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Carbon Nanotubes: Synthesis, Characterisation and Applications

ICMAT 2009

International Conference on Materials for Advanced Technologies 2009

AND

IUMRS - ICA 2009

International Union of Materials Research Societies-International Conference in Asia 2009

28 June - 3 July 2009, Singapore

Suntec Singapore International Convention & Exhibition Centre

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Symposium H

Carbon Nanotubes: Synthesis, Characterisation and Applications

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Scope of Symposium

Carbon nanotubes are one of the most important building blocks and materials in nanotechnology. Their unique combination of nano-sized diameter with macroscopic length scale has lead to many new phenomena and properties. Progress in large-scale synthesis, control of their structural properties, thin film transparent electrodes and nano-composites continues to widen their application in many new technologies.

Carbon nanotube research has over a short period time generated sufficient critical mass to be known as emerging technology on its own. This material is of high importance to the materials research community as it covers a broad range of fundamental understanding in nano-science as well as applications.

Symposium Topics

- Synthesis of carbon nanotubes
- Optical Spectroscopy
- Theory and Characterization of Nanotubes
- NEMS and Related Properties
- Electronics and Related Properties
- Physical Properties and Devices
- Biological and Chemical Properties and Devices
- Device Integration

Contents

Abstracts

A00047-01657

Energetic Properties and Work Function of K Intercalated Carbon Nanotube Tip: Applications to Field-Emission

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The knowledge of the work function energy plays a highly important role in an application of carbon nanotube for field emission devices. In this study, we calculated the interaction energy and the work function as defined at mid-gap of between HOMO and LUMO energy of the K intercalated onto the single wall carbon nanotube tip by using density functional theory (DFT). By using zigzag tube 2 unit cells, the tube diameter was $n = 9$. The intercalation of K is at the center of tube through the nanotube tip of SWNTs. It was found that the work function of K at the exterior is higher than the interior of carbon nanotube tip and K prefer to absorb onto interior more than exterior. The work function of the pristine carbon nanotubes tip (SWNTs) can reduced work function by intercalating K in both side wall of SWNT.

A00083-00366

Characteristics of Hot Extruded Composite Metals Dispersed with Un-bundled CNTs

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Characteristics of pure metal matrix composite material reinforced with carbon nanotubes (CNTs) have been examined. Pure Cu, Mg and Al powder coated by un-bundle CNTs were prepared by using the surfactant (surface active agent), having both hydrophobic and hydrophilic groups, via wet process. In the paper, the microstructural and mechanical properties of CNT-Cu composites particular were investigated in detail. Cu powder with a mean particle size of 150 μm and multi-wall CNTs with 20 nm in diameter were used as matrix materials and reinforcements, respectively. After dipping Cu powder into the solution with CNTs, the composite Cu powders coated with CNTs were served to heat treatment in hydrogen atmosphere to thermally resolve the surfactant films of the powder surface. The suitable temperature in heat treatment was determined by differential thermal analysis on the composite Cu powder. The extruded Cu including CNTs indicated an increase of 30% hardness and 17% yield strength, compared to pure Cu without CNTs. The relationship between CNT content in the surfactant solution and total volume of CNTs deposited on powder surface was investigated in detail. The dependence of the mechanical response of extruded material on CNT content was also discussed.

A00086-00885

Current-voltage Characteristics of Long Carbon Nanotubes Bundles

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Current-voltage (*IV*) characteristics of carbon nanotubes (NTs) depend on the diameter, length and the nanotube-substrate interaction. Remarkable is that the current saturation have been observed for meltallic as well as semicondcuting single-walled NT (SWNT) which is attributed to the electron back scattering by high energy optical and zone-boundary phonon and interband zener tunneling. However, series of independent transport measurements on various length demonstrated the absence of current saturation in NTs shorter than 55 nm. The mean free path of optical phonon scattering is in the range of 10–100 nm and therefore, the absence of current saturation was interpreted as ballistic transport through the NTs.

We have investigated the *IV* characteristics of millimeter-long NT bundles in the view point of technological applications and fundamental understandings. Millimeter long NTs with an average diameter of 50 nm are prepared by a simple pyrolysis technique. Taking the advantage of the long NTs, the electrical contacts have been made to the bundle using conventional method. Different bundles are taken on oxidised silicon or glass substrates and thin copper wires were connected to either side of the bundle with the help of conducting silver epoxy. We have observed the absence of current saturation in long NTs and that the current increases rapidly with applied voltage. The general theory of semiconductors along with the Joule heating satisfactorily reproduces the experimental *IV* characteristics suggesting that the non-linear *IV* characteristic is a temperature effect. It is also interesting to note that the bundle can carry current in mA range while the current carrying capacity is in μA range for individual nanotubes. Each nanotube in a bundle behaves like they are connected in parallel to each other and carry such a large current. It may be noted that the maximum current, *i.e.*, the current carrying capability of bundle increases with the number of tubes in the bundle.

A00180-00805

Interfacial Properties of Single-Walled Carbon Nanotubes

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Dispersing single-walled carbon nanotubes (SWNTs) in a solvent is required for many applications but common organic solvents offer insufficient solvation forces to suspend SWNTs. Surfactants or polymers are often used to stabilize aqueous SWNT suspensions; however bundled nanotubes remain due to strong van der Waals attractions. Conventional dispersion processes use high-shear homogenization, ultrasonication, and ultracentrifugation to remove nanotube bundles. However, alternative routes to remove SWNT bundles from suspensions are needed for economic large-scale dispersion. We have recently developed a novel separation which exploits the efficiency of liquid-liquid interfacial chemistry to remove bundles from aqueous dispersions. This interfacial process has demonstrated dispersion characteristics comparable to ultracentrifugation using simple glassware in which separation occurs within minutes. Therefore, this method is a promising approach to developing a simple and more economic large-scale dispersion process.

Key to understanding and improving this process is better comprehension of the interfacial properties of SWNTs. These interfacial properties include the interaction between surfactant – water – solvent – nanotube. The fluorescence emission energies of SWNTs are sensitive to the surrounding environment with suspended SWNTs being red-shifted in comparison to SWNTs in air. The extent of the shift is dependent on the surfactant, protein, or polymer that encases the nanotube. The optically excited electronic states of SWNTs are also highly mobile, making them sensitive to extrinsic effects that can reduce the quantum yield, including sidewall defects, protonation, surfactant inhomogeneties, bundles, and nanotube ends (i.e., lengths).

These changes in fluorescence are used to probe the interfacial properties of SWNTs and identify several new interfacial phenomena in SWNT systems. In some systems, we have observed the formation of emulsion-like environments surrounding the nanotubes by swelling the surfactant micelle with immiscible organic solvents. We have also demonstrated the ability to reorganize the surfactant structure surrounding SWNTs through both chemical and mechanical manipulations to improve the fluorescent properties of the suspension. For the largest diameter SWNTs in an SDS suspension, the fluorescence intensities can increase by as much as 20 times without changes to the absorbance or Raman spectra. In addition, these SWNTs are better protected from the fluorescence quenching effect of acid and show better suspension stability over time. These results show that SDS suspends all (n,m) types as well as SDSB and sodium cholate; however, the structure surrounding the largest diameter SWNTs often assumes a conformation that results in significant fluorescence quenching.

The ability to manipulate and control the surfactant structure surrounding SWNTs may enable new approaches to study the surfactant structure surrounding carbon nanotubes and their photophysical properties. We will show how these systems can be used to probe the polarizability of the SWNTs. The ultimate objective is to learn how to compensate for extrinsic factors and increase the quantum yields of bulk SWNT suspensions.

A00203-00388

Preparation of Thermoplastic Polyurethane / Functionalized Graphene Sheet Nanocomposites by In Situ Method and Their Properties

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The functionalized graphene sheet (FGS) was recently introduced as a new nano-sized conductive filler, however few papers as of yet have been reported about the polymer nanocomposite of FGS. In our previous study, we prepared thermoplastic polyurethane (TPU) / FGS nanocomposite by physical mixing method and examined their properties. Because FGS has oxygen-containing functional groups on the surface, the TPU can be grafted on FGS when the polymerization was carried out in the presence of FGS. So, in this study we prepared the TPU/FGS nanocomposite by in situ method and examined their properties. The gravimetry showed that TPU was grafted on FGS when the nanocomposite was prepared by in situ method. The modulus enhancement and the decreases of tensile strength and elongation at break by FGS were more pronounced compared to those nanocomposites prepared by physical mixing method. The FGS, finely dispersed in TPU matrix, effectively improved the conductivity. That is, the nanocomposite containing 2 parts of FGS per 100 parts of TPU had the conductivity of 2.07×10^{-3} S/cm, which is about 10^{8}-fold higher value compared to pristine TPU. Our results showed that the reinforcing effect of FGS was magnified by the grafting. However, the large reductions of tensile properties measured at large deformation, tensile strength and elongation at break, showed that the chain rearrangement by tensile force at large deformation was interfered by the grafting.

A00203-00432

Preparation of Waterborne Polyurethane/ Functionalized Graphene Sheet Nanocomposites by In Situ Method and Their Properties

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The nanocomposites of waterborne polyurethane (WPU) were prepared with functionalized graphene sheets (FGSs) which are a new type of nano-size conductive filler. The FGS were finely dispersed in a polymer matrix to improve the conductivity of the WPU. Conductivity of about 10^6 times that of pristine WPU was attained using three parts of FGS per 100 parts of the matrix polymer. The FGS increased the soft segment crystallinity whereas reduced the hard segment crystallinity. The modulus of the nanocomposites was increased as the content of FGS was increased. However, the tensile properties measured at high deformation, that is, the tensile strength and the elongation at break were decreased dramatically as the FGS content was increased. These results show that polyurethane segments are grafted on FGS, and the chain rearrangement by tensile force at large deformation was interfered by the grafting.

A00237-00481

Plasma-synthesized Arrays of Carbon Nanotubes and Related Nanostructures: A Deterministic Approach

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In this talk, I will discuss how unique and highly-unusual non-equilibrium features of low-temperature plasmas can be gainfully used for highly-controlled, ultimately deterministic synthesis of single- and multiwalled carbon nanotubes and carbon nanofibers. Several dedicated experiments will be reviewed and advanced physical growth models complemented by advanced numerical modelling under strongly non-equilibrium conditions are discussed. This synergetic approach is at its infancy despite more than a decade of research on the plasma-based synthesis of carbon nanotubes and related nanostructures. In particular, large-scale (~10^9 atoms) numerical simulations reveal that plasma-controlled dynamic delivery and redistribution of carbon atoms between the substrate and nanotube surfaces enable the growth of ultralong single walled carbon nanotubes (SWCNTs) and explain the common experimental observation of slower growth at advanced stages. It is shown that the plasma-based processes feature up to two orders of magnitude higher growth rates than equivalent neutral-gas systems and are better suited for the SWCNT synthesis at low nanodevice friendly temperatures. The growth of SWCNTs in a plasma is also studied using a surface diffusion model. It is shown that at low substrate temperatures (<1000 K), the atomic hydrogen and ion fluxes from the plasma can strongly affect nanotube growth. The ion-induced hydrocarbon dissociation can be the main process that supplies carbon atoms for SWCNT growth and is responsible for the frequently reported higher (compared to thermal chemical vapor deposition) nanotube growth rates in plasma-based processes. On the other hand, excessive deposition of plasma ions and atomic hydrogen can reduce the diffusion length of the carbon-bearing species and their residence time on the nanotube lateral surfaces. This reduction can adversely affect the nanotube growth rates. These results are in good agreement with the available experimental data and can be used for optimizing SWCNT growth in PECVD.

