Research Article

Journal of
Environmental
Nanotechnology

A Novel Synthesis of SWCNTs from Tapioca for Opto-Electronic Devices: 3D – High Efficiency Solar Cells, Flat Panel Displays, LEDs & Lasers, Magnetic Storage Devices: High Capacity Pen Drives and Nano Thermometers – A New Feasibility Study

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Received: 28.07.2017 Accepted: 21.08.2017 Published: 30-09-2017

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ABSTRACT

A novel modified AC method – VSA methodology (with KRS or NTFDS theory) was adopted in this present work for the preparation of SWCNTs from natural organics i.e., Tapioca leaves towards the possiblility of application to Opto-electronic devices : 3D – high efficiency Solar cells, Flat panel displays, LEDs & Lasers, Magnetic storage devices and Nano thermometers. Structural, Compositional, Surface Morphological and Nano structural Characterizations were carried out on harvested products. The effects of optimizations parameters like pH of the various dipping solutions (acidic, basic and neutral), volume of dipping solutions, various types and parts of the materials, various dipping timings, number of annealing and dipping, various annealing temperature, various time of annealing and various dipping solution temperatures on structural, compositional, surface morphological, nano-structural characterizations of materials and on high grade SWCNTs growth with high yield were studied intensively. Inferences from characterizations were derived and graphically emphasized. Correlation studies between these characterization inferences (such as grain size, purity) and above optimization parameters were carried out with a high light on yield of high grade SWCNTs. Beyond all of these, we have carried out a new feasibility study at first time, which comprises the possible usage of precursor organic carbon source i.e., Tapioca leaves for high grade SWCNTs with high yield via a low cost technique and methodology as value in commercial efforts.

Keywords: 3D – high efficiency Solar cells; Flat panel displays; High capacity pen drives and Nano thermometers; HRTEM; LEDs & Lasers; Magnetic storage devices; Modified AC method; Natural organics; NTFDS theory; Opto-electronic devices; SWCNTs; Tapioca leaves; VSA methodology.

1. INTRODUCTION

The present work showed that SWCNTs obtained by open air annealing and cooling of leaves of Tapioca. The present work made a break through via plays an alternative method to conventional, traditional methods such as arc discharge, laser ablation, metal catalysts, pyrolysis, and varieties of CVD methods and also removes the usage of synthetic chemicals. Due to that dehydration (removal of H_2O molecules from C-H-O matrix) takes place. Finally it allows carbon atoms only present in the material part. The modified AC method (Zhenhui Kang *et al.* 2005) – VSA methodology (with KRS or NTFDS theory) was adopted in this present work for the preparation of CNTs from natural organics. The entire steps such as Precursor materials selection with cleaning, Annealing, Sudden cooling, Interaction between red hot natural organic carbon resource materials and Dipping solutions (DS) [including Nano Thermo Fluid Dynamics (NTFDS) and Nano-drilling process] involved in this process were explained in detail. The characterizations performed on outcome products were internationally accepted, standard methods as followed by field specialists through out the world (Iijima, 1991; Iijima,1993; Ajayan and Ebbesen, 1997; Ajayan and Iijima, 1993; Yakobson and Smalley, 1997; Dresselhaus, 1996; Ebbesen, 1997; Dekker, 1999; Dujardin *et al.* 1994; Collins and Zettl, 1996; Dean and Chalamala *et al.* 1999; Winter *et al.* 1998; Dresselhaus *et al.* 1999; Calvert, 1999; Shaoping Xiao and Wenyi Hou, 2006; Zhiyang Rong, 2008; Rostam Moradian and Ali Fathalian, 2006; Chun Li *et al.* 2007; Rossi *et al.* 2004; Majumder *et al.* 2005; Mattia *et al.* 2007; Guoyong Xu *et al.* 2007; Teh-Hwa *et al.* 2007; Kuromochi *et al.* 2007; Bond *et al.* 2007; Xue, 2006; Wang *et al.* 2006; Chiu *et al.* 2002; Wang *et al.* 2005; Shiren Wang *et al.* 2006; Safarova *et al.* 2007; Bellucci *et al.* 2007; Zhenhui Kang *et al.* 2005).

2. EXPERIMENTAL DETAILS

Materials i.e., Tapioca leaves was collected from nature, cleaned in water and dried in open air. These materials were used without further purification. Then the materials were open air annealed (upto red hot) in a muffle furnace at various temperatures viz., 600 ºC and 800 ºC for various time of heating viz., 1 minute to 5 minutes. After that they were immediately dipped into various types of solutions viz., Sodium hydroxide (NaOH), Hydrogen peroxide (H_2O_2), Nitric Acid (HNO_3), Sulphuric Acid (H_2SO_4), Hydrochloric Acid (Hcl), Mineral Water (MW), Salt Water (SW), Double Distilled Water (D2W), Ice Water (Ice W), Hot Water (HW), Pure Water (PW), Ice water mixed double distilled water (IceW+D2W) and Hot water mixed double distilled water (HW+D2W) solution with various solution temperature ranging from 0 ºC to 100 ºC, various time of dipping viz., 30 seconds, 45 seconds, 60 seconds, 75 seconds, 90 seconds, and 120 seconds. The final samples were dried in open air at room temperature for 5 hours and then packed for characterization with mentioning synthesis conditions.

The above process was optimized with 11 Physical parameters viz.,

1. Nature (pH) of the dipping solutions (acidic, basic and neutral),
2. Volume of Dipping Solution ranges from 0.5 ml, 1.0 ml, 1.5 ml, 2.0 ml and 2.5 ml,
3. Various types of materials: conventional: varities of plants, trees: Tapioca,
4. Various Parts of the materials: leaves, stems,
5. Various Dipping solutions: Sodium hydroxide (NaOH), Hydrogen peroxide (H_2O_2), Nitric Acid (HNO_3), Sulphuric Acid (H_2SO_4), Hydrochloric Acid (Hcl), Mineral Water (MW), Salt Water (SW), Double Distilled Water (D2W), Ice Water (Ice W), Hot Water (HW), Pure Water (PW), Ice water mixed double distilled water (IceW+D2W) and Hot water mixed double distilled water (HW+D2W),
6. Various Dipping Timings: 30 seconds, 45 seconds, 60 seconds, 75 seconds, 90 seconds and 120 seconds,
7. Various Number of Dippings: 1,
8. Various Annealing Temperatures: 600 ºC and 800 ºC,
9. Various Time of Annealing: 1 minute to 5 minutes,
10. Various Dipping Solution temperatures: 0 ºC to 100 ºC,
11. Number of Annealing: 1

3. RESULTS & DISCUSSION

Characterization of SWCNTS

3.1 Structural Characterization Tapioca Leaves

Fig. 1 delivered X-ray diffract gram (XRD) of Tapioca leaves annealed at 600 ºC (2 minutes) dipped in NaOH solution @ 45 ºC (volume: 1.5 ml) for 90 seconds. Fig. 2 defined X-ray diffract gram (XRD) of Tapioca leaves annealed at 800 ºC (4 minutes) dipped in Hot water mixed with DD water @ 100 ºC (volume: 0.5 ml) for 30 seconds. The XRD spectrums showed amorphous (non-crystalline) nature.

