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Electromagnetic Field Detection in front of Vibrating Carbon Nanotubes

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Abstract

Vibrating carbon nanotube (CNT) generates electromagnetic (EM) field. This is experimentally verified through our present works. CNTs are synthesized by alternating current (AC) arc discharge between the two high pure graphite rods of the same diameter in an open air environment. To confirm the synthesis of CNTs, scanning electron microscope (SEM) and transmission electron microscope (TEM) micrographs of the deposited carbon on the electrode ends are taken. During the arc discharge EM field is detected in an anechoic chamber.

1 Introduction

Carbon nanotubes (CNTs), first reported in [1], are crystal cylindrical tubes structure in the form of either single walled with diameters as small as 0.4 nm, or multi-walled (co-centric) consisting of nested tubes with outer diameters ranging from 5 to 100 nm with high aspect ratio [2].

There are a number of methods of making CNTs such as arc method, laser method, chemical vapor deposition, ball milling, diffusion flame synthesis, electrolysis, use of solar energy, heat treatment of a polymer, and low-temperature solid pyrolysis, etc. The carbon arc discharge method is the most common and perhaps easiest way to produce CNTs, as it is rather simple. In general, this method uses direct current (DC) to arc discharge between two graphite in a chamber filled with supporting gases at subatmospheric pressure [3]. CNTs can also be produced by alternating current (AC) arc discharge method but in He gas environment or graphite electrodes loaded with Ni and Fe powders [4]. Again for the synthesis of CNTs arc-discharge is used in open air in [5], but DC has been used. However, the arc-discharge method which has found extensive use in CNT synthesis, to the best of the authors' knowledge, open air AC arc-discharge has till now not been used explicitly in synthesis of CNT. In this work, CNTs are synthesized through AC arc-discharge between two high-purity identical graphite rods placed end to end as electrodes (see Fig. 1) in normal air pressure inside an open-front arc-discharge chamber. Scanning electron microscope (SEM) and transmission electron microscope (TEM) images are taken to confirm the deposited CNTs on the top of the electrodes ends.

The CNT has varieties of application ranging from various structural materials to electromagnetic. Depending upon the geometrical structure, it can function as either metallic or semiconductor [2]. This nature of CNTs has attracted researchers to systematically investigate its performance under wide range of conditions. Among the most important classes of interactions that has been in the focus in recent years are the fields of electromagnetic. Use of resonating CNTs in field emission configuration to demodulate radio frequency signals has been studied in [6]. In this work, electromagnetic (EM) fields from the vibrating CNTs are identified in an anechoic chamber during arc discharge process and compared with the environmental EM noise of the anechoic chamber.

2 Carbon Nanotube âĂŞ Synthesis

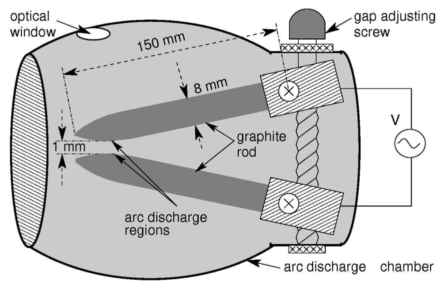


Figure 1. Schematic diagram of arc-discharge set-up.

The history of CNTs is closely related to the mass production of fullerenes. The arc-discharge method is the one by which CNTs were first produced and recognized. They evaporated graphite rods in contact by applying an AC voltage in the presence of an inert gas to produce fullerenes. But the most utilized methods use DC to arc discharge between two graphite in a chamber filled with supporting gases at subatmospheric pressure [3].

In this work, CNTs are synthesized through an arc-discharge between two high pure graphite rods of the equal diameter (8 mm) and equal length (150 mm) placed end to end as electrodes as shown in the Fig. 1. The arc-discharge is done inside an arc-discharge chamber in normal air pressure. The arc-discharge chamber consists of a stainless steel chamber with open in frontal direction, provided with optical window for process visualization. The gap adjusting screw shown in the Fig. 1 is used to adjust the gap between the arc discharge regions (front end) of the graphite rods. An alternating current of peak to peak value 24 A driven by a potential difference of approximately 327 V (peak to peak) and frequency 60 Hz is applied between two electrodes to discharge. When arc discharge region of the electrodes come a little closer, arc discharge starts immediately. The gap between the arc discharging region of the graphite rods is kept fixed and the gap is about 1 mm (see Fig. 1). Due to this discharge, a high temperature generates at and near the discharge region of the graphite rods and electrodes evaporate to form fullerenes and form a small rod-shaped which are deposited on the arc discharge regions includes CNTs.