A00317-00620

Caculation of Young's Moduli of Graphene Sheets and Carbon Nanotubes using Analytical Solution and Numerical Simulation

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The supreme mechanical properties of Carbon nano-tube (CNT) are rendered them as a new generation of reinforcing agents for polymeric composites. Prediction of mechanical properties of CNT is one of the important issues which should be addressed reasonably through its development procedure. Experimental measurements for mechanical properties of CNTs are either complicated procedures or given highly scattered data. As a consequent, researchers are stimulated to obtain the properties using simulation and modeling techniques.

The main goal of this research is to predict Young's modulus of Graphene sheets and carbon nanotubes using nano-scale continuum mechanics approach. For this purpose, the lattice molecular structure of a Graphene sheet is simulated with an equivalent frame structure representing carbon-to-carbon chemical bonds. This simulation is carried out using a link between inter-atomic potential energies of molecular structure and strain energies of an equivalent continuum structure. Namely, the lattice structure of a Graphene sheet can be substituted with equivalent honeycomb-like continuum structure conventionally utilized as a core material in composite sandwich laminates. Then, the displacement field of a unit element of the structure is investigated using complementary potential energy of the structure. Deformations of frame elements are derived using Castiglinao's theorem and subsequent strain fields is derived. Then stress fields are developed and elastic modulus of a Graphene sheet is derived. A presented

closed-from solution leads us to a simple equation to obtain Young's modulus of a Graphene sheet. The presented equation implies on isotropic behavior of a Graphene sheet.

A Carbon nano-tube can be treated as a schematically rolled Graphene sheet. Two different configurations of Carbon nanotubes as Armchair and Zigzag are also investigated. A simple formulation is presented for them based on an extension of the developed method for the Graphene sheet, taking into account the curvature radius of a rolled Graphene sheet. The variation of CNTs Young's modulus in term of tube thickness and tube diameter is also investigated. The result represents a high dependency on the tube thickness, while dependency on the tube diameter is more tangible for smaller tube diameters. For large diameters, both Young's moduli of Zigzag and Armchair configurations of CNTs approach a unique bounding value which is previously obtained as Young's modulus of a Graphene sheet.

The obtained analytical results have been verified by finite element models. A finite element model of a Graphene sheet and six different finite element models of various configurations of CNTs are constructed using beam elements to simulate the same behavior of the analytical formulation. The results of finite element analyses coincide very well with results predicted by analytical solution. This can be inferred that both models simulate the same structural behavior. The predicted results for Young's modulus of Graphene sheets and CNTs are in reasonable agreements with theoretical and experimental published data.

A00403-01141

Synthesis and Characterization of Amorphous Hollow Carbon Spheres

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Nanostructured carbon materials have attracted enormous attention in last two decades due to their unique chemical, electrical, and mechanical properties. In this work, the amorphous hollow carbon spheres with diameters in the range of 100-750 nm, which are dispersed among bent graphitized carbon nanotubes, are synthesized by using radio frequency plasma enhanced chemical vapor deposition in mixed CH_4/H_2 gases. The carbon spheres were characterized with scanning electron microscope, energy-dispersive X-ray spectroscopy, Raman spectroscopy, and transmission electron microscopy. It is found that MgO and Co nanoparticles as well as hydrogen play crucial roles in the formation of the amorphous hollow carbon spheres. Moreover, a possible growth mechanism of the carbon composites has been proposed. The results of this study provide new insights into the fundamental understanding of nanostructural carbon materials toward applications in nanodevices.

A00423-00814

Reinforcing Effects of MWNTs and Alcohol Steam on the Electrospun Silk Ffibroin/Polyamide 6-66 Nano-scale Fiber Nonowoven

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Electrospun silk fibroin fiber mats have some drawbacks, such as instability in water and poor mechanical properties. These limitations can be improved by coelectrospun regenerated silk fibroin with polyamide 6/66. In the research, MWNTs were used to reinforce fibroin/polyamide 6/66 composite nano-scale fibers by electrospinning, and the fiber nonwoven mat was treated by the steam of absolute alcohol. With increasing of MWNTs, fiber diameter decreased on the second order exponential, the crystallinity firstly increased then decreased and reached the maximum when the content of MWNTs was 0.9wt% in the spinning solution. MWNTs remarkably enhanced the breaking stress and initial modul of the silk fibroin/ polyamide 6/66 composite nano-scale fiber nonwoven, they increased by 95% and 76% respectively at 0.9wt% MWNTs. Otherwise, excessive MWNTs in the spinning solution induced worse mechanical properties due to the drawbacks within fibers. After being treated for a week by the steam of absolute alcohol, the crystal structure and mechanical property of the electropun composite nano-scale fiber nonwoven was significantly improved, especially at lower content of MWNTs. The crystallinity increased to 63.9% from 55.8%, and the stress at break, initial modul and strain at break increased by 45%, 103% and 134% respectively when the content of MWNTs was 0.1wt% in the spinning solution.

Acknowledgments:
This research is financial supported by scientific and technological research projects of Ministry of Education, P.R. China (No.2006056)

A00445-01530

p-n Junctions Formed with Carbon Nanotubes Deposited onto Ga-Doped ZnO Thin Films

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Expecting that ZnO can pave the way for next generation electronic and photonic devices, recently, it has attracted wide attention with the notable advantages such as good transparency, material stability, wide bandgap, and high exciton binding energy at room temperature. In order to design, develop and utilize the engineered band-structures of ZnO, it is considered as primary requirement to achieve both *p*- and *n*-type ZnO materials. However, since the successful window for process condition to achieve the *p*-type ZnO still remains very narrow, we outsource more efficient way to fine the *p*-type materials with carbon nanotubes (CNTs) that highlights inherent *p*-type semiconducting properties. Moreover, thanks to the tunable transparency of the CNT films, they can give an excellent harmony with *n*-type Ga-doped ZnO (GZO) films for transparent electronic devices. Additionally, Spray method for the CNT deposition can be developed to a future printing process for device fabrication, therefore cost-effective mass production of the devices. However, unfortunately, no previous works on the CNT-GZO *p-n* junction has been reported in spite of its huge potential for future applications.

In this work, for the first time to our knowledge, we demonstrate a novel and elegant way to realize the *p-n* junction with the *p*-type CNT and the *n*-type GZO employing all-room-temperature processes such as spray method and rf-magnetron sputtering, respectively. The morphology of the *p-n* junction is examined using scanning electron microscope (SEM) ensuring the targeted structures. The electrical measurements verify explicitly the ohmic behaviors of both the Au-CNT contact and the non-annealed Au-GZO contact. The current-voltage (I-V) analysis of the junction illustrates typical diode characteristics with a threshold voltage of less than 1 V, which is remarkably lower than that of other wide-band gap materials such as GaN and ZnSe. The estimated ideality factor has a huge value implying that it still need to be improved in terms of the quality of the junction as well as every contact in the device. The whole sequence of the design, fabrication, characterization and analysis of the CNT-GZO *p-n* junction devices is presented.

A00526-00956

Removal of Lead(II) and Cadmium(II) Ions from Aqueous Solutions by Adsorption on Activated Carbon Prepared from Cashew Nut Shells

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Cashew nut shells were converted into activated carbon powders using KOH activation plus CO_2 gasification at 1027 K. The increase both of impregnation ratio and activation time, there was swiftly the development of mesoporous structure with increasing of mesopore volume ratio from 20-28% and 27-45% for activated carbon with ratio of KOH/char equal to 1 and 4, respectively. Activated carbon derived from KOH/char ratio equal to 1 and CO_2 gasification time from 20 to 150 min were exhibited the BET surface area increasing from 222 to 627 m^2/g. And those were derived from KOH/char ratio of 4 with activation time from 20 to 150 min exhibited high BET surface area from 682 to 1026 m^2/g. The adsorption of Lead(II) and Cadmium(II) ion was investigated. This adsorbent exhibited excellent adsorption for Lead(II) and Cadmium(II) ion. Maximum adsorption presented at 99.61% at pH 6.5 and 98.87% at optimum conditions. The experimental data was calculated from Freundlich isotherm and Langmuir isotherm model. The maximum capacity of Pb^{2+} and Cd^{2+} ions was found to be 20 mg/g and 5.38 mg/g, respectively.

A00579-01284

Preparation and Characterizations of Align Carbon Nanotubes on Porous Silicon Substrate

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Carbon Nanotubes (CNTs) is versatile nano-materials which can be produced either in powder form, random or align structure. Several methods used to synthesize align-CNTs (a-CNTs) including e-beam induced deposition method, Thermal Chemical Vapor deposition and others. The a-CNTs are most expensive structure compared to the others form. The a-CNTs is suitable for electronics,

sensors, nano-probe and other high accuracy nanodevices application. Porous Silicon (PSi) is one of the most potential nanostructured materials after Canham, 1990 observed visible luminescence under ultraviolet light excitation. PSi is widely used in many applications such as nano-optoelectronic devices, bio-sensors, chemical-sensor, optical sensor. In this paper PSi used as nano-template to produce align- Carbon Nanotubes (a-CNTs).

Porous Silicon was prepared using electrochemical technique with silicon wafer as a substrate and ethanoic acid electrolyte which consists of Hydrofluoric acid and Ethanol. The PSi prepared under photon assisted with 20 $mAcm^{-1}$ current density. PSi was used as template to produce a-CNTs using Two-Zone Thermal Chemical Vapor Deposition (2Z-Thermal-CVD). The optimum preparation parameters of CNTs on PSi were successfully produce a-Carbon Nanotubes (a-CNTs).

The optimum parameters were used are 5 minutes deposition time and 700^{o}C deposition temperature. The a-CNTs clearly observed in align perpendicular to the PSi substrate. The open ended of CNTs tubes also observed from this micrograph. The a-CNTs on PSi is very potential for optical devices and optical waveguide.

The samples properties will be characterized using Photoluminescence Spectrometer (PL) to study the light emission from PSi guided by a-CNTs. While Fourier Transform Infra-red Spectrometer (FTIR) is to study the optical property of CNTs on PSi . The possible growth mechanism of a-CNTs on PSi will be discussed.

A00647-01162

Synthesizing Carbon Nanotube on Nanostructure Porous Silicon Using Monometallic Catalyst from Palm Oil Precursor

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This paper reports a study on carbon nanotube (CNT) synthesized by thermal chemical vapor deposition (TCVD) method using eco-friendly carbon source; palm oil. Palm oil vaporized optimally at 450^{o}C in argon atmosphere at ambient pressure. The use of palm oil indicates that by-product formation particularly amorphous carbon is reduced compared to other organic carbon source. The effect of different monometallic catalyst nikel, Ni and iron, Fe on nanotube produced were extensively discussed. The catalysts were coated on porous silicon template to enhance precursor decomposition for distinguish yield and quality of carbon nanotube. The samples were grown at fixed temperature for 10 minutes and continued with 10 minutes annealing process. The field emission scanning electron microscopy (FESEM), infrared and Raman spectroscopy were systematically studied on carbon nanotube. Thermogravimetric analysis (TGA) was also presented in this study. Both Ni and Fe play a role in synthesizing high quality nanotube. However the synthesized carbon nanotubes were found to have very little pollutant of metal catalysts. The detailed of carbon nanotube properties will be discussed further.