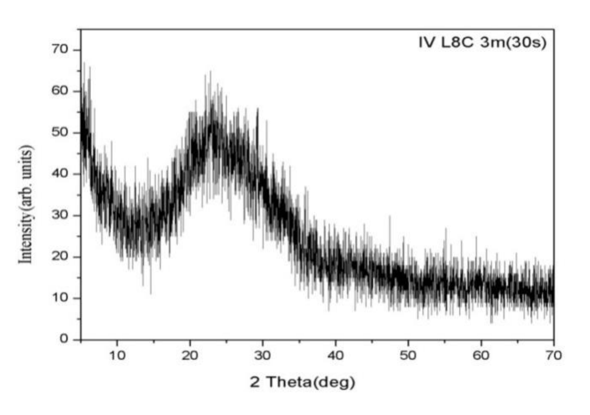


Fig. 1: X-ray diffract gram (XRD) of tapioca annealed at 600ºC (2 minutes) dipped in NaOH solution @ 45 ºC (Volume: 1.5 ml) for 90 seconds.

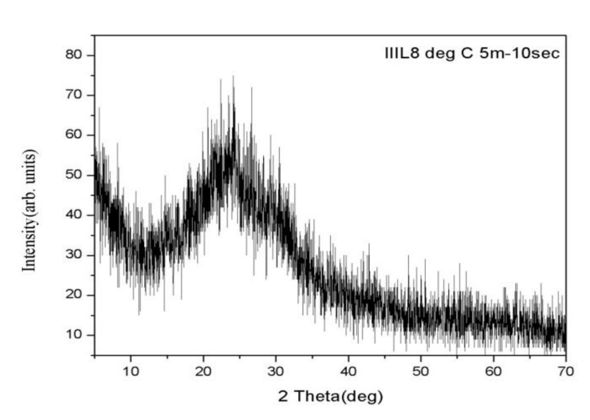


Fig. 2: X-ray diffract gram (XRD) of Tapioca annealed at 800 ºC (4 minutes) dipped in Hot water mixed with DD water @ 100oC (volume: 0.5 ml) for 30 seconds.

Open air dry of tapioca fresh leaves after taken out from field and annealing at 600 ºC (2 min) and 800ºC (4 minutes) leads to complete dryness of leaf. Due to that dehydration (removal of H_2O molecules from C-H-O matrix) takes place in the leaf. Finally it allows carbon atoms only present in the leaf. After annealing, we have to immediately undergone that leaves by dipping into NaOH solution with solution temperature 45 ºC and Hot water mixed with DD water with solution temperature 100 ºC. Due to sudden cooling, the carbon lattices present in the leaves were cracked, split up into individual atoms. Finally that lattice formation is disappeared, leads to amorphous (non-crystalline) nature.

3.2 Compositional Characterization Tapioca Leaves

Fig. 3 confirmed the EDAX studies on Tapioca leaves annealed at 800 ºC (2 mints) dipped in Mineral water (volume: 2.5 ml) for 60 seconds. Fig. 4 interpreted the EDAX studies on Tapioca leaves annealed at 800 ºC (2 mints) dipped in Sodium Hydroxide (NaOH) (volume: 2.5 ml) for 60 seconds. The EDAX spectrums showed compositional elements present in the Tapioca leaves.

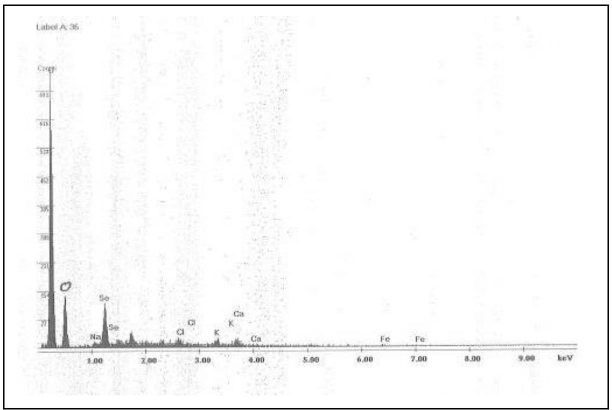


Fig. 3: EDAX studies on Tapioca leaf annealed at 800 ºC (2 mints) dipped in Mineral water (volume: 2.5 ml) for 60 seconds.

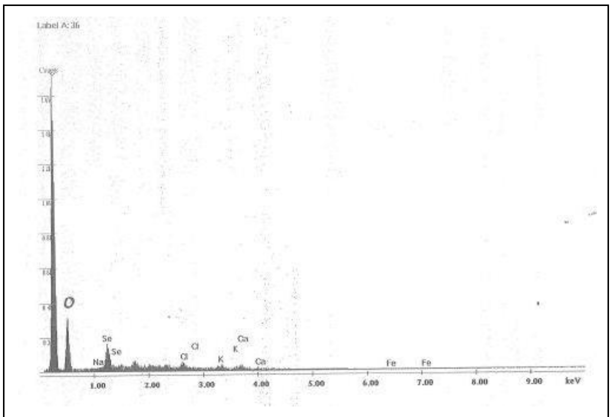


Fig. 4: EDAX studies on Tapioca leaf annealed at 800 ºC (2 mints) dipped in Sodium Hydroxide (NaOH) (volume: 2.5 ml) for 60 seconds.

Presence of rich Carbon atoms (1st prominent peak in EDAX spectrum) confirmed that the formed tubes are made up of carbon atoms. Which was authentically shows the formation of CNTs. Due to high temperature annealing, dehydration takes place, H_2 atom was removed. Which was evidentially shown from the edax spectrum (i.e., H_2 not found in the EDAX spectrum) Presence of O_2 atom in the EDAX spectrum evidentially shows that oxygen was injected / feed up during annealing. Presence of (Silicon) Si,(Oxygen) O shows that the leaf was enriched with SiO_2 (Soil) in which the plant (herb) was grown. Na, Se, K, Cl, Ca and Fe proved that the Soil was enriched with fertilizer and roots of plant sucked these essential elements (nutrients) from soil for its growth and stability.