3 SEM and TEM Studies

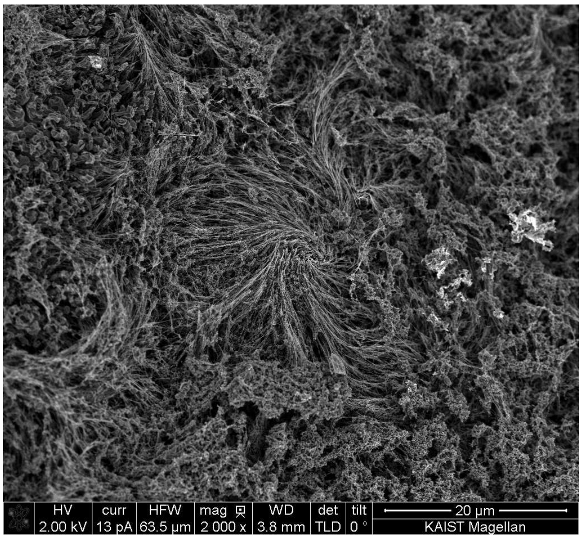


Figure 2. SEM micrograph of the arc discharge region of the graphite electrode used in arc discharge.

A study is conducted by FEI Magellan 400L extreme high resolution scanning electron microscope (SEM) and FEI Tecnai G2 F30 highly advanced transmission electron microscope (TEM) to characterize the texture (elemental particles and their aggregating) as well as the structure (crystallinity) of the deposited carbon.

The enlarge SEM image of the material deposited on the discharge region of the graphite rod (see Fig. 1) is obtained and shown in Fig. 2. The figure shows the presence of nano scale cylindrical tubes along with several other elements.

The more enlarge SEM images of the deposited material are also obtained and shown in the Fig. 3. It shows the morphology of the sample obtained from the graphite rods through arc discharge. It is observed that the carbon particles exhibit a cylindrical with nanosized diameter which are known as CNTs. From the Fig. 3, it is seen that the diameter of the CNT varies from 5.721 nm to 39.29 nm. From the

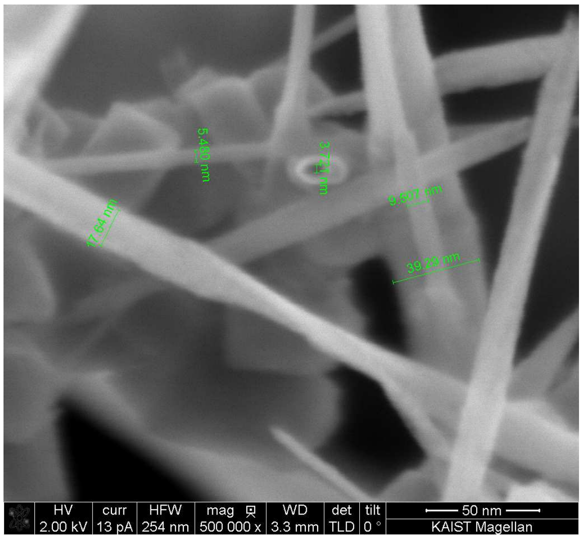


Figure 3. SEM images of the fabricated CNTs in 50 nm scale.

above figures, it is clear that CNTs, deformed CNTs, aggregate carbon nanoparticles and agglomerate carbon particles are formed in all cases.

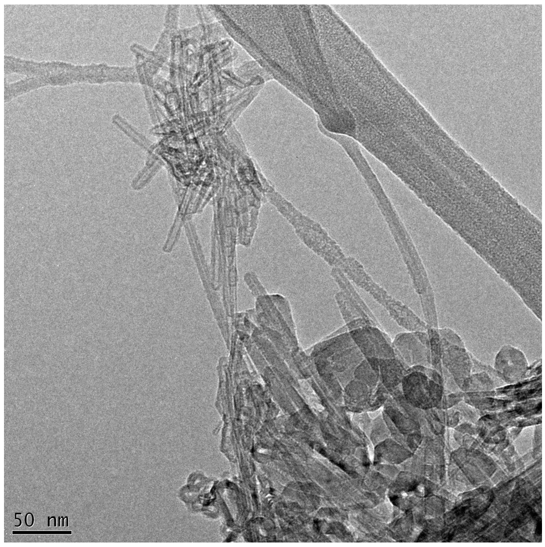


Figure 4. TEM micrographs of the deposited carbon on the electrodes end in 50 nm scale.