A00647-01164

Temperature Effect on Carbon Nanotube Synthesized from Palm Oil Precursor

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The effects of temperature changes on carbon nanotube (CNT) by thermal chemical vapor deposition (TCVD) method were systematically studied. Bio-hydrocarbon source; palm oil was used as precursor and argon act as carrier gas. The samples were grown on iron, Fe nanoparticles coated on porous silicon template at atmospherics pressure. The nanotube synthesizing process took 30 minutes at different temperature; 650, 700, 750, 800, 850 and 900^{o}C. The CNT characteristics were then investigated using infrared (IR) and Raman spectroscopy. Field emission scanning electron microscopy (FESEM) and thermogravimetric analysis (TGA) were also presented in this studied. The experimental results showed that CNT properties are highly dependent on temperature changes.

A00758-01353

Study of Electrical Properties of Single Walled Carbon Nanotubes and Conducting Polymer Composites as a Function of Nanotube Length

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The electrical properties of single walled carbon nanotubes (SWNTs) dispersed in conducting polymer poly (3-octylthiophene) (P3OT) are studied and their electron transporting properties have been investigated as a function of their concentration and length. For this purpose three types of SWNT samples having similar diameters and different lengths have been used. The SWNT powder was dispersed in the P3OT solution already dissolved in xylene in concentration 10 mg/ml. The weight ratio of SWNT to polymer was varied from 0 to 30% w/w. For making a homogeneous suspension, the mixture was ultrasonicated for 30 min. and was then placed in an orbital shaker for ~10 hrs. After shaking the suspensions were kept undisturbed for two days allowing impurities and undispersed SWNT bundles to settle down. Upper 80% of the solution, containing homogeneously dispersed SWNTs in the polymer matrix, was decanted off for further experimental work. For electrical measurements, an ITO coated glass was taken and etched using HCl in order to obtain the desired electrode pattern. Over the patterned glass substrate, a thin film of the P3OT-SWNT composite was coated using a spin coating unit. The thickness of the films was measured by Talystep and was kept ~100±10 nm. After spin coating the samples were annealed in a vacuum oven at ~150ºC for 30 min. Annealing is required so as to remove any residual solvent still present in the film. The samples were transferred to the vacuum coating unit where Al was deposited over the film through a mask and the desired electrode pattern for cathode was made. The conductivity was measured using Keithley Multimeter Model 2000. The conductivity variation of the nanocomposites as a function of SWNT concentration showed percolation behavior where a threshold concentration of nanofillers is required for conduction to take place. It was observed that with increase in SWNT concentration the conductivity of the system increases. However the rate of increase of conductivity is very low initially and as the concentration crosses the critical value the conductivity starts increasing rapidly. At lower SWNT concentrations the nanotubes are almost isolated from each other hence the conductivity of the system is governed by the polymer however as the concentration crosses the threshold value where a conducting path is established by the nanotubes in the volume of the polymer matrix, SWNTs dominates the conductivity and the increase in the conductivity occurs by several orders of magnitude. Similar trend was observed for all the three samples. However the percolation limit is observed to be strongly dependent on the length of the nanotubes. As the length of the SWNTs increases the threshold moves towards lower concentrations. The reason is that for short nanotubes, a number of interconnections are required between the participating SWNTs for completing the conduction path however for longer nanotubes a few interconnections serve the purpose.

A00764-01346

Charge Transport Properties of Multiwall Carbon Nanotubes

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The Charge transport properties are analyzed for the disordered multiwall carbon nanotube sample in the temperature range from 1.3K to 100K and in the magnetic field upto 11T. Metal-insulator transition occurs in this system via critical regime. The conductivity shows the Mott type 3D Variable range hopping (VRH) behaviour. The Magnetoresistance (MR) is negative for the whole temperature range. Results are analyzed in the terms of weak localization, electron-electron interaction and variable range hopping. The H^2 dependence at low magnetic field and $\sqrt{H}$ dependence at higher magnetic field is found. Inelastic scattering lengths are also deduced from the low temperature magnetoconductance data, which are suggestive of the inelastic electron-electron scattering in the dirty limit.

A00833-01453

Experimental Study on Thermal Conductivity Enhancement of Alkali Treated Carbon Nanotube Composite as Phase Change Material

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With high thermal conductivity, CNTs were selected to adding into the organic basis to get the composite phase change materials. In this study, TMNTs were obtained by ball milling the mixture of the potassium hydroxide and PMNTs. The thermal conductivity enhanced nanocomposites PCMs were prepared by adding the TMNTs into the melting PA and the intensive sonication was used to make well dispersed and homogeneous composites. The homogeneous PA/TMNT composites enhanced the thermal conductivity in both liquid state and solid state. And the enhancements of the thermal conductivity are much higher than the reported data with the same ratios of the loadings

and at the same temperature. The enhancement ratios increase with the mass fraction of TMNTs. The thermal conductivity of PA/TMNT composites varies slightly with temperature at temperatures lower than 55°C and higher than melting point and it increases considerably from 55°C to the melting point. The enhancements of the composites are 46% at 25 °C and 38% at 65 °C for the composite with 1.0 wt% TMNTs, respectively.

A00937-01639

Temperature Effects on the Synthesis of Multi-Walled Carbon Nanotubes by Ethanol Catalytic Chemical Vapor Deposition

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Since carbon nanotube (CNT) was first identified by Iijima in 1991, it has attracted much attention due to its unique properties. It has been shown that CNT exhibits excellent thermal, electrical, chemical, and mechanical properties. And therefore it is avidly sought for nanoelectronics catalyst support media, gas adsorption media, electrochemical storage material and as reinforcing agents in composite materials.

In recent ten years, many methods for synthesizing CNTs, such as arc discharge, flame synthesis, and chemical vapor deposition, have been developed. But large-scale synthesis of high-purity CNTs is still a problem. So the research on synthesis of CNTs is still needed.

In this paper, we report ethanol catalytic chemical vapor deposition (ECCVD) for synthesizing CNTs, which employs ethanol as carbon source, ferrocene as catalyst precursor. And we have studied the effects of temperature on the synthesis of CNTs.

Massive CNTs with higher graphitization were obtained by ECCVD. And we found that the aligned CNTs preferred to grow on quartz substrates at higher synthesis temperature without using pump system. In addition, we found that the synthesis temperature had a complex influence on the synthesis of CNTs, including the graphitization of carbon nnaotubes, the diameter of CNTs and the alignment of CNTs.

A00937-01654

Single-Walled Carbon Nanotubes Synthesized by Floating Catalytic Chemical Vapor Deposition and Deposited at Low Temperature Region

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In this paper, we report the synthesis of single-walled carbon nanotubes by floating catalytic chemical vapor deposition at the synthesis temperature varying from 750°C to 900°C and deposited at low temperature region.

To synthesize single-walled carbon nanotubes, ethanol was employed as carbon source, ferrocene as catalyst precursor, high pure N_2 and 3%H_2/Ar as carrier gas. The experimental setup is a horizontal tube furnace equipped with mass flow controller. Ferrocene was placed at the feed-mouth of the tube furnace, and the ethanol vapor was introduced into furnace tube by bubbling under carrier gas flow. During synthesis experiments, the gas flow rate was kept at 100sccm for N_2 and 3%H_2/Ar, the pressure in furnace tube was kept at atmospheric pressure, and no pump system was used. The synthesis time was 3h.

Three hours later, we obtained massive film-like products of single-walled carbon nanotubes at low temperature (normally lower than 400°C) region away from high temperature. We employed high-resolution transmission electron microscopy (HRTEM) and Raman spectroscopy to characterize the single-walled carbon nanotubes.

The HRTEM observation reveals the single wall structure of single-walled carbon nanotubes, and their diameter is about 1nm. The Raman spectrum of single-walled carbon nanotubes gives the radial breathing modes (RBM) clearly. The frequencies of RBM are about at 181.9cm^{-1} and 200.5cm^{-1}. According to $d=248/\omega_{RBM}$ nm, we know the diameters of these single-walled carbon nanotubes vary from 0.9nm to 1.2nm.

A00998-02186

The Thermal Dissipation Study of Carbon Nanotubes uesd in High Power LED

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This study used two different diameter carbon nanotubes doped within the epoxy that was used to high power LED die bonding. We investigate the thermal interface material to improve the thermal problem for high power LED die bonding interface application. The diameter of carbon nanotubes was 50nm and 15nm, respectively. The lowest thermal resistance was exhibited 67 K/W when we used 15 nm diameter carbon nanotubes doped within epoxy. The CNT doped in epoxy device that significantly enhances the thermal dissipation of high power LED. Such device increase the thermal dissipation of high power LED by up to 10%.

A01031-02007

Fabrication and Characterization of Carbon Nanotube Electrode in Anodized Alumina Templates for Electrochemical Sensing

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In this work, carbon nanotube (CNT) in anodized alumina templates electrode is developed as a new electrochemical electrode for chemical sensing application. The electrode fabrication is started from sputtering of 500 nm-thick aluminum contact layer on silicon substrate. Next, 10 nm-thick alumina, 5 nm–thick stainless steel catalyst and 2 μm-thick aluminum layer were successively deposited by sputtering process. The top aluminum layer was then anodized in a 0.3 M oxalic acid solution at room temperature at a constant applied voltage of 40 V for 10 minutes. The resultant aluminum oxide film was removed by phosphoric acid (4 wt.%). A second anodization was then performed for 45 minutes under the same condition. The aluminum oxide layer was etched again by phosphoric acid for 30 minutes in order to expose the stainless steel catalyst. CNTs were synthesized in the pores by thermal chemical vapor deposition (CVD) process with water-assisted etching at a growth temperature of 700 °C. Its electrochemical sensing performance is evaluated for ascorbic acid detection with different concentrations ranging from 10^{-5} to 10^{-3} mol.l^{-1}. Cyclic voltammogram curves show irreversible oxidation peak at ~0.3 V. The amperometric response is linear with a high sensitivity of 0.5 A/mol l^{-1} and a minimum detection of ~$0.2x10^{-3}$ mol l^{-1}. The electrochemical sensing performance of CNT in AAO templates are found to be significantly better than CNTs grown with no AAO template with sharper reaction peaks and lower minimum detection limits. Thus, electrode is a potential candidate for the electrochemical electrode for chemical detection.

A01090-01891

Hydrophilicity and Hydrophobicity Study of Carbon Nanotube Film

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Since the discovery of Carbon nanotubes (CNT), these 1D nano scaled tubes have attracted a lot of attention from researchers around the world. Their atypical nano-scale structure as well as superior electrical, thermal and physical properties, nanotubes have been foreseen as the next generation material for numerous applications. In particular to many bio related application, such as biosensor, nano biomedical devices, etc. Therefore, it is necessary to investigate the hydrophobicity and/or hydrophilicity properties of CNT film, which have a large impact on the fluidic transport and even on the performance of the bio system. Surface properties of CNTs film with various morphologies have been studied with contact angle measurement and scanned electron microscopy (SEM). CNTs are believed to be hydrophobic; however it is found that CNT film could be either hydrophilic or hydrophobic. CNTs film with high density tends to be highly hydrophobic and CNTs film with low density is hydrophilic. CNT films hydrophilicity or hydrophobicity properties are also found to be affected factors such as film thickness and CNT alignment.