3.3 Surface Morphological Characterization

SEM studies were carried out with a JEOL JSM-840 operated at 20 KV.

Tapioca Leaves

In Fig. 5, Surface morphology (SEM) of 800 ºC (5 minutes) annealed red hot Tapioca dipped in Hot Water mixed with Double Distilled Water (HW+D2W)solution (volume: 2.5 ml) for 30 seconds, shows close up view of earliest high grade SWCNTs threading out (earliest tubular growth of graphene layer rolling) from carbon core. In Fig. 6, Surface morphology (SEM) of 800 ºC (3 minutes) annealed red hot Tapioca dipped in Hot Water mixed with Double Distilled Water (HW+D2W) solution (volume: 1.5 ml) for 60 seconds, shows close up view of intermediate stage of free standing, shuffled high grade SWCNTs already threaded out from carbon core (an authentication, also a better evidence for SWCNTs growth) .

In Fig. 7, Surface morphology (SEM) of 800 ºC (2 minutes) annealed red hot Tapioca dipped in Hot Water mixed with Double Distilled Water (HW+D2W) solution (volume: 1 ml) for 90 seconds, shows close up view of pre-final stage of free standing, semi-matured, shuffled high grade SWCNTs already threaded out from carbon core (an authentication, also a better evidence for SWCNTs growth) . In Fig. 8, Surface morphology (SEM) of 800 ºC (2 minutes) annealed red hot Tapioca dipped in Mineral Water(MW) (volume: 1.0 ml) for 90 seconds, shows close up view of clustering of hexagonal carbon matrices due to poor coagulation during sudden cooling-dipping.

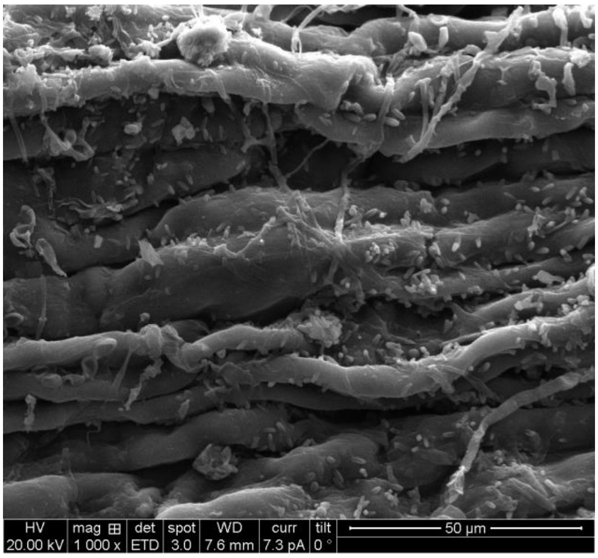


Fig. 5: Surface morphology (SEM) of 800 °C (5 minutes) annealed red hot Tapioca dipped in Hot Water mixed with Double Distilled Water (HW+D2W) solution (volume: 2.5 ml) for 30 seconds, shows close up view of earliest high grade SWCNTs threading out (earliest tubular growth of graphene layer rolling) from carbon core.

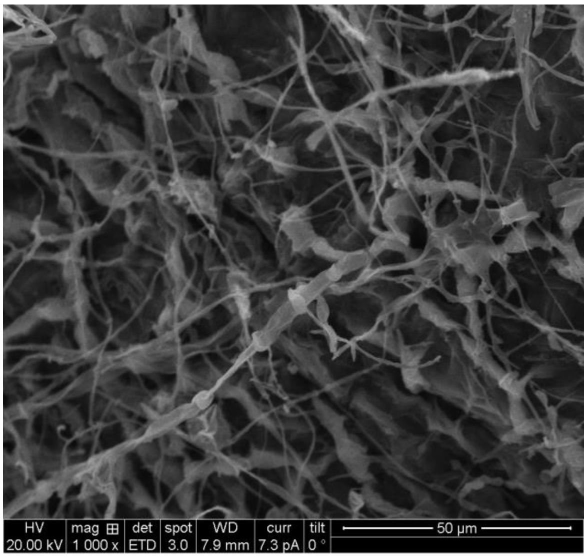


Fig. 6: Surface morphology (SEM) of 800 °C (3 minutes) annealed red hot Tapioca dipped in Hot Water mixed with Double Distilled Water (HW+D2W) solution (volume: 1.5 ml) for 60 seconds, shows close up view of intermediate stage of free standing, shuffled high grade SWCNTs already threaded out from carbon core (an authentication, also a better evidence for SWCNTs growth).

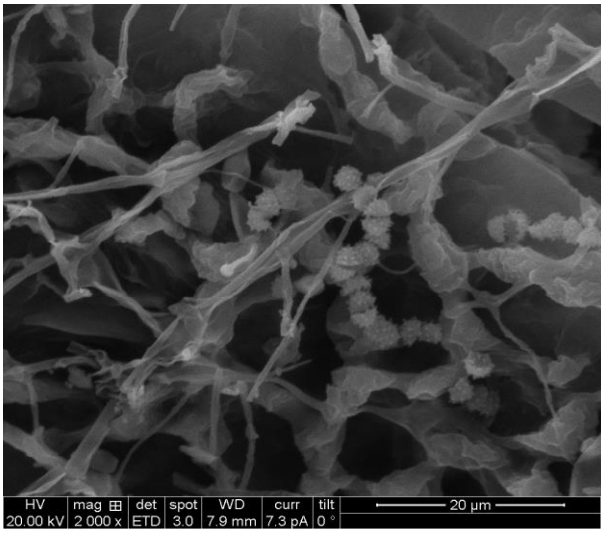


Fig. 7: Surface morphology (SEM) of 800 °C (2 minutes) annealed red hot Tapioca dipped in Hot Water mixed with Double Distilled Water (HW+D2W) solution (volume: 1 ml) for 90 seconds, shows close up view of pre-final stage of free standing, semi-matured, shuffled high grade SWCNTs already threaded out from carbon core (an authentication, also a better evidence for SWCNTs growth).

