KINEMATIC MOTION OF POSITIVE CARBON ION SPECIES: A PROPOSAL METHOD

M.S. Roslan[a], Saktioto[b], and J.Ali[c]

[a,c]Institute of Advanced Photonics Science, Nanotechnology Research Alliance,
UniversitiTeknologi Malaysia (UTM), 81310 Johor Bahru, Malaysia
[b]PhysicsDept, Math and Sciences Faculty, University of Riau, Pekanbaru, Indonesia

Abstract

The ion carbon species are massively produced througharc plasma for synthesizing carbon nanotube. Positive ions would have tendencies to move towards the negative charged cathode. The moving of the massive ions generated electric field in direction parallel with the ion movement. In this paper, we discuss the particle collisions subsequently resulting a new carbon species namely carbon nanotube (CNT) composed from single/many graphene layer rolled up alike nanostraw structure.

Keyword:*Carbon ion, arc plasma, and carbon nanotube.*

INTRODUCTION

CNT astonished researcher since the first unexpected discoveries in 1991[1] by the arc discharge method in processsynthesizing carbon fullerene. CNT possesses unique properties as it has high-quality of both transparency and conductivity. This made CNT suitable to be used in numerous applications such as quantum nanowires [2], optical hologram [3], and field emitters[4].

In vacuum arc discharge, plasma generated between the different potential of electrodes. Single or various cathode spots could possibly occur randomly. The cathode spot is the resultant of the current conduction between the electrodes. It gives characteristic of the plasma generated. The cathode spot has tiny size in micro-range level. Nevertheless it is very dense and carries current density up to $10^8 A/cm^2$. The excessive current density causes the relative material of electrode surface to extend superheating and evaporates within the cathode spot region. Incidentally plasma is generated and enlarges regarding to anode potential with speed approximately 10^4 m/s[5].

In this study,arc discharge method is used to produce CNT. Graphite compound is used as electrode to initate carbon plasma in order to produce CNT. DC power supplied is applied in between the eletrode gap at voltage ~12V and current ~90A.The applied voltage give potential to sustain plasma up

to few seconds. The plasma itself generate very dense electron up to 10^{22}[6]. This raise the potential of the plasma itself accelerate ion and electron inside it. All the trajectories of ion and electron inside plasma is not uniform for single particle case.The carbon ion is massive rather than the electron that is 10^6 lighter. This ensure electron move much faster than carbon ion.Collective behavior of plasma enhance the positive carbon ion to shift it movement toward negative potential at cahthode and vice versa for the case of electron. This result in CNT deposition occurs at cathode surface.
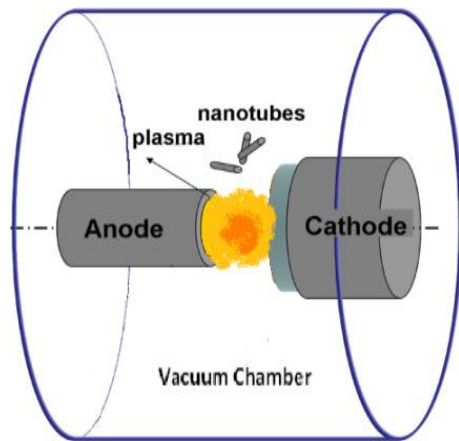

Fig.1 Arc discharge method

Arc discharge is a simple method to produce high quality of CNT. In arc discharge process, a high current voltage is applied in gap between two electrodes of order millimeter. Usually the discharge process is conducted inside vacuum chamber at low pressure. Several researchers inject the chamber with inert gas and catalyst to enhance CNT growing; however, CNT can also grow without the aid of metal catalyst. CNT usually grow on nanoparticle metal catalyst. Fig 1 shows the schematic diagram for arc discharge method.