A01102-01903

A Thermal Rectifier from Cone-shaped Carbon Nanotube

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Traditionally, information is carried and processed by electrons and photons. Very recently, phononic (thermal) devices have been brought forward theoretically, in which phonon– a heat pulse through lattice, is used to carry and process information, which has added a new dimension to information science and technology in addition to electronics and photonics. In addition to information processing, the thermal devices might also have broad applications for heat control/management in the future. Elementary phononic devices such as diode, transistor and logic devices have been proposed. Similar to the electric counterpart, the thermal rectifier is the most fundamental phononic component.

In this work, with molecular dynamics simulations method, we demonstrate that the carbon nanocone, a cone-shaped carbon nanotube structure, is an excellent thermal rectifier. It shows that the graded geometric asymmetry is of remarkable benefit to improve the rectification ratio. Obvious thermal rectification ratio in large temperature range, from 200K to 400K, has been observed. Further more, rectification ratio in nanocone is less dependent on the length which is in stark contract to other nano structure thermal rectifier. The mechanism of the nanocone thermal rectifier is explained by that the heat flux is controlled by match/mismatch of the phonon power spectra between the top and bottom atomic layers of nanocone.

In contrary to the previous studies of thermal rectifiers which usually have three or two coupled segments, the nanocone can control the heat current by itself. More importantly, in carbon nanocone we don't need any on-site potential required in previous theoretical models, which is hard to control experimentally, and moreover, the onsite (substrate) potential generally reduces the heat current significantly.

In conclusion, as a potential thermal rectifier, carbon nanocone has many advantages over other nanostructures.

A01175-02011

Niobium Carbide (Nb_2C) Contact for Carbon Nanotube Based Devices

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Metal carbides could be promising as low resistance contact to carbon nanotubes, as demonstrated by titanium carbide (TiC). In addition, metal carbides could be thermodynamically more stable than pure metals. In this paper, we have found that the formation of niobium carbide, Nb_2C, by annealing in vacuum at 700 ^oC can drastically change the properties of the contact between niobium (Nb) and single-wall carbon nanotube (SWNT). Prior to annealing, no current could be measured flowing through a SWNT in contact with two Nb electrodes with a spacing of 600-800 nm at a bias of 1 V across the contacts. Although annealing in vacuum at 400 ^oC has led to measurable current through the SWNT, the I-V relation between the contacts is highly nonlinear with a resistance of over 2 MΩ and no niobium carbide phases are detected. With further annealing at 700 ^oC, X-ray diffraction spectra have revealed the formation of Nb_2C and the I-V relation becomes linear with a much reduced resistance of ~ 0.43 MΩ. This is due to the reduction of both the Schottky barrier height (SBH), and barrier width with the formation of Nb_2C between the electrodes and SWNT. The reduced SBH has been confirmed by our current temperature dependence analysis and is most likely a direct consequence of the higher workfunction of Nb_2C (~5.2 eV) than of Nb (~4.3 eV), while the smaller barrier width could be a result of the better bonding between the electrode and SWNT after the formation of Nb_2C. Preliminary comparisons have shown that Nb_2C contact to SWNT are at least as good as, and could be better than, the TiC contact. In order to exploit the Nb_2C contact, it is important that annealing of Nb at a higher temperature of 900 ^oC be avoided as that will lead to the formation of another niobium carbide phase, NbC, which has a lower workfunction (4.85~4.95 versus ~ 5.2 eV) and a higher resistivity (160 versus 107 μΩcm) than Nb_2C, thus degrading the contact. Annealing in oxygen present ambient should also be avoided to prevent the formation of niobium oxides, which can also degrade the contact.

A01175-04207

Comparison between Double- and Single-Wall Carbon Nanotube Effect Transistors

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Double-wall carbon nanotube field effect transistors (DWNT FETs) have been fabricated and compared with single-wall carbon nanotube FETs (SWNT FETs). DWNT FETs exhibit 3 distinct types of field-effect characteristics corresponding to the following outer-inner shell combinations of the DWNT: S-S, S-M, and M-M or M-S (where S and M refer respectively to the shell semiconducting and metallic character). The S-S DWNT FETs display behavior similar to that of the semiconducting SWNT FETs, with a substantial p-conduction ON current (I_{ON}) to OFF current (I_{OFF}) ratio I_{ON}/I_{OFF} ~10^3-10^4 and a low $I_{OFF} \leq 10^{-10}$ A; while M-M or M-S DWNT FETs behaves like metallic SWNT FETs, with hardly any gate voltage modulation effect. On the other hand, the S-M DWNT FETs show unique features with a very low I_{ON}/I_{OFF} ~10, although the I_{ON} is similar to that of S-S DWNT FETs. This is attributed to the inter-shell coupling in the DWNT. Owing to the penetration of electron wave functions in the inner metallic shell into the outer semiconducting shell in the S-M DWNT, nonzero local density of states (DOS) in the original forbidden energy gap of the outer semiconducting shell could be created, thus resulting in new conducting channels in the outer shell and leading to reduced gate control in the S-M DWNT FETs.

In comparison to the semiconducting (S)-SWNT FETs, the S-S DWNT FETs show a higher p-conduction I_{ON}, a lower inverse sub-threshold slope (S) and a similar I_{OFF}. The higher I_{ON} for S-S DWNT FETs is not surprising as the outer-shell diameter of DWNT is larger than the diameter of SWNT (2.5 versus 1.5 nm), which leads to a lower Schottky barrier height (SBH) at the contacts for DWNT FETs. The lower S for S-S DWNT FETs than for S-SWNT FETs may be explained partially by the higher I_{ON} of the former. Currently, we cannot rule out that S is not affected by the double layer structure of DWNT. Further studies are in progress to investigate this. The similar I_{OFF} for S-S DWNT FETs and S-SWNT FETs means a higher I_{ON}/I_{OFF} ratio for the former despite a larger outer-shell diameter of DWNT than the diameter of SWNT. This may signify certain advantages of DWNT over SWNT as the channel of FETs. In our experiments, S-S DWNT FETs demonstrate both ambipolar (70 %) and unipolar (30%) characteristic which is contrary to large diameter (> 1.5 nm) S-SWNT FETs which normally show ambipolar characteristic owing to the small band gap of large diameter SWNTs. This may be resulted from the two layer structure of DWNTs, where ultra small diameter inner tube can cause large variation in the work function of DWNTs.

A01187-02033

Synthesis of Single-walled Carbon Nanotubes with Uniform Diameters and Chiralities by CO Disproportionation on Ni-MCM-41 Catalysts

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The coexistence of tubes with various chiralities and diameters in commercially available SWCNTs has been a bottleneck for fundamental research and fabrication toward high-performance devices. Fortunately, in chemical vapor deposition (CVD) methods for carbon nanotube growth, the diameters of carbon nanotubes are believed able to be determined by the size of the metallic catalyst nanoparticles. Metallic clusters usually migrate and sinter under the harsh carbon nanotube synthesis conditions; therefore, a catalyst with the ability to stabilize these metallic nanoparticles is required to achieve good carbon nanotube diameter control.

Recently, we have developed a nickel catalyst ion-exchanged in the well-ordered mesoporous silica material MCM-41 by isomorphous substitution of silicon. The diameter distribution of SWCNT was observed to correlate with the size of the nickel clusters formed in Ni-MCM-41 during the SWCNT synthesis process. Uniform SWCNT diameters can be achieved by using optimized pre-reduction and reaction condition. By precisely controlling the pore size distribution of mesoporous materials, we found that carbon precursors like CO could be catalytically pyrolyzed and then SWCNTs grow up on the nickel clusters inside the ordered meso-channels. The confined space effect makes it possible to prevent nickel clusters from migrating or sintering and obtain SWCNTs with much higher purity and yield. As the SWCNT diameter decreases, the number of possible selections (n, m) on the graphite sheet for forming SWCNT decreases, which means that the diversity of possible chiral conformations decreases.

A01224-02106

P3HT as the Surfactant on the Dispersion Single-walled Carbon Nanotubes

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Single-walled carbon nanotubes (SWCNTs) have become an interesting and important subject due to their outstanding properties. However, raw SWCNTs are usually composed of ensemble of different chiralities and usually forms bundles of tubes, which severely obscures the advantages of the SWCNTs. For the analysis, purification, modification and applications of SWCNTs, various dispersion techniques have been developed to achieve mono-dispersed SWCNT. In this work, P3HT, a widely studied light-emitting polymers, has been used as the surfactant for the dispersion of SWCNTs. The solvent effect, in particular, on the dispersion of SWCNTs using P3HT surfactant was investigated. Chlorobenzene, chloroform, toluene, o-xylene and p-xylene, have been tested for this purpose. The absorption spectra suggest that the final solubility of the SWCNTs was highly dependent on the solvent, with the chlorobenzene giving the highest solubility. The electronic and photovotaic properties of devices made from these P3HT/SWNTs composite were also discussed.

A01274-02215

Van Der Waals Interaction Between Carbon Nanotubes, Fullerenes and Small Atomic Clusters

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The dispersion forces (Casimir and van der Waals (vdW)) play vital role in nanotechnology (such as nano electro-mechanical systems and nano electronic devices). They are also critical for understanding the growth mechanism of fullerenes, nanotubes and formation process of ropes/ bundles. The accurate determination of the long-range dipole-dipole dispersion coefficient (C_6) and its dependence on the size and shape of the materials is an important area of research today. In this work, we have employed time-dependent density-functional theory (TDDFT) to calculate the vdW coefficient of finite-length carbon nanotubes (CNT) and fullerenes as a function of size (n) and shape. We have also calculated the C_6 coefficient between the CNTs and small alkali-metal atom clusters (Na_n and K_n with $n \leq 20$) as well as carbon clusters (with $n \leq 100$). The dispersion coefficient is obtained via Casimir-Polder expression which relates it to the frequency-dependent linear polarizability at imaginary frequencies. The frequency-dependent polarizabilities are calculated by direct TDDFT linear response theory using response module of Amsterdam Density Functional code.

We observe CNTs are easily polarizable in direction parallel to tube axis. The values of polarizability depend on diameter, which show that CNT with smaller diameter is more polarizable than that with larger diameter. This trend matches well with results available in the literature. We find that these quasi one-dimensional structures are more polarizable than the fullerenes having similar 'n'. This can be attributed to the geometry of CNT which can be easily polarized along the tube direction. Our results on vdW interaction show that the interaction between CNT's are stronger than that between fullerenes and also CNTs interact more strongly with small alkali metal (Na and K) and carbon clusters. As CNTs are more polarizable than fullerenes, their interactions with themselves and with atomic clusters are stronger than that for the fullerenes. The values of interaction coefficient for $K_n > Na_n >> C_n$. The free electron nature of the alkali metal atoms contributes to the high polarizability and in turn to large vdW coefficients. We have also studied the variation of C_6 with the size (n) of CNT. It is found that the both polarizability and C_6 coefficient varies non-linearly with size(n). In addition, the tube with smaller diameter interact strongly with each other as compared to that with larger diameter ones because they are more polarizable than the tube with larger diameter. The strong anisotropy in polarizability and higher values of C_6 coefficient can play important role in electric field aligned growth of CNT and formation of ropes/bundles, respectively.

