potential energy when an external force is applied to it but releases the energy in a single rapid burst once the force is removed. An effective power source needs to store energy over a period of time, release the energy only when needed and discharge the energy at a desired power level. A CNT based portable power source should have a basic architecture made of four main components: a CNT spring, a supporting structure for the spring, a generator-motor combination, and a coupling mechanism between the spring and the generator. For example the energy generated during de-acceleration of a locomotive can be stored in a Carbon Nanospring in the form of potential energy and can be used when climbing an uphill.

2.2 Hydrogen Storage in Carbon Nanotubes

Hydrogen is actually of great interest because it is the cleanest, sustainable and renewable energy carrier with a significantly reduced impact on the environment. There is no large-scale utilization of hydrogen because of several major problems, which constraint the development of hydrogen economy. Its explosive nature and large volume are the two main hindrances for the transportation and storage purposes.

Carbon is well known as one of the better adsorbents for gases. This feature places the CNTs as the best storage option with high energy density and large capacity. Hydrogen is either adsorbed in the hollow space in a CNT or in the interstitial places between CNT wound together. This is one of the most important techniques to store hydrogen with the potential to meet the capacity goals (6.5 wt.%) set by US Department of Energy (DOE) as well as the advantages of low weight and ease of desorption

It has been observed that hydrogen can be adsorbed on carbon nanotubes by

- Physisorption
- Chemisorption.

Physisorption takes place when hydrogen maintains its molecular structure and is based on weak van der Waals forces that carbon atoms exert on hydrogen molecules. At a given temperature, the amount of gas adsorbed is only a function of the pressure and is desorbed when pressure decreases.

In *chemisorptions*, atoms of hydrogen forms chemical bonds with the carbon of the nanotubes i.e. the covalent C–H interaction. It is difficult to determine if hydrogen is adsorbed exclusively by physisorption or chemisorption. As the strength of the interaction between hydrogen and adsorbent materials increases, molecular hydrogen tends to dissociate into atomic hydrogen and subsequently diffuse into the adsorbents.

2.3 Hydrogen Storage mechanism in CNT

Three samples of SWNTs collected from a batch of SWNTs, but pretreated in three different ways, are denoted as sample 1, sample 2, and sample 3. Their pretreatment processing methods and the hydrogen adsorption amounts are listed in Table. The apparatus consists of a copper sample cell, a stainless steel H2 reservoir container, a H2 source, a vacuum system, a high-pressure gauge, and high-pressure bellows valves through which the above components are all connected. The volume of the system is measured to be 45.10 ml. In the hydrogen adsorption experiments, each of the SWNT samples is placed in the sample cell and heated to 423 K. The system was then fully vacuum-degassed for several hours. When the sample cell is cooled to room temperature (about 298 K), hydrogen is admitted into the apparatus to a certain pressure and this begins the hydrogen adsorption. The changes in pressure were monitored versus time. The adsorption rate decreases after the first 60 min, and at that time, 70% of the whole adsorption capacity is achieved.

The H2 storage capacities for the three samples, from highest capacity to lowest, are sample 3 > sample 2 > sample 1. Sample 2 was soaked in HCl acid (37%) for 48 hours to partly eliminate the residual catalysts and was then rinsed with de-ionized water; it showed a somewhat higher H2 adsorption capacity than sample 1 (the as-prepared product). This indicates that catalyst particles are probably inert with regard to H2 adsorption.

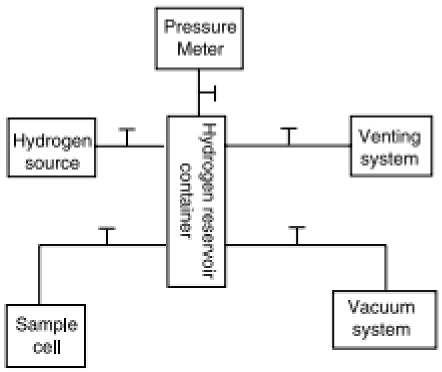


Fig. 2. The schematic diagram of the apparatus used for H_2 adsorption experiments.