Particle collisions have possibilities to create new element. In this research we focused on the formation of CNT from particle collision. Researchers show that two colliding carbon particle could possibly generate carbon nanotube by applying diffusion equation [7]. Carbon dimers initiallycombine after having inelastic collision, and those have sufficient concentration gradient and diffusive flux that able to form CNT.

THEORETICAL CONSIDERATION: ION CARBON TRAJECTORIES MODEL

In this study, we propose the ion trajectories initiated from the plasma between the electrodes. The ionsare considered move at very high speed that exceed the drifting velocity oppose it. The positive ion moves with velocity, v at z axis as follows (non-relativistic)

$$\vec{v}(C_x^{+A}) \cdot \vec{z_i} \neq 0$$

$$\vec{v}(C_x^{+A}) \times \vec{z_i} = 0$$

However, the motion of the positive carbon ion scattered in all direction. Particular ions move in direction parallel with z-axis while several ion making angle with it. The ions moving with angle reduce the ion speed and lower the tendency for ion to reach cathode straightforward. Motion of carbon also effected from the collision between the ions. This cause the increase of diffusion length or the scale length is greater than the cross section scale down the probability for ion to move toward cathode.

Nevertheless, some of the electron collide with ion and neutralize. The particle charge is diminished and the neutralize ion will no longer move toward cathode. Some particle gain excess electron becoming radical transform the particle to become negative charge and this will lead the motion toward anode.

Since $n_{ion} \approx 10^{22}/m^3$, we can rewrite the formulation for the particle speed for each species as

$$\left[\sum_{i=1}^{10^{22}} \vec{v}_i \cdot \vec{z}_i \right] n = \sum_{i=1}^{10^{22}} \frac{(\vec{z}_i)^2}{t_i} \cdot n$$

$$= \vec{v} \frac{N}{z^2} \qquad (1)$$

Where the total number of particle, N is

$$\sum_{i}^{10^{22}} n_i v_i = N$$

So

$$\sum n_i (\vec{v}_{0i} \cdot \vec{z}_i) = \vec{N} \cdot \vec{z}$$

Taking the positive value (for one direction toward cathode),then it can be written as

$$\sum n_i |\vec{v}_{0i} \cdot \vec{z}_i| = |\vec{N} \cdot \vec{z}|$$

The collision frequency in plasma define as

$$\tau^{-1} = \frac{v}{\lambda_m} = n_n \sigma v$$

Where λ_m is mean free path, for particle to collide, σ is the cross section area. The collision time between carbon particle is given by
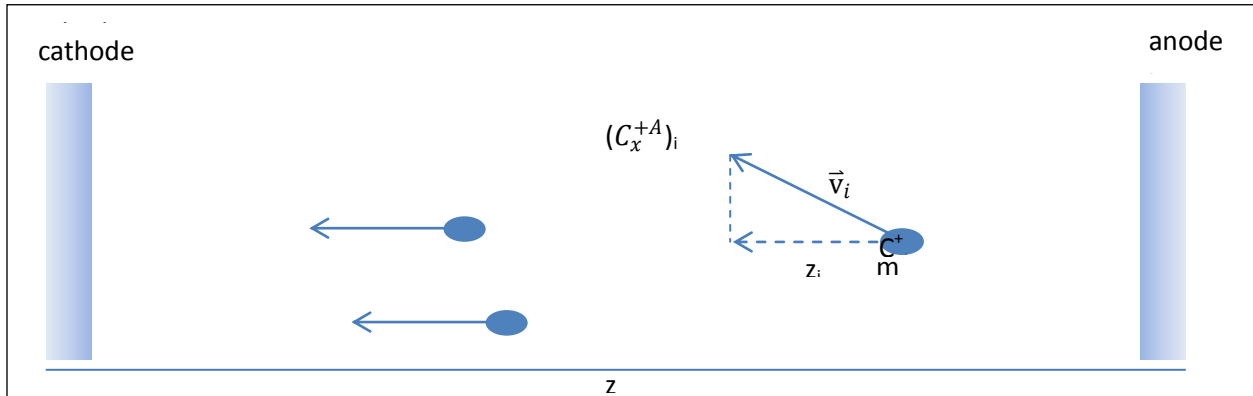
$$\tau = \frac{1}{n_n \sigma v}$$