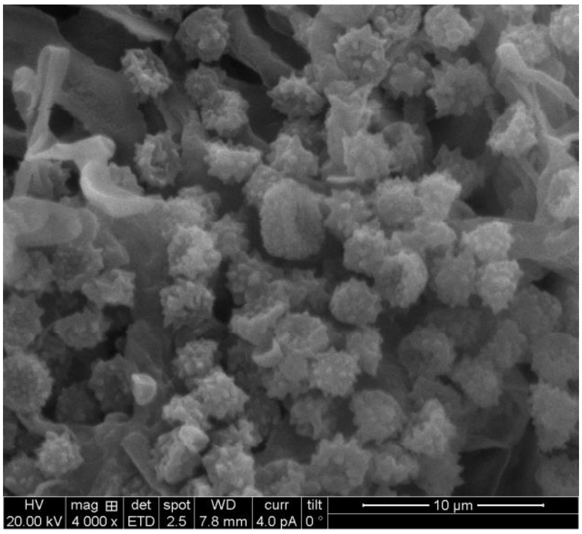


Fig. 8: Surface morphology (SEM) of 800 °C (2 minutes) annealed red hot Tapioca dipped in Mineral Water(MW) (volume: 1.0 ml) for 90 seconds, shows close up view of clustering of hexagonal carbon matrices due to poor coagulation during sudden cooling-dipping.

In Fig. 9, Surface morphology (SEM) of 800 ^{o}C (1 minute) annealed red hot Tapioca dipped in mineral water (MW) (volume: 0.5 ml) for 120 seconds, shows close up view of very poor coagulation of hexagonal carbon matrices due to sudden cooling-dipping. In Fig. 10, Surface morphology (SEM) of 800 ^{o}C (3 minutes) annealed red hot Tapioca dipped in Mineral Water (MW) solution (volume: 1.5 ml) for 60 seconds, shows close up view of intermediate stage of free standing, shuffled moderate grade tubular SWCNTs threaded out from clustering of hexagonal carbon matrices (originated due to poor coagulation during sudden cooling-dipping). (an authenticated better evidence for SWCNTs growth).

In Fig. 11, Surface morphology (SEM) of 800 ^{o}C (5 minutes) annealed red hot Tapioca leaf dipped in Mineral Water (MW) solution (volume: 2.5 ml) for 30 seconds, shows close up view of final stage of free standing, shuffled, matured moderate grade tubular SWCNTs threaded out from clustering of hexagonal carbon matrices (originated due to poor coagulation during sudden cooling-dipping). (an authenticated better evidence for SWCNTs growth). In Fig. 12, Surface morphology (SEM) of 800 ^{o}C (1 minute) annealed red hot Tapioca leaf dipped in Sodium Hydroxide (NaOH) Solution (volume: 0.5 ml) for 120 seconds, shows very poor coagulation of basic carbon core regions.

In Fig. 13, Surace morphology (SEM) of 800 ^{o}C (3 minutes) annealed red hot Tapioca dipped in Sodium Hydroxide (NaOH) Solution (volume: 1.5 ml) for 75 seconds, shows close up view of (intermediate stage) scattering of hexagonal carbon networks which were already derived from inner carbon core. In Fig. 14, Surface morphology (SEM) of 800 ^{o}C (4 minutes) annealed red hot Tapioca dipped in Sodium Hydroxide (NaOH) Solution (volume: 2.0 ml) for 45seconds, shows close up view of tubular textured high grade SWCNTs threading out [via graphene sheet rolling] from base carbon core.

In Fig. 15, Surface morphology (SEM) of 800^{o}C (5 minutes) annealed red hot Tapioca dipped in Sodium Hydroxide (NaOH) Solution (volume: 2.5 ml) for 30 seconds, shows close up view of well advanced, free standing, super matured SWCNTs which were already threaded out from (via graphene layer rolling)base carbon matrices. In Fig. 16, Surface morphology (SEM) of 800^{o}C (1 minute) annealed red hot Tapioca dipped in Hot Water mixed with Double Distilled Water (HW+D2W) solution (volume: 0.5 ml) for 120 seconds, shows a clear evidence for deriving of high grade SWCNTs from carbon core species.

In Fig. 17, Surface morphology (SEM) of 800 ^{o}C (3 minutes) annealed red hot Tapioca dipped in Hot Water mixed with Double Distilled Water (HW+D2W)solution (volume: 1.5 ml) for 75 seconds, shows an intermediate growth stage of high grade SWCNTs from carbon core species via hexagonal carbon clusters. In Fig. 18, Surface morphology (SEM) of 800^{o}C (4 minutes)annealed red hot Tapioca dipped in Hot Water mixed with Double Distilled Water (HW+D2W)solution (volume: 2.0 ml) for 45 seconds, shows close up view of pre-final, matured high grade SWCNTs-tubular texture threaded out from core species via graphene rolling.

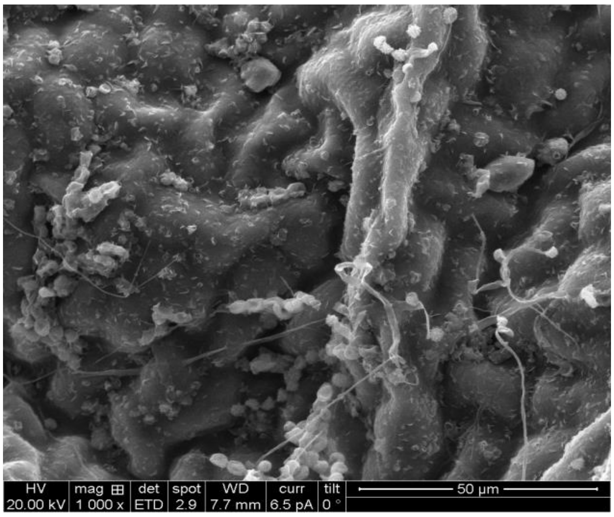
In Fig. 19, Surface morphology (SEM) of 800 ^{o}C (4 minutes) annealed red hot Tapioca dipped in Mineral Water (MW) (volume: 2.0 ml) for 45 seconds, shows close up view of in-homogeneously distributed moderately grown hexagonal carbon networks originated from carbon core species due to explosion during sudden cooling-dipping. In Fig. 20, Surface morphology (SEM) of 800 ^{o}C (3 minutes) annealed red hot Tapioca leaf dipped in Mineral Water (MW) (volume: 1.5 ml) for 75 seconds, shows eagle view and evidential proof for the origination of tubular SWCNTs from hexagonal carbon network distribution in an intermediate stage.

3.4 Nanostructural Characterization

HRTEM studies were carried out with a JEOL JSM-840 operated at 20 KV.