A01276-03401

Development of a Low Cost Carbon Nanotube Based Alcohol Sensor

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A single walled carbon nanotube (SWNT) based alcohol sensor is presented. The response of the sensor is based on the principle of resistance variation of SWNT film

as the gap between the individual SWNTs varies within the SWNT-polymer composite film. For this purpose, the SWNT powder was dispersed in a Poly (methyl methacrylate) (PMMA)-Nitro methane solution in 2mg/ml concentration. The ratio of SWNT: PMMA is kept to be 1:2 w/w. The suspension was homogenized by ultrasonication followed by shaking in an orbital shaker for ~5 hrs. The homogenized solution was ultracentrifuged for 15 min. and the upper 80% portion of the suspension was decanted off for further experimental work. For sensing alcohol, an ITO coated glass was taken and patterned by etching to obtain two electrodes. The solution was first drop casted between the two electrodes and then kept in vacuum oven at 100 ÂºC for 30 min. for removing remaining unwanted solvent. The sample was then placed in a closed chamber and the electrodes were connected to the Keithley Multimeter model 2000. The ethanol is then sprayed into the chamber and the resistance of the sample is measured in absence and in presence of ethanol. It was observed that in presence of ethanol the resistivity of the film increases by ~2 orders of magnitude and it varies with dose of the alcohol. The increase in resistance may be attributed to (i) swelling of polymer matrix due to adsorption of ethanol onto the SWNT-PMMA film surface-which move SWNTs farther apart (ii) charge transfer between OH group of alcohol to the nanotubes. Same experiment was repeated with functionalized SWNTs. It was found that with functionalized SWNTs the increase in resistivity is by ~3 orders of magnitude.

A01314-02298

The Effects of Catalyst Treatments on the Growth of Millimeter High Vertically-aligned Carbon Nanotube Arrays

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Carbon naonotube bears many excellent physical and chemical properties, and will find wide potential applications in mechanical components, conductive films, and even the emerging clearn energy technologies.Millimeter high vertically-aligned carbon nanotube arrays were synthesized by a simple catalytic chemical vapor deposition (CCVD) method. By controlling the pretreatment parameters such as temperature, flow rate, and pretreatment time, we can tune the height of vertically-aligned carbon nanotube arrays. SEM and AFM results indicate that the growth of carbon nanotubes is correlated with the catalyst morphologies; XPS characterizations suggest that the chemical reduction of catalyst layer is critical for growth; prolonged duration of hydrogen reduction reduces iron oxides, and also leads to agglomeration of catalyst film.

A01319-02306

Re-growth Aligned Carbon Nanotubes with Improved Field Emission

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Re-growth (2nd generation) multi-walled carbon nanotubes (MWNTs) were grown on recycled substrate after the as-grown (1st generation) MWNTs were transferred to other substrates using polydimethylsiloxane (PDMS) as intermediation. Field emission studies showed ~ 2.6 times improvement in field enhancement factor and more uniformed emission surface for the 2nd generation of MWNTs. Here the turn-on field has been much reduced. Such significant improvements were attributed to new emission sites made up of sharp carbonaceous impurities encompassing both tip and upper portion of the 2nd generation of MWNTs. Hence, we present a technique that enables the production of MWNTs with better field emission quality.

A01334-02333

Simulation of Electron Irradiation Effects in Carbon Nanotubes - Introduction of Relativistic Effect -

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Energetic beam irradiation to nanostructures is expected to become a technique to tailor the structure with desirable properties. We have recently developed a molecular dynamics simulation including the interaction between an electron and a carbon atom to study the deformation process of carbon nanomaterials under electron beam irradiation. In present paper, we introduce relativistic effects into the simulation model to improve the accuracy of the simulation.

The scattering angle of the incident electron is determined using the Mott cross section, which is derived from the exact solution of the Dirac relativistic wave equation. The transferred energy from the electron to the carbon atom and the scattering angle of the carbon atom are determined based on the binary collision theory including a relativistic effect. The collision atom in the target materials is randomly selected. Tersoff-Brenner and Lennard-Jones potentials are used in the simulation to describe the short-range and long-range interactions among carbon atoms, respectively.

The carbon atoms are ejected from single-walled carbon nanotubes by the electron irradiation above 95 keV. We also demonstrate the structural changes in carbon nanotubes under electron irradiation.

This work was supported by the Grants-in-Aid for Scientific Research from the Japan Society for the Promotion of Science.

A01349-02351

Enhanced Field Emission from Titanium-coated Carbon Nanotubes

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Recently, carbon nanotubes (CNTs) have generated a lot of enthusiasm among the research community owing to their superior electrical, thermal, and mechanical properties. One of the applications of CNTs is electron emitters. The unique geometry and high aspect ratio of CNTs make CNTs an ideal candidate for electron source by field emission. However, CNTs have a relatively high work function of about 5 eV. In addition, for CNTs to be used for electronic application, they would need to achieve high interfacial adhesion with a substrate. One way to overcome these weak points is to modify the CNT surface by a thin coating of low work function metal. Metal coating also leads to the strong adhesion between CNTs and a substrate.

In this paper, inductively-coupled plasma-enhanced chemical vapor deposited (ICP-CVD) CNTs have been successfully coated with titanium (Ti) by a sputtering method. C_2H_2 was used as a source gas for CNT growth. Various thickness of Ti with 50, 100, 300, 1000 Å, was coated. Surface morphologies of Ti-coated CNTs were investigated by scanning electron microscopy and Raman spectroscopy. In prior to Ti coating, CNTs were etched by using N_2 plasma in order to obtain lower spatial density of CNTs. Field emission characteristics of as-grown and Ti-coated CNTs were measured using a diode-type configuration in a vacuum chamber of 10^{-7} Torr.

SEM images of CNTs grown by ICP-CVD showed vertically-aligned CNTs with high density. Spatially dense CNTs deteriorate field emission efficiency by electric-field-screening effect. The N_2 plasma etching with time of 0 ~ 12 min led to remarkably sparse CNTs. With increasing etching time, CNTs became shorter, rougher on surface, and bound into bundles with a lower density. Increasing etching time resulted in a high amount of amorphous carbon due to ion bombardment, which could be confirmed through I_G/I_D ratios of CNTs by Raman spectroscopy. Most CNTs were etched out after 12 min etching. 8 min etching seemed to be optimal by SEM inspection. While Ti-coated CNTs with thickness of 50 ~ 100 Å maintained previous shapes, Ti-coated CNTs with thickness of 1000 Å seemed to be a metal post by merging individual CNT into bundle.

The field emission measurement showed that the turn-on electric field of N_2-plasma etched CNTs without Ti coating was approximately 2.8 V/μm, while turn-on field of 50 Å Ti-coated CNTs was 2.0 V/μm. Moreover, emission current density of 150 μA/cm^2 was obtained from 50 Å-coated CNTs, as compare to 40 μA/cm^2 from bare CNTs. A luminescence pattern on a phosphor-coated-ITO anode glass showed better uniformity from 50 Å Ti -coated CNTs than bare CNTs. The resultant emission characteristics revealed that thin(50Å-thick) Ti-coated CNTs could be a better electron emitter with a lower emission voltage and a higher emission efficiency.

Acknowledgement:
This work was supported by the Korea Research Foundation Grant funded by the Korean Government(MOEHRD, Basic Research Promotion Fund)(KRF-2008-313-D00389).

A01390-02421

Direct Tensile Test of Carbon Nanotube Bundles

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Carbon nanotubes (CNTs) have been predicted to have high modulus and strength, while the intrinsic mechanical properties of CNTs are very difficult to test directly because of their small size. By synthesizing millimeter to centimeter long CNT arrays and then preparing them into CNT bundles through chemical and mechanical processing, we have gained capability to measure directly the tensile strength and Young's modulus of CNTs. The dependences of mechanical properties on bundle diameter, bundle length, CNT alignment, and CNT quality have been extensively studied. The results have demonstrated CNT's great potential in fiber-composite applications. The CNT's intrinsic properties will also be discussed through size scaling.

A01424-02466

Assessment of (n,m) Selectively Enriched Small Diameter Single-Walled Carbon Nanotubes by Density Differentiation from Cobalt-Incorporated MCM-41 for Macroelectronics

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Uniformly semiconducting or metallic single-walled carbon nanotube (SWNT) networks are ideal materials for flexible and large-area electronics (macroelectronics). With the goal of developing optimal enrichment and evaluation solutions toward economical production of monodisperse SWNTs for macroelectronics, we selectively enriched SWNTs, which have small diameters (<0.9 nm) and a narrow (n,m) distribution, synthesized on cobalt-incorporated MCM-41 catalysts. The (7,5) enriched SWNTs were obtained from sodium cholate (SC) dispersion, whereas (6,5) were from cosurfactant mixtures of sodium dodecyl sulfate (SDS):SC at 1: 4. Density gradient ultracentrifugation was applied to further refine the separation. Subsequently, SWNT thin-film field effect transistors (FETs) were fabricated using enriched SWNTs. We characterized the chiralities by photoluminescence excitation spectroscopy, optical absorption spectroscopy, Raman spectroscopy, and electrical transport measurements. Among these techniques, results demonstrate that the electrical transport measurement (through I_{on}/I_{off} ratio) of thin film FETs is the most sensitive technique to evaluate the purity of semiconducting SWNTs. Enriched SWNTs via only SC produced more devices with higher on-/off-current ratios (up to 1×10^6) compared to SWNTs obtained from SDS/SC cosurfactants. These results are different from previous studies using laser-ablation-grown SWNTs (1.1-1.4 nm), encouraging more comprehensive models to explain diameter dependent chirality selection using surfactants.

Acknowledgments:
This work was supported by Nanyang Technological University (AcRF Grants RG38/06 and RG106/06) and Defense Science & Technology Agency, Singapore (MINDEF-NTU-JPP/08/03). We acknowledge experimental helps from Peng Chen, M. B. Chan-Park, Long Qing Chen, Bo Wang and Herry Gunadi Sudibya.

A01457-02532

The Effect of Different Buffer Layer Preparation on the Growth of the Aligned Carbon Nanotubes

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Carbon nanotube (CNT) has been at the forefront of novel nanoscale research worldwide because of its unique structure-dependent electrical and mechanical properties. CNTs possess great potential as functional materials for applications such as field electron transmitter (FET), field emitters, sensors, actuators, etc. All these require CNTs to be grown in a unidirectional manner in order to enhance their functionality. As such, there is a need to explore the methodology used in order to produce good quality, highly aligned CNTs.