Fig. 2 Ion trajectory model

PRELIMINARY RESULT AND DISCUSSION

Carbon ion from plasma is moving randomlyin all direction. This also happened with electron, in contrast electron is much lighter than ion. Quasineutrality ensure that the total charge in plasma maintain that net electric field inside is remain zero or in neutral. Carbon ion inside plasma remains unstoppable since the plasma exists. Positive charge carbon ions in plasma retaining move toward the negative potential of the cathode.This engenders internal energy initiate from collective behavior between the moving ions (toward cathode) and electrons (toward anode) at opposite direction causing ambipolar diffusion.

The carbon ions have high kinetic energy upon the mechanic motion. The applied voltage potential between electrodes speed the acceleration as the result from current produced following Ohm's law, $J=nev$. This indicate that enormous current density incoming from great velocity of ion (and electron as well).There are some probabilities to carbon ion trajectories to form CNT where the kinetic energy is much higher than the potential energy subject to internal energy.

On the other hand, external potential energy as voltage applied to the electrode are high enough to create repulsive force with the same charge for those particle located closer with potential surface. The ion stood nearer with anode (electron closer with cathode surface) will be forced.

Based on initial value where pressure,$P=100$torr, by using Saha-Boltzmann relation, the electron temperature calculated is 10500°K. By applying this calculation into equation of average velocity

of ion and electron at Local Thermodynamic Equilibrium (LTE) plasma,

$$\bar{v} = \sqrt{\frac{8kT}{\pi m}} = \sqrt{\frac{8RT}{\pi M}}$$

$$= \sqrt{\frac{8(8.314472J\ K^{-1}mol^{-1})(10500°K)}{\pi(0.012kg/mol)}}$$

$$\bar{v} = 4304.19 m/s = 4.30 kms^{-1}$$

This velocity can generate current density calculated from Ohm's law. Consider the ion charge related to electron charge $n_e = n_i$ for the most probable +1 carbon, C^+ ion produced inside the plasma.

$$J = nev = (10^{22} \times 1.6e^{-19}C$$
$$\times 4304.19 m/s)$$

$$J = 68.9 MA/m^2$$

By applying Maxwell-Boltzmann distribution, define the energy function f(E,T) is the probability per unit energy locating particle in the energy interval dE for specific gas temperature is obtained,

$$\int_0^\infty f(E,T)dE = 1$$

With consideration of Maxwellian distribution function, we have

$$f(E,T) = \frac{2\pi}{(\pi kT)^{\frac{3}{2}}} E^{1/2} e^{-E/kT}$$

where E in eV, T is the absolute gas temperature in K, and Boltzmann constant k=8.6170eV/K.