Tapioca Leaves

In Fig. 21, HRTEM image shows poor Coagulation of Scattered pentagonal, hexagonal carbon networks, which forms Graphene sheets(due to sudden cooling inside dipping solution) from 800 ^{o}C (2 minutes) red-hot Tapioca leaf when dipping in Mineral Water(MW) (volume: 0.5 ml) for 120 seconds, kept at room temperature based on single time annealing and single time dipping process. In Fig. 22, HRTEM image shows an intermediate stage of very poor coagulation of scattered pentagonal, hexagonal carbon networks, which forms graphene sheets from 600 ^{o}C (2 minutes) red-hot Tapioca leaf when dipping in NaOH solution (volume: 1 ml) for 90 Seconds (the dipping solution was kept at room temperature) based on single time annealing and dipping.



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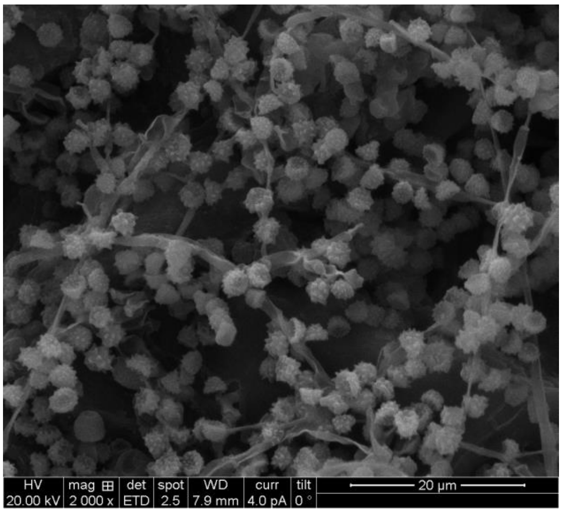


Fig. 10: Surface morphology (SEM) of 800 °C (3 minutes) annealed red hot Tapioca dipped in Mineral Water (MW) solution (volume: 1.5 ml) for 60 seconds, shows close up view of intermediate stage of free standing, shuffled moderate grade tubular SWCNTs threaded out from clustering of hexagonal carbon matrices (originated due to poor coagulation during sudden cooling-dipping). (an authenticated better evidence for SWCNTs growth).

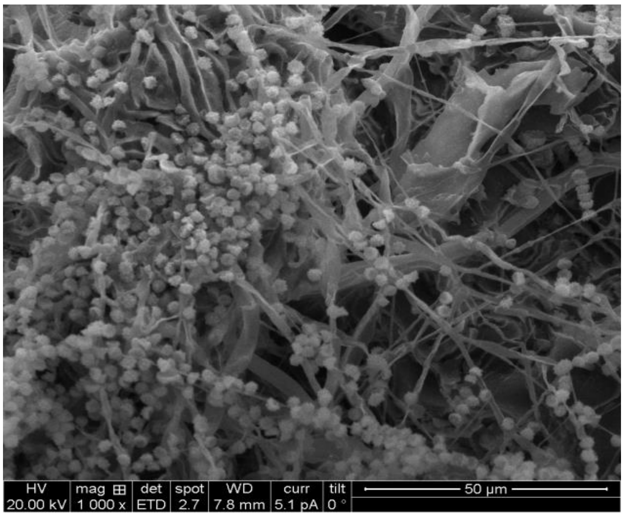


Fig. 11: Surface morphology (SEM) of 800 °C (5 minutes) annealed red hot Tapioca leaf dipped in Mineral Water (MW) solution (volume: 2.5 ml) for 30 seconds, shows close up view of final stage of free standing, shuffled, matured moderate grade tubular SWCNTs threaded out from clustering of hexagonal carbon matrices (originated due to poor coagulation during sudden cooling-dipping). (an authenticated better evidence for SWCNTs growth).

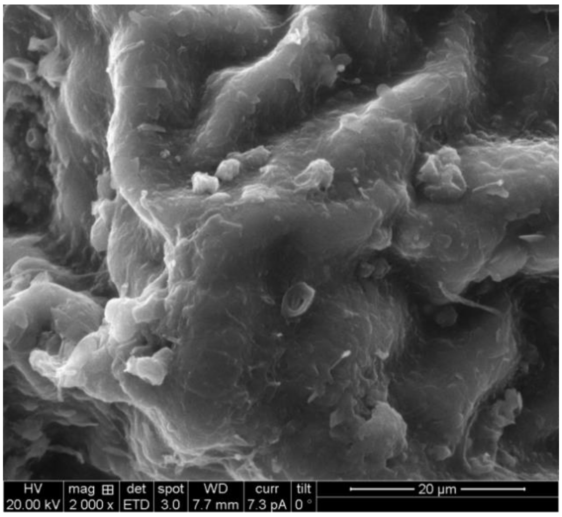
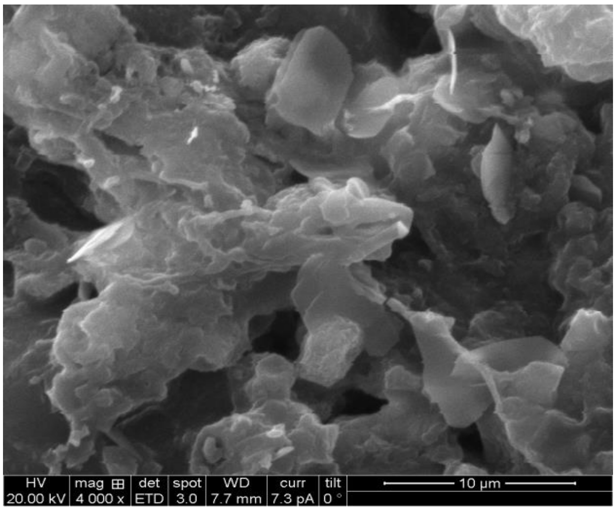


Fig. 12: Surface morphology (SEM) of 800 °C (1 minute) annealed red hot Tapioca leaf dipped in Sodium Hydroxide (NaOH) Solution (volume: 0.5 ml) for 120 seconds, shows very poor coagulation of basic carbon core regions.