The role of the Al_2O_3 buffer layer has been proven to be a very effective promoter for the aligned growth of carbon nanotubes. This work studies the effect of different preparation methods of Al_2O_3 buffer layer on the CNTs produced via catalytic thermal chemical vapour deposition (CVD). Vertically aligned multiwalled carbon nanotubes (MWCNTs) grown on silicon substrate were analyzed using Raman and scanning electron microscopy (SEM). Analyses were also performed on the surface roughness of the Al_2O_3 buffer layer using atomic force microscopy (AFM). The buffer layer produced by heating the deposited Al film at 5°C/min and soaked at 600°C for 2 hours produces CNTs film with the highest thickness because of its fastest growth rate.

A01468-02547

Hydrogen Evolution Kinetics of Zirconium Doped $NaAlH_4$

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Onboard hydrogen storage is a challenging field of research and need to be solved for transportation applications resulting in achieving hydrogen economy. The task of providing large capacity and low temperature reversible solid hydrogen storage for mobile applications has focused lately on a class of reducing agents known as alanates. $NaAlH_4$ has been proposed as a viable hydrogen storage media among these alanates. It was recently reported that a few percent of Ti doping in $NaAlH_4$ renders accelerated and reversible hydrogen release under moderate conditions. In this work, the effect of Zr doping will be presented. The structural aspects are investigated using XRD & SEM. The hydrogenation properties were determined by the Sievert type instrument. These studies will result in identifying the catalytic dehydrogenation reaction rate of zirconium addition to sodium alanate.

A01506-02617

Effect of Adsorption Metal Atom on the Transport Properties of Single Wall Carbon Nanotubes

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Due to the development of nano scale science and technology, investigation of nano device based on carbon nanotube (CNT) with functional property has been progressed in experimental and theoretical field. One of the significant improvement of the CNT based materials are achieved by metal adsorption and metal coating manipulations during the last decade. The effort of metal adsorption is explained by the dramatically changing of electronic structure of itself arise from the charge transfer effort and structural deformation effort. For example, ohmic contact between metallic CNT and semi-conducting CNT is actualized by transition metal coating only in specific transition metal spices.

On the other hand, mechanical bending effect is also affect for the electronic property of CNT. For the mechanical bending and atomic defect, selection of chiral angle and diameter of CNT is critical effort for the electronic structure of itself. Introducing the pentagon-heptagon defect pair to connect the several kinds of metallic and semi-conducting single wall carbon nanotube (SWNT) pair, the electronic property of SWNT is depend on the combination of SWNTs. Moreover, in case of pushing the middle part of SWNT to arise the structural deformation and broken bond, conductance reduction are caused arise in only for zigzag tubes not for armchair tubes Thus, controlling the size of adsorption metal and metal spices for suitable CNT is significant effort for development of CNT based nano device. Recently, constructing the nano metal particle on the CNT with desired size has been achieved by thermal manipulations. We have been focus on and investigated theoretical background of this phenomena by the first principles calculations to reveal the metal agglutination mechanism on SWNT surface.

In this study, we investigate the metal atom adsorption effect for the electron transport properties of metallic and semi-conducting CNTs by first principle calculations. All calculations, the non equilibrium green's function is adopted to treat the semi infinite effect of electrodes. We choose the (5,5) and (10,0) single wall carbon nanotubes (SWNT), as the typical semi-conducting and metallic SWNT, and Al (1 0 0) electrodes and carry out the first principle calculations based on density functional theory by using openmx code. Comparing the transport property of each SWNT with Pt, Cu, Ag and Au atom adsorption case, we clarify the charge transfer effect effect and the structure deformation effect for the transport property of SWNT in Al electrode case.

A01530-02674

Characterisation of Electric Conductivity in Rapid Vacuum Arc Annealed Multi-walled Carbon Nanotubes

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We characterized the electric conductance of multi-walled carbon nanotubes (MWCNTs) which improved by a rapid vacuum arc thermal annealing process. This thermal treatment allows us to modify the structure of MWCNTs to reduce the defects. As MWCNTs has been use for nano-conductors and enhancer of conductive polymer, the conductivity of MWCNT become an important issue for further electronic conductive applications.

Carbon nanotubes can be classified into two main groups by its structure; single-walled (SW) and multi-walled (MW). SWCNT has unique property which exhibits metallic or semiconducting based on its structure. Furthermore, electron conduction via such one-dimensional material could enhance many quantum behaviors. As the "ballistic transportation" shows electron transported through SWCNT via single layer graphene without scattered by phonon or other resistance origin. On the other hand, MWCNT was though to be a conductor which exhibits metallic properties due to multi-laying graphitic structure. Electron may transport via interlay space through the pi-bound vibrations.

MWCNTs produce from the chemical vapor deposition (CVD) method usually exhibited high density of structure defects due to nitrogen incorporated in the carbon networks. We developed an effective method to improve the structure by reducing defect density dramatically in the MWCNT. We therefore focus on the electric conductive measurement on such well-structured carbon nanotubes. The conductivity of the MWCNT was measured by nano-electrodes which drown by a focus ion beam (FIB) system directly onto an individual carbon nanotube. We found that the rapid thermal annealed MWCNT has semiconductor property which higher conduction at room temperature. Compare to the non-treated control sample, the results show that the well-constructed MWCNT may conduct electron through its outer layer of graphene and behavior as semiconductor. With the conduction increases by the thermal stimulation of carrier concentration, the conductivity exponentially increases with the temperature.

This project is financially sponsored by National Science Council of Taiwan (grand no. NSC 95-2112-M-036-001-MY2).

A01534-02928

Effect of Silicon Nitride Interfacial Layer in Alignment of Multi Walled Carbon Nanotubes and their Field Emission Properties

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Carbon nanotube (CNT) based field effect transistors (FET) have attracted considerable attention in the field of nano electronics. Also, silicon nitride is utilized as an integrated oxide layer in FETs. By thermal decomposition of ferrocene and xylene at 900 ºC, we have synthesized vertically aligned CNT samples directly on amorphous hydrogenated silicon nitride (a-SiN_x: H; thickness 180 Å ± 10 Å with a refractive index of 1.95 ± 0.05) deposited on n-type silicon (100) substrate and studied their field emission properties. The CNT samples were characterized by scanning electron microscopy (SEM), transmission electron microscopy (TEM), high resolution TEM (HRTEM), energy dispersive X-ray analysis (EDX), X-ray diffractometry (XRD) and atomic force microscopy (AFM). Field emission properties of these aligned MWNTs were studied in a diode configuration with an interelectrode distance of 400 µm. The cross-sectional SEM and TEM results revealed that the length of the aligned CNTs was 100 µm and their diameter was in the range of 50-90 nm. AFM, XRD and HRTEM analysis showed that high temperature annealing of a-SiN_x: H film in oxygen results in formation of crystalline silicon oxide (SiO_x) within the matrix of a-SiNx. It is suggested that active sites created on SiO_x and a-SiN_x:H clusters provide mechanical support for the alignment of long carbon nanotubes. It is proposed that a thin layer of a-SiN_x: H prevents silicide formation between catalyst (Fe) and silicon thus lengthening the catalyst life. Field enhancement factor of these aligned CNTs was estimated from slope of Fowler-Nordheim plot in high voltage range. It was found to be ~ 15660, which is very high as compared to the same estimated from the CNTs synthesized on silicon oxide (~ 10,100).

A01548-03019

Solution Processed CNT-PEDOT:PSS Composite and its Application in Organic Electronics

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Carbon nanotubes have been the subject of extensive research during the past decade because of their exceptional electrical, mechanical, optical, thermal and chemical properties. These tiny nanostructures have eventually paved their way into the exciting and promising field of organic electronics which is expected to dominate the area of low cost and flexible electronics in the near future We have prepared carbon nanotube and PEDOT:PSS [(Poly (dioxyethylene thienylene):(polystyrenesulphon ic acid)]based composites using different concentrations of carbon nanotubes and utilized the same for different organic electronics applications; initially studying the film properties of the formed composite and then utilizing the same for organic light emitting diodes. The composites have been utilized as the hole injecting layer in the fabrication of organic light emitting diodes. Studies on I-V characteristics of the formed film, electroluminescence (EL) intensity and turn-on voltage of the formed devices have been carried out. It is observed that the CNT-PEDOT:PSS composite based films exhibit improved and higher current as compared to pure PEDOT:PSS based film. The CNT concentration has been optimized for best results and thus the CNT-PEDOT:PSS composite based film has been utilized in organic light emitting diodes. The results related to this work will be presented here.

One of the authors (MB) is grateful to Netaji Subhas Institute of Technology, New Delhi, India for providing her Teaching-cum-Research Fellowship to carry out this work.

A01552-02705

Effect of Biocompatible and Mesoporous Single Walled Carbon Nanotube Matrices on Osteoblastic Cell Cultures

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There is a great interest in developing coatings with tunable chemical and biological properties. For biological applications, these engineered films however must be biocompatible and remain stable in physiological environments. Single walled carbon nanotube (SWNT) is a type of a carbon allotrope that potentially can be used to form active coatings in medical devices. However, long term matrix stability and effect of its physical characteristics, like roughness and porosity, on cell activity must be thoroughly investigated. We have studied osteoblast cells on three dimensional single walled carbon nanotube networks to investigate the toxicity effects on long term cell culturing. We found using total protein, cell viability, and toxicity assays that there is no detrimental effect on cell cultures on SWNT substrates. We have investigated the effect of SWNT network roughness and porosity on the cell response. Results showed that surface roughness and corresponding surface energy effect cell adhesion and initial cell movement. This study provides additional clues on how nanotube substrate characteristics can be modified to control cell response. Our study suggests that optimized nanotube matrix may be critical in future implantable nanodevices.

A01556-02911

One-Dimensional Carbon Nanomaterials from Flames: A Review

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The present contribution provide a comprehensive review in the one-dimensional (1D) carbon nanomaterials (including carbon nanotubes (CNTs) and carbon nanofibers (CNFs)) from flames and summarizes valuable achievements in our group with respect to their synthesis, microstructures, growth mechanism, properties, well-aligned controlment and fabrication of 1D junction carbon nanostructures. The synthesis methods include fuels, conditions and substrate pre-treatment, such as polishing/etching, coating Ni/Fe metallic salt and pulse plating. Thereinto, using pulse plating method, the diameter of CNTs/CNFs would be precisely controlled by adjusting the plating parameters. Generally, the hollow-cored CNTs only grew with Ni-contained catalyst, and solid-cored CNFs grew with Fe-contained catalyst. Due to the abundant oxygenous functional groups absorbed on the surface of both CNTs and CNFs, CNTs exhibit special physical property on low-temperature PL emission and CNFs have both double-layer capacitance and pseudo-capacitance.

It has been fund that the electric and magnetic fields provided an obvious influence upon the growth of well-aligned CNTs and its microstructures. Tailoring pulsed electric field, an "graphite – nongraphite – graphite - nongraphite-……" CNT junction can be synthesized. Based on the transformation of CNFs from amorphous microstructures to crystalline strip-shaped ones after heat-treated above 1000 ºC, 1D CNF junction containing "crystalline" and "amorphous" segment has been fabricated by using the a spark plasma sintering (SPS) system and its electrical transport property exhibits a rectification behaviour.

Acknowledgments:
This work was supported by the Specialized Research Fund for the Doctoral Program of Higher Education (No. 20070486016.), Ministry of Education, China, and National Basic Research Program of China (973 Program) (No. 2009CB939700).