Carbon positive ion possesses collision time $\tau=2.32\times10^{-21}$s corresponding to collision frequency $v=4.304\times10^{20}$ Hz for the cross section area 1mmx1mm. The result of energy for carbon species in Fig. 3 shows that the carbon positive ion acquires temperature nearly reached 1eV thus the kinetic energy of carbon ion is 1.15eV. The Maxwellian plot shows that a slightly increment energy distribution, f(E) as a function of E. In this case, the probability for determining particle per eV is very low which is measured to have probability 0.5 particle at the peak of the distribution function (0.1 to 1.0 eV).
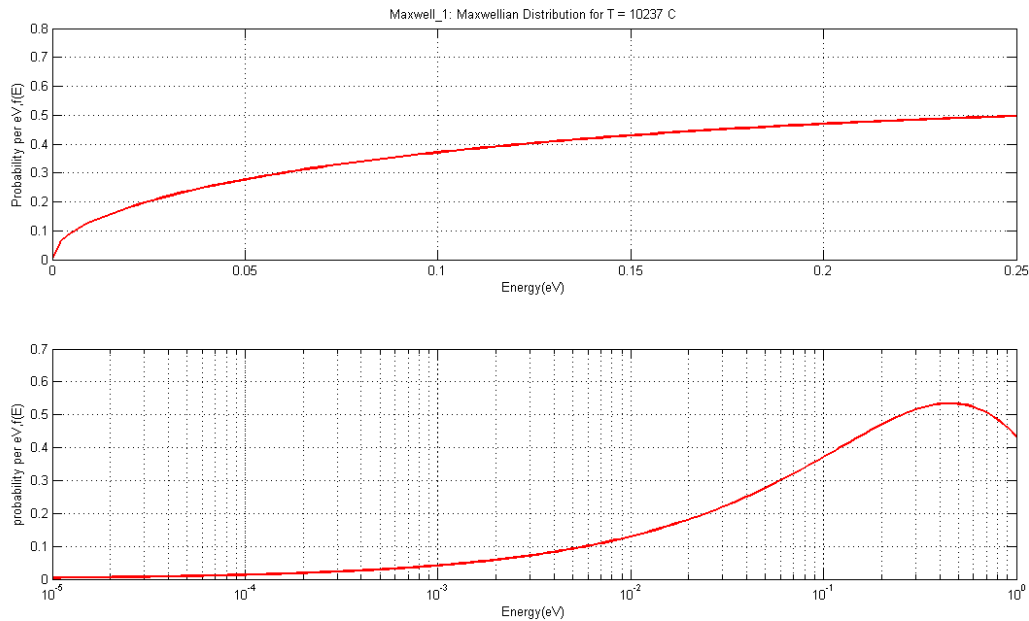
Fig. 3 Energy distribution for carbon ion at T=10500 K.

The intensely high temperature in correspond with low pressure executed from the plasma, based on the ideal gas law

$$P = nkT = (10^{21} \times 1.38 \times 10^{-23} JK^{-1} \times 10500K$$

$$P = 14500 \; Pa$$

The temperature also indicating the spectrum light emitted from the plasma based on Wien displacement law (wavelength of maximum black-body emission) $\lambda_{max} = 2.50 \times 10^{-5}T^{-1}$ cm. The subsequent wavelength radiated is λ_{max}=2.38nm indicate the plasma spectrum layinUltraviolet (UV) range.

CONCLUSION

A proposal method of positive ion species to form CNT is underway to describe the kinematic motions of carbon ion. Arc discharge is the fastest and easiest method to synthesize CNT. Coalescence between carbon ions particles in plasma is able to produce CNT at sufficient concentration gradient and diffusive flux. The arc plasma generated during synthesizing CNT consumes high kinetic energy at 1.15eV and very high temperature at 10500 K or closely with 1eV. The enhanced controlling of the pressure give a better ion speed thus improves CNT formation.

REFERENCES

[1] S. Iijima, Nature, 354 (1991).

[2] H. Ajiki, T. Ando, Solid State Communications, 102 (1997) 135-142.

[3] S. Larouche, D.R. Smith, Nature, 491 (2012) 47-48.

[4] W.A. de Heer, J.-M. Bonard, K. Fauth, A. Châtelain, D. Ugarte, L. Forró, Advanced Materials, 9 (1997) 87-89.

[5] E. Oks, Low-Pressure Discharges for Plasma Electron Sources, in: Plasma Cathode Electron Sources, Wiley-VCH Verlag GmbH & Co. KGaA, 2006, pp. 1-22.

[6] M. Kundrapu, I. Levchenko, K. Ostrikov, M. Keidar, Plasma Science, IEEE Transactions on, 39 (2011) 2876-2877.

[7] M.J. Height, J.B. Howard, J.W. Tester, J.B. Vander Sande, The Journal of Physical Chemistry B, 109 (2005) 12337-12346.