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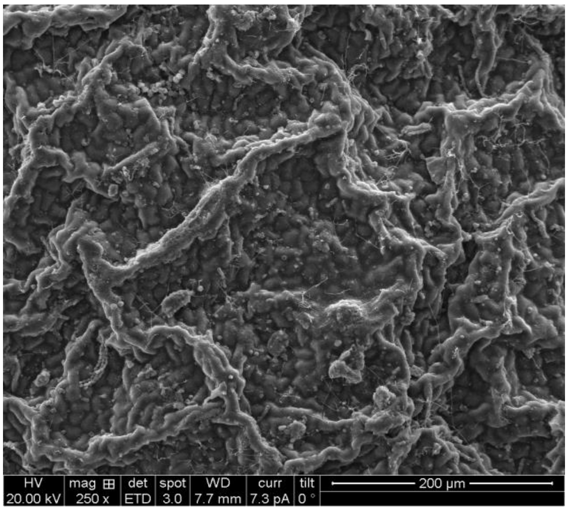

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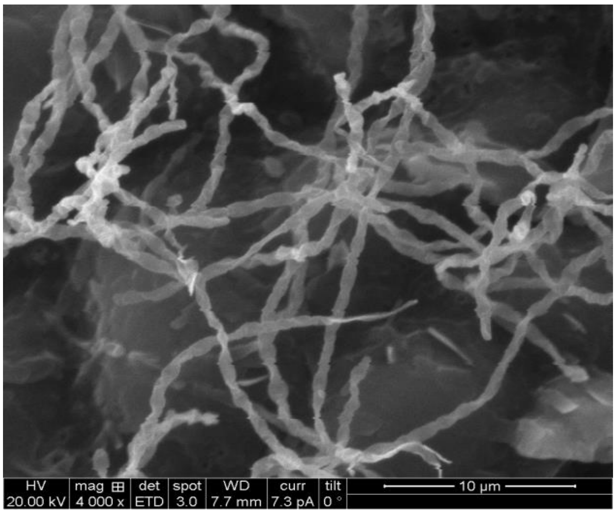

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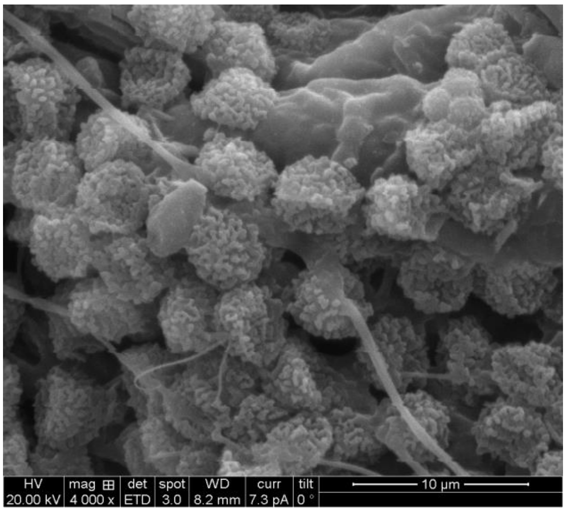

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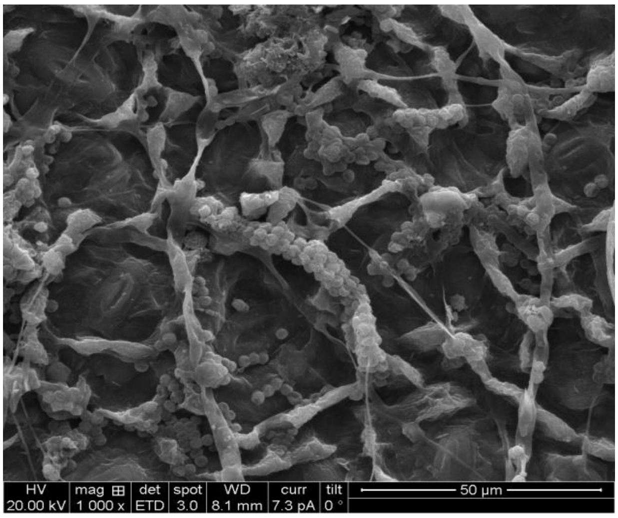

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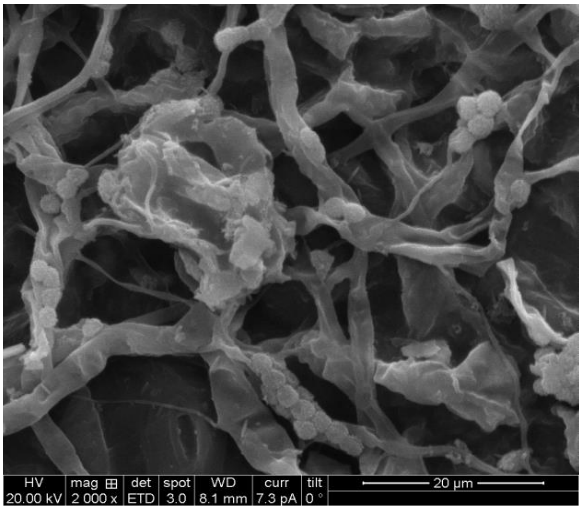
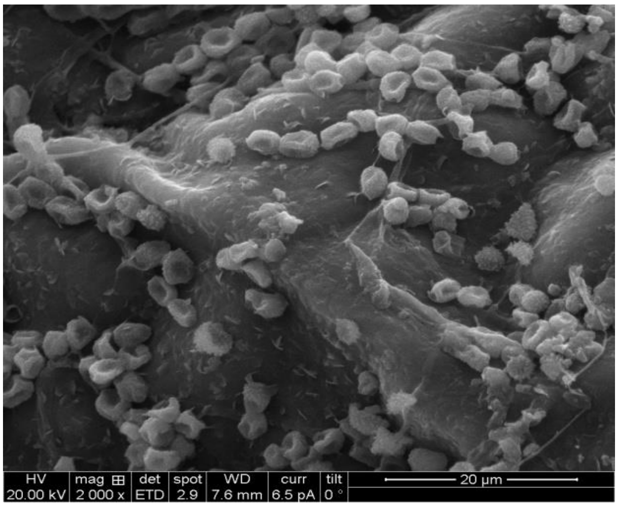


Fig. 18: Surface morphology (SEM) of 800 °C (4 minutes)annealed red hot Tapioca dipped in Hot Water mixed with Double Distilled Water (HW+D2W)solution (volume: 2.0 ml) for 45 seconds, shows close up view of pre-final, matured high grade SWCNTs-tubular texture threaded out from core species via graphene rolling.