TEM images displayed in Fig. 4 show clearly that the deposited carbon on the wall of the electrodes is the turbostratic structure of graphite; that is, the deposited carbon is partially graphitized, not in a complete graphite phase.

Fig. 5 clearly shows well-graphitized layers of the CNTs, the hollow shell morphology, and turbostratic structure deposited on the electrode ends. These CNTs consist of more than one concentric carbon shells with some spacing, which is consistent with that of graphite, only a little bit of carbonaceous material attached to its surface. From Fig. 5 the

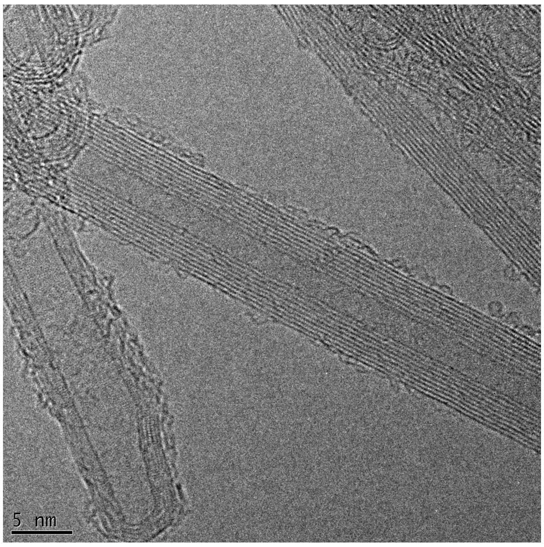


Figure 5. TEM micrographs of the deposited CNTs on the electrodes end.

walls of the CNTs can be counted.

4 EM field due to the vibration of CNTs

CNTs synthesized by arc discharge method are highly crystallized. The Q-factor dependences on Young's modulus, the nanotube with a high Q-factor shows a high Young's modulus. From [7, eq. (2)], Q-factor (Q) is defined in terms of kinetic energy as

$$Q = \frac{2\pi}{\left(1 - \frac{E_n}{E_{ext}}\right)^{1/n}} \tag{1}$$

where E_n is the kinetic energy after n-th vibration and E_{ext} is the initial kinetic energy for the vibration. Again the Q-factor of individual CNT is

$$Q = \frac{f_0}{\triangle f} \tag{2}$$

where $\triangle f$ is the 3dB band-width and f_0 is the frequency of the vibration. From (1) & (2), frequency of vibration and the band-width depend on the the energy loss of the vibrating CNT. The Q-factors for arc-produced nanotubes are varied in the range of 300 - 2000 with a center of 1000 [7]. The resonant frequency of a CNT is related to the Young's modulus (Y) and length (L) given by

$$f_0 = \frac{1.875^2}{2\sqrt{3}\pi}\sqrt{\frac{3YI}{m_0 L^3}} \tag{3}$$

where I is the moment of inertia given by $\pi\left(r_0^4 - r_i^4\right)/4$, m_0 the mass of the nanotube and r_0 & r_i the outer and inner radii of the nanotube respectively.

The CNT formation process on a nanoscopic level is the result of collisions between clusters, ions and neutrals leading to particle attachment [8]. CNT vibrations occur during certain manufacturing processes and as part of some nondestructive evaluation processes [9]. This vibration produce time-dependent dipole moments and consequently, electric and magnetic fields are generated [10].