A01601-02785

High Performance Hybrid CMOS Device Utilizing Zinc Oxide Nanowire and Single Walled Carbon Nanotube Networks

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Zinc oxide (ZnO) nanowire and single walled carbon nanotube (SWCNT) networks have been proposed as an alternative to organic and amorphous semiconductors for plastic electronics. Although the mobility of the ZnO and SWCNT networks is lower than that of individual nanowires and nanotubes, they offer the advantages of high transparency and flexibility. A major drawback of using individual nanowires and nanotubes in nano or microelectronic applications is the lack of a manufacturable process to precisely assemble nanowires into small devices. The use of ZnO

networks avoid this issue for relatively large area macroelectronic devices since the devices exhibit the average properties of a large number of random individual nanowires and nanotubes. In this work, we have deposited uniform ZnO nanowire and SWCNT thin films using an easy, scalable, stamping method and characterized their electronic properties. In addition, we have demonstrated a high performance and manufacturable hybrid complementary inverter (gain ~ 0.9) combining SWCNT networks as the *p*-type (hole carrier) thin film transistor (TFT) and ZnO nanowire networks as the *n*-type (electron carrier) TFT has been demonstrated for the first time.

A01652-02941

Optical Study of Graphene: From Fundamental Studies to Applications

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Graphene exhibits many exciting properties, such as anomalously quantized Hall effects, massless Dirac-Fermions like charge carrier, existence of a minimum conductivity, which make it an exciting candidate for the future nano-electronic devices.

Raman spectroscopy has been historically used to probe structural and electronic characteristics of carbon materials. In this talk, we use Raman imaging to study graphene in the following aspects. (1) Raman imaging in together with contrast imaging can be used to unambiguously determine the graphene thickness. (2) Determination of graphene axes using Polarized Raman spectroscopy (3) Raman imaging of folded graphene sheets has revealed the two dimensional Dirac-like (single layer graphene-like) character of electronic states and with reduction of Fermi velocity. (4) We have also studied the effect of top insulator layer deposition (SiO_2, HfO_2, PMMA) with different techniques (ALD, PLD, Sputtering, spin coating) on the properties of graphene. The effect of high temperature annealing and molecular doping is also studied. (5) Uniaxial strain is applied on graphene, and the strain is detected by Raman spectroscopy and imaging. Bandgap opening on graphene, which is critical to its application, is possible by applying such strain. The results obtained here by Raman imaging help on the better understood of fundamental properties of graphene and might speed up its application on future electronic devices.

A01668-03084

A Novel All-plastic Liquid-gated Single-walled Carbon Nanotube Field Effect Transistor for Biosensing Applications

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The introduction of single-walled carbon nanotubes (SWCNTs) as sensing element in the area of biosensor has lead to many attractive sensing protocols and new device architectures. Earlier, biosensing has been performed with SWCNTs in field effect transistor (FET) or electrochemical format and sensing with SWCNT FET have been typically carried out in dry state, after the biomolecules have been bound to the surface of the SWCNT. However, this format is not a practical for real time detection of biomolecules as measurements can only be taken before and after the bio molecular interaction has taken placed.

In this work, we describe the fabrication of a novel polymer based liquid-gated singe-walled carbon nanotube field effect transistor (LGFET) and its application for probing bimolecular interactions in real-time. The device presented is fabricated all in plastic and consists of only two-materials, namely: poly (dimethyl siloxane) (PDMS), and SWCNT. Furthermore, this device operates in liquid environment, in that the gate bias is actually applied to the liquid sample. Hence, this capability allows the LGFETs to probe biomolecule interactions in its most native environment, and in real-time.

The device sensing performance for the interaction of 2, 4-dichlorophenoxyacetic acid (2, 4-D) antibody/antigen system is here demonstrated. The transfer characteristic of the device is observed to shift toward the negative potential direction upon the interaction and binding of the complementary molecule. This negative shift indicates that the antibody/antigen interaction give rise to enrichment of positive charge in the local SWCNTs environment.

Applying the gate bias to the liquid sample, however, has its own drawback. Simple DC gate bias would induce electrolysis reactions at a voltage higher than $\pm$1 V. Hence, we have introduced a pulsed-gate method to prevent electrolytic reactions from taking place kinetically. Pulsed-gated bias allows the LGFET to operate within an operating window beyond $\pm$1V. Pulsed-gated LGFETs will allow extending the applicability of the sensor to wider range of molecules.

*This research is supported by Institute of Materials Research and Engineering (IMRE), Agency of Science, Technology and Research (A*STAR) and School of Materials Science and Engineering (MSE), Nanyang Technological University (NTU)*

A01678-02903

Characterization of TiO_2/Multi-walled Carbon Nanotube Composites

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Nanosize anatase titania/multi-walled carbon nanotube (MWCNT) composite photocatalysts of various Ti/C atomic ratios were prepared with modified sol-gel method under pH >7. $Ti(OC_3H_7)_4$ was used as the precursor for the titania, and an as-purchased MWCNT was modified with acid under heating condition prior to the growth of the titania on it. These composites were characterized in aspects of morphology, surface area, titania particle size, organic functional groups, C1s Raman shift, crystalline phases, light absorbance in ultraviolet (UV)-visible (VIS) region, and first-shell molecular environment around Ti atom. Photocatalytic activity of the composites was evaluated by de-colorization of a dye under UV irradiation.

The composites of a lower Ti/C ratio have greater surface area and finer titania due to a better dispersion of titania on the modified MWCNT. Chemical bonding forms between the titania particles and the surface of modified MWCNT through carboxylic groups, as evidenced by the results from Fourier-Transform Infrared (FTIR), C1s Raman spectra, X-ray diffraction (XRD) patterns, and X-ray absorption spectroscope (XAS) spectra. The XAS results indicate a concomitantly increased first-shell coordination number and Debye-Waller factor for the Ti structural environment. For the XRD patterns from composite catalysts, the peak intensities assigned to MWCNT tend to be much more shielded than those of titania. DR-UV/VIS results indicate that both UV and VIS light absorption levels from the composites increase with increasing MWCNT fraction. A slight blue-shift in the band gap of TiO_2 occurs in the composites, as compared with pure titania nano powders. Some composites show a greater photocatalytic activity than the pure titania due to the separation of electrons from holes by the MWCNT support.

A01692-02936

Fabrication and Superplasticity of MWCNTs/Al Composites

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Since the discovery of carbon nanotubes (CNT) by Iijima in 1991, CNTs have attracted increasing attention attributed to their extraordinary mechanical and physical properties. One of the most promising applications of CNTs is regarded as effective nano-scale reinforcements for Al composites. These Al composites incorporates the high strength and high stiffness reinforcements to offer a combination of good mechanical properties and high temperature durability that render them attractive materials for commercial automotive, aerospace and advanced military applications. However, limited research has been done in the field of CNTs reinforced Al metal matrix composites, due to the detrimental interfacial phases between CNTs and matrix at elevated temperature and suitable processing techniques.

The work here reports the fabrication of multi-walled carbon nanotubes (MWCNT)-reinforced Al metal matrix based composites with improved mechanical properties by cold compaction and sintering of mechanically milled powder. Investigations were carried out to find the optimized processing conditions, the resultant microstructure and the distribution of the CNTS in the Al matrix and the mechanical properties, in particular, the superplastic behavior, was investigated.

A01710-02984

Possibility of SWNT Chirality Control by Free Electron Laser Irradiation during Alcohol Catalytic Chemical Vapor Deposition

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Single wall carbon nanotubes (SWNTs) reveal metallic or semiconducting properties depending on their diameter and/or chirality. For applying SWNTs to nanoscale electronic devices, the preparation volume, the diameter, the alignment and the chirality must be controlled. However, the chirality control method has not been established. We propose a novel technique to control the chirality using free electron laser (FEL) irradiation. The optical absorption wavelength of SWNTs depends on a particular chirality. The FEL used in this work is featured

by the variable wavelength (0.8 - 5 μm) and very sharp pulses width, approximately 500 ps. We expect that the FEL irradiation with the particular wavelength enhances the growth of the SWNTs which have the chirality resulting in the particular wavelength absorption.

As the experimental, quartz was used as the substrates which was cleaned by annealing for five min at 500 °C in atmospheric air. They were dipped in the two types of catalyst ethanol solution: one was the solution dissolving with Co and another with Mo. The concentration of catalysts was 0.1 wt%. As the first step Mo catalysts were formed and successively Co catalysts. The dipping speed was 600 μm/s. After each dipping the substrate was annealed for five min at 400 °C in air.

SWNTs were grown by alcohol catalytic chemical vapor deposition (ACCVD) method using ethanol. FEL with the wavelength ranging from 800 nm to 1450 nm was in-situ irradiated during ACCVD process. The obtained SWNTs were characterized by a micro-Raman scattering spectroscopy excited with the second harmonic of YAG laser (@532 nm) and diode laser (@785 nm).

In the SWNTs grown without FEL irradiation the peak of radial breathing modes (RBM) was observed at 227.7 cm^{-1} (@532 nm) and 223.8 cm^{-1} (@785 nm). On the other hand, in the SWNTs grown under 800 nm FEL irradiation the peak of RBM was observed only at 225 cm^{-1} (@785 nm). The diameters of the SWNTs were estimated *ca.*1.1 nm from the RBM peak value. Then the simulation by Strano suggests that the irradiation of FEL with the wavelength of ca. 800 nm is effective to promote the synthesis of semiconductive SWNTs with the diameter of 1.1 nm. From the investigation based on Kataura plot and resonance Raman effects, the RBM derived from metallic and semiconductive SWNTs is observed in the 532 nm and 785 nm excited Raman spectrum, respectively. As an experimental result, the 800 nm FEL irradiation resulted in promotion of semiconductive SWNT growth with the chirality, (n, m) = (9, 7) or (13, 2). Conclusively the obtained results insist that the FEL irradiation during ACCVD is a novel hopeful process to control the SWNT chirality.

A01753-03074

The Effect of Different Size of CNT in the Polymer Matrix

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Polymer nanocomposites have attracted substantial attention from academic and industrial researchers because of their superior thermal and mechanical properties compared to those of their micro- and macrocomposite counterparts containing an equivalent volume fraction of inorganic filler. Presently, polymer nanocomposites reported in the literature are typically based on polymer matrices reinforced by nanofillers such as montmorillonite (MMT) platelets or carbon nanotubes (CNT). The Carbon nanotubes (CNT) with quasi-one-dimensional structure can be metallic or semiconducting depending on their structural parameters. This makes the CNT as central elements in composite materials for many electronic applications. They also have high stiffness and tensile strength, which make them preferable for the composites with desired mechanical properties. Unfortunately, it is difficult to obtain homogeneously dispersed CNT nanocomposites arises from the non-reactive nature of the CNT surface and the unavoidable bundle formation due to van der Waals attraction during synthesis. It is a key factor to reinforcement of composites that the CNT can disperse efficiently in the polymer matrix. According to the literatures, the size of fillers in the composite affects the properties of the composite. In our previous research, the CNT modified with maleic anhydride by plasma (mCNT) and the mCNT can have good dispersion in the polymer matrix. Therefore, we prepared two different sizes (0.05-0.2 μm, 0.8-1.5μm) of mCNT and discussed their influence in the polymer matrix. With various ratio of two different mCNT, we can obtain an optimum ratio when total contents of CNT in the polymer matrix were 1.0, 2.0 and 3.0 wt%. Moreover, the conductivity of the CNT/polymer can maintain 3×10^{-3} S/m.