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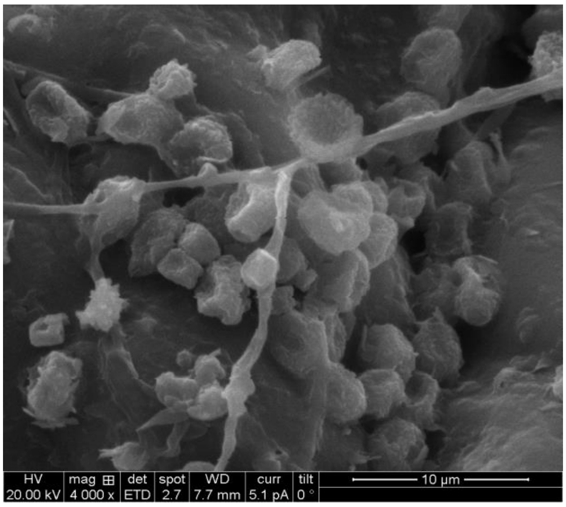

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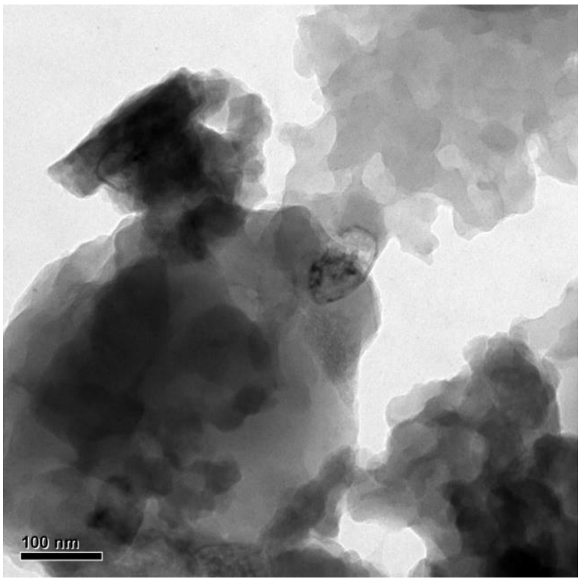

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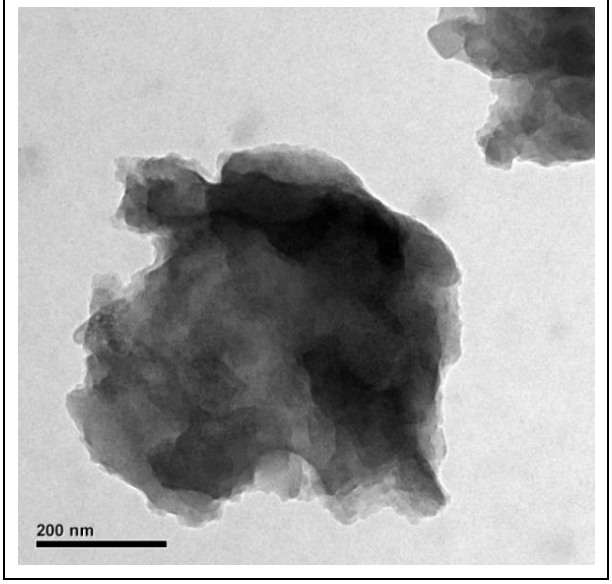

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The effects of optimizations parameters like pH of the various dipping solutions (acidic, basic and neutral), volume of dipping solutions, various types and parts of the materials, various dipping timings, number of annealing and dipping, various annealing temperature, various time of annealing and various dipping solution temperatures on structural, compositional, surface morphological, nano-structural characterizations of materials and on high grade SWCNTs growth with high yield were studied intensively. Parameters, as inferences from above characterizations were calculated, tabulated and graphically emphasized. Correlation studies between these characterization inferences (such as grain size, purity) and optimization parameters were carried out with a high light on yield of high grade SWCNTs. Beyond all of these, we have carried out a new feasibility study at first time, which comprises the possible usage of precursor organic carbon source i.e., Tapioca leaves for high grade SWCNTs with high yield via a low cost technique and methodology as value in commercial efforts.

4. CNCLUSION

In this over all study, Tapioca leaves (under conventional materials) plays as a suitable material for high grade SWCNTs growth. Also any Dipping Solution (of Volume: 2.5 ml) having pH=7, i.e., neutral solution (normally maintained at room.temp., RT) (with 30 Seconds as optimum time of dipping) act as an optimum medium which provides suitable environment for high grade, large quantity SWCNTs growth. Similarly 800 ^{o}C (having annealing time: 3 minutes) provides suitable background thermal history for high grade, large quantity SWCNTs growth based on single time annealing and dipping process. High purity precursor material yield high grade SWCNTs.

Tapioca Leaves

Fig. 23 delivered the Profile of Quantity of SWCNTs formation (%) with different dipping solution with an over view on Quality grades of grown SWCNTs, from Tapioca leaves. Also it confirms that neutral (having pH=7) and basic (having pH.>7) dipping solutions provide suitable environment for high yield of high grade SWCNTs. All of these works have value in nanotechnology, nano-materials processing and device fabrication efforts either as a technical or scientific basis, also as a contribution to the present day state of the art of energy efficient opto-electronic devices such as 3D – high efficiency Solar cells, Flat panel displays, LEDs & Lasers, Magnetic storage devices and Nano thermometers.

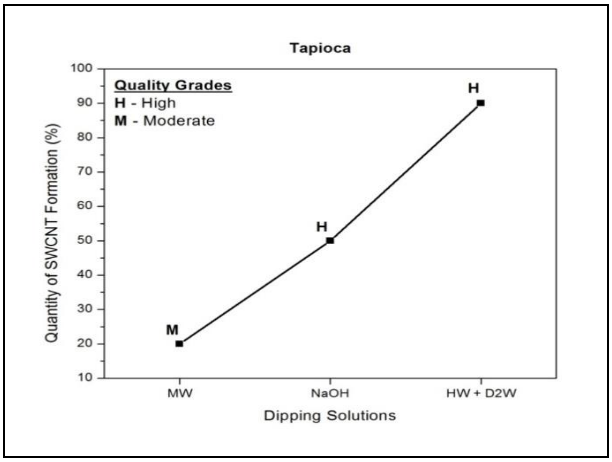

Fig. 23: Profile of Quantity of SWCNTs formation (%) with different dipping solution with an over view on Quality grades of grown SWCNTs, from Tapioca leaves.

ACKNOWLEDGEMENTS

The authors like to acknowledge the supports provided by Department of Metallurgy, Solid state structural chemistry unit, IISc, Bangalore and PSG Institute of Adv. Studies, Coimbatore.