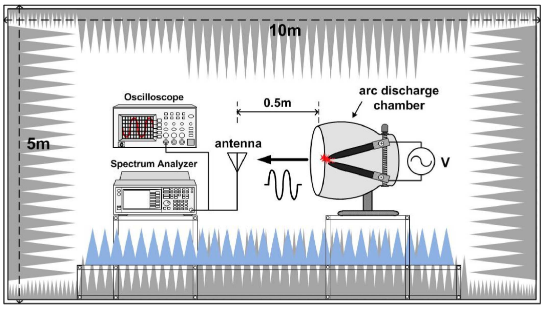
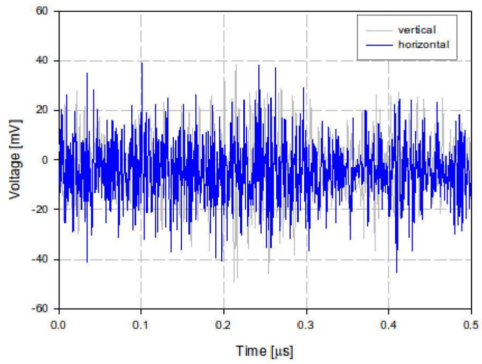
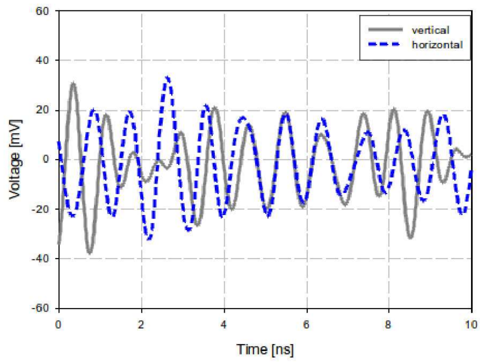


Figure 6. Field measurement inside the anechoic chamber.



(a)



(b)

Figure 7. Measured time-domain signal during arc discharge (a) large scale (b) expanded scale.

Fig. 6 shows a EM field measuring system in an anechoic chamber with broadband (0.65 GHz $\sim$ 11 GHz) double-ridged horn antenna (W5DH-0611). Details of the anechoic chamber are in [11]. During arc discharge process, multi-walled CNTs of various length are developed and these CNTs vibrate with their resonant frequency. Due to the vibration of CNTs, EM fields are generated which are simultaneously detected in a LeCroy WavePro760Zi 6 GHz oscilloscope and in a Agilent-E4440A spectrum analyzer shown in the Figs. 7 & 8 respectively.

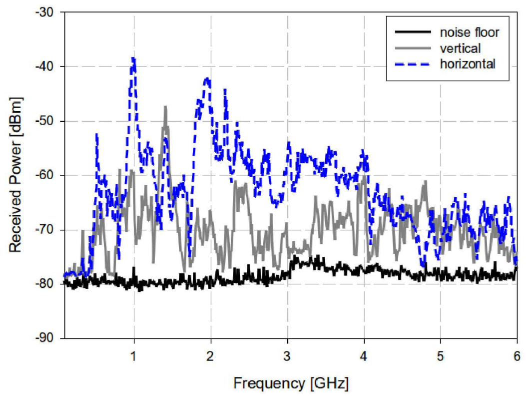


Figure 8. Measured power with and without the graphite rod arc discharge.

Fig. 7(a) shows the time domain received signal for the time discharge start ($t = 0\ s$) to $t = 0.5\ \mu s$ and the expanded scale of this signal from discharge start ($t = 0\ s$) to 10 ns is shown in the Fig. 7(b). In these figures, vertical and horizontal indicate that the received field when the polarization of receiving horn antenna along vertical and horizontal direction respectively.

In Fig. 8, the received field components are also compared with the environmental noise of the anechoic chamber received in the spectrum analyzer when there are no arc discharge. On an average, the power of the received EM field due to the vibration of CNTs is 15 dBm higher than the environmental noise of the anechoic chamber and also the peaks are much more than its average value. Measured noise floor shown in Fig. 8 increases at and near frequency 3 GHz. This is may be due to the spectrum analyzer itself.

The resonant frequency of a CNT is a strong function of its length, wall thickness, and diameter. A large number of CNT shown in this work would cover a broad distribution of the above three parameters. Therefore, the emission observed frequency spectrum is very broad rather than a single frequency with its harmonics.

5 Conclusion

Synthesis of CNTs by AC arc discharge in normal air atmosphere is presented. SEM & TEM images of the deposited materials at and near the arc discharge region of the graphite roads show the presence of a large variety of multilayer nanostructures like MWCNT, deformed MWCNT, graphitic nanoparticles. The CNT formation process on a nanoscopic level is the result of collisions between clusters, ions and neutrals leading to particle attachment. During arc discharge process, CNTs attached with the graphite rods vibrate and generate EM fields. These fields are identified through the measurement in an anechoic chamber and also compared with the environmental noise of the anechoic chamber when there are no arc discharge.

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