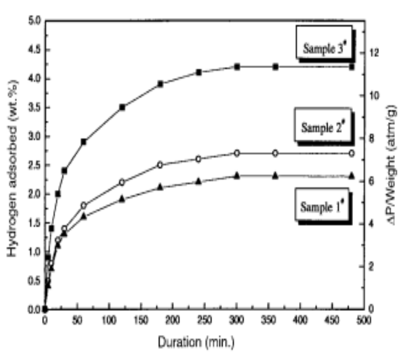


Fig. 3. The amount of H_2 in weight % for SWNT samples, and the pressure change versus the adsorption time.

Sample	Storage capacity (weight %)	Initial mass (mg)	F
1	2.4	480.1	
2	2.8	501.3	
3	4.2	492.7	

Table 1: hydrogen adsorption amounts

2.4 Variation in results:

The experimentally reported hydrogen storage capacities for different CNTs are summarized in Table 2. A large variation in the data of hydrogen storage capacity in CNT reported by different scientific groups is obvious. Storage capacities in the range of 0.01–
20 wt.% have been reported by different laboratories. A common problem in correlating data effectively has been related to inconsistencies of test conditions. Moreover, many approaches have addressed atypical experimental conditions, such as, high-energy hydrogen atom implantation or unusual simulation parameters, such as, absolute zero.

The nanotubes considered in molecular simulations are open tubes, well structured, without amorphous carbon and impurities, having well determined and chosen diameters and geometrical location in the bundles. Despite the promising characteristics of SWNTs for hydrogen physisorption (cylindrical shape, size not larger than a few molecular diameters), theoretical storage results predicted values quite far from the practical applicability target of 6.5 wt.% at ambient temperature and pressure. However, some others give maximum storage capacities around 5–14 wt.%.This controversy may be related to the interaction potential models used to describe the gas–solid interaction. Essentially, all the theoretical calculations address one or the other aspects of the problem Moreover, the calculations favor adsorption in between the tubes rather than inside the tubes.

Experimental approach is also difficult due to some different reasons. Discrepancies concerning hydrogen storage capacity of CNTs are mainly attributed to:

(a) Different experimental conditions, such as, hydrogen pressure and temperature.

(b) Different methods of CNTs synthesis resulting in different specific surface areas.

(c) Different processing histories and pretreatment procedures of CNTs prior to adsorption (d) Different configurations of CNTs, such as, tube diameters, tube lengths, bundle size, the longitudinal shape and orientation and inter tube spacing, which allow hydrogen either to move into the tube or to be constrained in the interstitial pores. Furthermore, CNTs opened in the edge are able to adsorb hydrogen on both the inside and outside walls, whereas closed CNTs do not.

(e) Different purification methods of CNTs.

(f) Different activation by the presence of varying amounts and types of impurities within the samples. The nanotube samples used, in experimental investigations are not of high purity, containing amorphous carbon and several impurities. Moreover, nanotubes were often only available in small quantities, which are required for adsorption measurement methods carried out on very sensitive devices inevitably less accurate than conventional apparatuses. Small calibration errors in sorption techniques may largely influence the interpretation of the final results.

Summary

Hydrogen storage represents one of the essential challenges in developing a clean-burning hydrogen economy, effort has been directed on optimizing the present storage technologies. This paper deals with explain how hydrogen is adsorbed on the CNTs and discussing the reasons for the variation in the experimental and theoretical results. Adsorption on CNT may be physisorption, a result of weak Van der waals forces or chemisorption, bond formed by C-H interaction.

The results proved that the storage capacity of SWNTs and MWNTs for hydrogen is lower than 1 wt.% at ambient temperature, but the capacity can be raised to 8 wt.% when the temperature of adsorption is decreased. The hydrogen storage property of CNTs can be enhanced by purification, preparing carbon materials in different geometrical forms, dense alignment of nanotubes, doping, creating defects. Carbon nanotubes technology represents a new direction for solid hydrogen storage especially if these materials can be altered to store large amounts of hydrogen at room temperature.

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