FUNDING

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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REFERENCES

Ajayan, P. M. and Iijima, S., Capillarity-induced filling of carbon nanotubes, *Nature*, 361, 333-334(1993). https://doi.org/10.1038/361333a0

Ajayan, P. M. and T. W. Ebbesen, Nanometre size tubes of carbon, *Rep. Prog. Phys*., 60(10), 1025-1062(1997). https://doi.org/10.1088/0034-4885/60/10/001

Bellucci, S., et al, AFM Characterizations of CNTs, *Journal.Phy.Conf.Series* 61(2007) 99-104

Bond, J., Lefebvre, J., Austing, D. G. and Finnie, P., CVD of SWCNTs freely suspended over NT supports, Nanotechnology, 18(13), 135603(2007). https://doi.org/10.1088/0957-4484/18/13/135603

Calvert, P.,*Nature* 399,210 (1999) 409

Cees Dekker, Carbon nanotubes as molecular quantum wires, *Phys. Today*, 22-28(1999) 391

Chiu, P. W., Duesberg, G. S., Weglikowska, U. D. and Roth, S., Interconnection of CNTs by chemical functionalization, *Appl. Phy. Lett*., 80(20), 3811-(2002). https://doi.org/10.1063/1.1480487

Chun Li, Guojia Fang, Longyan Yuan, Nishuang Liu, Lei Ai, Qi Xiang, Dongshan Zhao, Chunxu Pan and Xingzhong Zhao, Field emission from carbon nanotube bundle arrays grown on self - aligned ZnO nanorods, Nanotechnology, 18(15), 155702(2007). https://doi.org/10.1088/0957-4484/18/15/155702

Collins, P. and Zettl, A., *Appl.Phy.Lett*, 69, 396 (1996).

Dean, K. A. and Chalamala, B. R., Field emission microscopy of carbon nanotube caps, *J.Appl.Phys* 85(7) (1999) 396. https://doi.org/10.1063/1.369753

Dresselhaus, M. S., Science of Fullerenes and Carbon nanotubes, Academic Press, New York, 965(1996).

Dresselhaus, M. S., Williams, K. A. and Eklund, P. C., MRS Bull, 24,11,45 (1999) 404

Dujardin, E., Ebbesen, T. W., Hiura, T. and Tanigaki, K., Capillarity and wetting of carbon nanotubes, *Science* 265(5180), 1850-1850(1994).

Ebbesen, T. W., Carbon nanotubes: Preparation and properties, CRC Press, Boca Raton, 391.(1997) .

Guoyong Xu, Wei-Tai Wu, Yusong Wang, Wenmin Pang, Qingren Zhu and Pinghua Wang, Functionalised CNTs with polystyrene-block-poly (N-isopropylacrylamide) by in-situ RAFT Poymerization, *Nanotechnology*, 18(14), 145606(2007). https://doi.org/10.1088/0957-4484/18/14/145606

Iijima, S. and Ichihashi, T., Single-shell carbon nanotubes of 1-nm diameter, *Nature*, 363, 603-606(1993). https://doi.org/10.1038/363603a0

Iijima, S., Helical microtubules of graphitic carbon, *Nature*, 354(6348), 56-58(1991). https://doi.org/10.1038/354056a0

Kuromochi, H., Tokizaki, T., Yokoyama, H. and Dagata, J. A., Why nano-oxidation with CNT probes is so stable : I.Linkage between hydrophobicity and stability, *Nanotechnology*, 18(13), 135703(2007). https://doi.org/10.1088/0957-4484/18/13/135703

Majumder M, *et al.*, Nanoscale hydrodynamics: enhanced flow in carbon nanotubes, nature 383 (2005) 438-444

Mattia, D., Korneva, G., Sabur, A., Friedman, G. and Y.Gogotsi, Multifunctional CNT with nanoparticles embedded in their walls, *Nanotechnology*, 18(15), 155305 (2007). https://doi.org/10.1088/0957-4484/18/15/155305

Rossi, M. P., Ye, H., Gogotsi, Y., Babu, S., Ndungu, P. and Bradley, J. C., Environmental SEM study of water in carbon nanopipes, *Nano Lett.*, 4(5), 989-993(2004).
https://doi.org/10.1021/nl049688u

Rostam Moradian and Ali Fathalian, Ferromagnetic semiconductor single wall CNTs, *Nanotechnology*, 17(8), 1835-1842(2006).
https://doi.org/10.1088/0957-4484/17/8/005

Safarova, K., Dvorak, A., Kubinek, R., Vujtek, M. and Rek, A., Usage of AFM, SEM, TEM for the research of CNTs, *Mod. Res. Edu. Topics Micro.*, 513-519(2007).

Shaoping Xiao and Wenyi Hou, Studies of Size effects on CNTs : mechanical properties by using differential potential functions, *Fullerenes, nanotubes and carbon nanostructures*, 14(1), 09-16(2006).
https://doi.org/10.1080/15363830500538425

Shiren Wang, Zhiyong Liang, Tina Liu and Chun (Chuck) Zhang, Effective amino - functionalization of CNTs for Reinforcing epoxy polymer composites, *Nanotechnology*, 17(6), 1551-1557(2006).
https://doi.org/10.1088/0957-4484/17/6/003

Teh-Hwa Wong *et al.*, Nanosecond Laser pulse - induced electron emission from MWCNTs films, *Nanotechnology*, 18 135705(2007).
https://doi.org/10.1088/0957-4484/18/13/135705

Wang, Y., Iqbal, Z. and Malhotra, S. V., Functionalization of CNTs with amines and enzymes, *Chem.Phys.Lett* 402(1-3), 96-101(2005).
https://doi.org/10.1016/j.cplett.2004.11.099

Wang. S., Liang, Z., Wang, Ben. and Zhang, C., Statistical characterization of SWCNTs length distribution, *Nanotechnology*, 17(3), 634-639(2006).
https://doi.org/10.1088/0957-4484/17/3/003

Winter, M., Besenhard, J., Spahr, K. and Novak, P., *Adv.Mater*.10,725 (1998) 402

Xue, Q. Z., Model for the effective thermal conductivity of CNT Composites, *Nanotechnology*, 17(6), 1655-1660(2006).
https://doi.org/10.1088/0957-4484/17/6/020

Yakobson, B. I. and Smalley, R. E., Fullerence Nanotubes: $C_{1,000,000}$ and Beyond: Some unusual new molecules-long, hollow fibers with tantalizing electronic and mechanical properties – have joined diamonds and graphite in the carbon family, *American Scientist*, 85(4), 324-337(1997).

Zhenhui Kang *et al.*, Obtaining CNTs from grass,*Nanotechnology*,16 (2005) 1192-1195.

Zhiyang Rong, Fabrication and characterization of CNTs for bio-medical applications, M.Sc Thesis,Aug., 01-83(2008).