A01789-03135

Preparation and Characterization of PANI / SWNT, PANI /MWNT Composite Film for Hydrogen Sensing

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Conducting polymers and their derivative has been widely used as active layer of gas sensors. Among them polyaniline is known its easy synthesis and environmental stability. Its redox behavior make it potential candidate for

gas sensing. Any interaction with polyaniline that alters its inherent oxidation state will affect its conductivity. Functional additivities incorporated into the polyaniline structural matrix such as SWNT, MWNT, metal oxide can change the electrical characteristics of polyaniline. This versatility has made polyaniline for broad scope of design and development of smart sensors.

In the recent work, we will present the response of spin coated thin film of PANI & SWNT/PANI, MWNT/PANI as a chemresistor type hydrogen gas sensor. PANI is chemically synthesized by chemical oxidative polymerization at low temperature and then doped with SWNT & MWNT by ultrasonication method. The gas sensing response of SWNT/PANI film has found to be higher then MWNT/PANI and undoped PANI films. These films have been characterized by I-V characteristics, UV-VIS spectroscopy, XRD and optical microscopy. The Conductivity of PANI/CNT composite films has found to be higher then pure PANI films. The XRD spectrum shows the crystalline nature of composite after doping of CNT.

A01822-03173

Quick and Easy Metal-Semiconductor Separation of SWCNTs

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It is well known that there are two or three electronic types in single-wall carbon nanotubes (SWCNTs), such as metal, semiconductor, and narrow gap semiconductor, depending on their wrapping structures. Because none of synthesis methods can produce single electronic type SWCNT, metal-semiconductor separation is indispensable for practical applications of SWCNTs. After the great works by Arnold et al.[1], now we can obtain high-purity (up to 99 %) metallic and semiconducting SWCNTs by using density gradient ultracentrifugation (DGU). Interestingly, high-purity metallic SWCNTs change their color drastically with their mean diameter. We can control their color and can produce three primary color cyan, magenta, and yellow that work as conductive full color inks. [2] Although DGU gives us high quality separation, we still have to reduce time and cost of the separation for the industrial application. Recently, we found the agarose gel can separate SWCNTs-SDS solution into metallic and semiconducting phases without any special treatment. [3] This new method can separate SWCNTs with high purity, high efficiency, and totally low cost. In this presentation, we will show our recent progress in the separation and some device applications.

[1]. M.S. Arnold et al., Nat. Nanotechnol. 1 (2006) 60.
[2]. K. Yanagi et al., Appl. Phys. Express 1(2008) 034003.
[3]. T. Tanaka et al., Appl. Phys. Express 1 (2008) 114001.

A01865-03223

Strategy of Carrier Control of Carbon Nanotube Transistor

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Pure carbon nanotubes have been known to exhibit ambipolarity. This is very different from the conventional semiconductors that are controlled by an intentional doping with extrinsic materials. This has been a serious drawback in adopting carbon nanotubes for CMOS technology. Carbon nanotubes show p-type behavior in ambient conditions. The difficulty arises from the absence of stable n-type dopants under ambient conditions. A series of chemical approaches have been done in our group to search for n-type dopants. NADH and viologen molecules have demonstrated successfully to show n-type behavior by donating electrons to nanotubesand furthermore show high stability in ambient conditions. In addition to these approaches, we will also demonstrate a way of utilizing ambipolarity of nanotubes without such intentional dopings that ambipolarity is in fact advantageous in fabricating CMOS inverter and logic circuits.

A01885-03813

Nanoelectronically Functional Carbon Nanotubes Created by Plasma Processing

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Nanocarbons of carbon allotropes have drawn great attention due to their high potential for unique properties and a variety of applications. Since carbon nanotubes among them are furnished with one-dimensional hollow inner-nanospaces, it is the interesting idea on the ripple-effect point to inject various kinds of atoms and molecules into the nanospaces based on plasma nanotechnology, which could lead to innovative functionalization of the pristine ones. For that purpose original approaches using nanoscopic plasma processing mainly in ionic plasmas have been performed in order to develop SWNT(single-

walled carbon nanotube)-, and DWNT(double-walled carbon nanotube)-based materials with novel functions corresponding to nano electronic and biological appilications.

Firstly, individually freestanding SWNTs are successfully produced on a flat substrate with a diffusion plasma CVD, which results in inducing a strong photoluminescence brightening .

Then, in order to fill the inner nanospace of such pristine SWNTs and DWNTs with charge-/spin-exploited atoms and molecules, various kinds of gaseous and liquid plasmas are generated, which comprise positive and negative ions of the atoms and molecules such as alkali metals, halogens, ferromagnetic elements, fullerenes, ionic liquids, and DNA. Here the substrate bias method is mainly utilized in these plasmas, where the positive and negative ions with their energies and fluxes controlled are irradiated to immersed substrates coated with the pristine carbon nanotubes.

Consequently, we have innovatively created alkali-metals encapsulated SWNTs and DWNTs (Cs@SWNTs / DWNTs), halogen-elements encapsulated SWNTs and DWNTs (I@SWNTs / DWNTs), ferromagnetic-atoms encapsulated SWNTs (Fe@SWNTs), some kinds of fullerenes encapsulated SWNTs and DWNTs [C_{60}@ SWNTs / DWNTs, C_{70}@SWNTs / DWNTs, C_{84}@SWNTs / DWNTs, C_{59}N@)SWNTs / DWNTs, (Li@C_{60})@SWNTs), hetero-atoms and -molecules encapsulated SWNTs and DWNTs [(Cs/C_{60})@SWNTs / DWNTs, (Cs/I)@SWNTs / DWNTs], Ionic-liquids encapsulated SWNTs (IL@ SWNTs), and DNA molecules encapsulated SWNTs (DNA@SWNTs).

Finally, their electronic, magnetic, and optical properties are intensively investigated using a configuration of field effect transistor (FET) and a SQUID magnetometer, respectively. As a result, we have for the first time clarified unusually localized electronic structures inside Cs@SWNT, and realized the continuous transition of air stable electronic transport from p-type to n- type semi-conducting property by adjusting an amount of dosed atoms and molecules inside SWNTs and DWNTs (Cs@SWNTs / DWNTs, I@SWNTs / DWNTs, C_{60}@SWNTs / DWNTs, C_{70}@SWNTs / DWNTs, C_{59}N@ SWNTs / DWNTs, (Li@C_{60})@SWNTs, IL@SWNTs, DNA@SWNTs). We have also succeeded in forming nano structures of magnetic semiconductor (Fe@SWNTs) and ultimate air-stable nano pn junctions with rectifying characteristic [partially filled SWNTs and DWNTs, (Cs/ C_{60})@SWNTs / DWNTs, (Cs/I)@SWNTs / DWNTs)], finding distinct negative differential resistance of extremely high peak-to-valley ratio over 10^3 (C_{60}@DWNTs, C_{70}@DWNTs, C_{84}@ DWNTs), and observing photoinduced electron transfer phenomena (C_{60}@SWNTs, C_{70}@SWNTs, C_{59}N@SWNTs, DNA@or decorated SWNTs).

A01922-03308

Influence of Nitrogen-doping on the Structure and Electrochemical Characteristics of Multi-wall Carbon Nanotubes

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Nitrogen-doped carbon nanotubes (CNTs) were synthesized by aerosol-assistant chemical vapor deposition (CVD) method using ferrocene as a catalyst source and acetonitrile as a precursor for CNT growth. To change the nitrogen doping level the acetonitrile was diluted with toluene. Nitrogen content in surface layers of CNTs was determined using x-ray photoelectron spectroscopy data. It was found that increase of acetonitrile fraction in the reaction mixture continuously increases the doping level. The fine N 1s spectra of CNTs showed three well-recognized maxima which by result of quantum-chemical calculation were assigned to pyridinic, graphitic and molecular nitrogen state. Portion of N_2 molecules in a product is marked when ratio of acetonitrile and toluene is higher than 25:75. Probably CNT walls can incorporate a limiting concentration of nitrogen atoms and excess of atoms are formed molecules intercalated between CNT layers.

The measurements of charge-discharge characteristics for CNTs and nitrogen-doped CNTs showed increase of lithium capacity for the latter samples. At the first charge cycle the capacity for the sample produced from pure acetonitrile constituted 740 mA h/g and than dropped to 284 mA h/g. The process of lithium intercalation of nanotubes was modeled using density functional theory (DFT) with B3LYP method. By the results of calculations the lithium cation more readily interacts with pyridinic-like nitrogen. We found that lithium can penetrate inside of nitrogen-doped CNT through atomic vacancy, which zigzag boundaries are presented by nitrogen atoms. The estimated barrier for intercalation of nitrogen-doped nanotube with lithium cation is 1.35 eV.

The electrical double-layer performance of CNTs and nitrogen-doped CNTs was compared in acid and alkali electrolyte. Incorporation of nitrogen in CNT walls enhances electrochemical capacity from 10 F/g to 50 F/g. The higher chemical activity of nitrogen-doped CNTs compared to pure ones was confirmed by the thermogravimetric measurements. The change in the electronic structure of nitrogen-doped CNTs with charging was probed using UV photoemission spectroscopy. The stop of the charging process at positive potential results in downshifting of the Fermi level of CNTs. Such shifting

is explained by transfer of electrons from carbon to the anions adsorbed on CNT body from electrolyte.

A01930-03330

Carbon Nano Test Tubes: Interactions of Nanotubes with Molecules and Colloidal Particles

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Due to their tubular nature, carbon nanotubes have been demonstrated to encapsulate different molecules, thus forming quasi-1D molecular systems. The behavior of molecules is significantly affected by the confinement in nanotubes, and the encapsulated molecules can locally perturb and modulate the intrinsic electronic properties of carbon nanotubes.

Unlike molecular species, colloidal particles preferentially interact with the surface of nanotubes and adsorb on the nanotube exterior either forming discrete 1D arrays or extended 2D networks depending on the conditions of assembly. The surface chemistry of particles and the ratio of particle diameter to nanotube diameter are most important parameters controlling the assembly of nanotube-particle heterostructures.

This work is supported by the EPSRC, the Royal Society (UK) and the European Science Foundation.

A01948-03376

Carbon Nanotube Solar Energy Conversion Devices

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Multifunctional carbon nanostructures are currently under active investigation for producing innovative materials, composites, and optoelectronic devices, whose unique properties originate at the molecular level. Among the wide variety of carbon allotropes recently discovered, C_{60}, single wall carbon nanotubes (SWNT) and single wall carbon nanohorns (SWNH) are of particular interest. C_{60} is entirely made of pentagons and hexagons resulting in 0.78 nm sized truncated icosahedral carbon spheres. In contrast, the structure of SWNT has a cylindrical shape, which can be conceptually generated by wrapping a one-atom-thick layer of a graphene sheet into a seamless cylinder. The diameter of most SWNT is around 1 nm – similar to that of C_{60} – with a tubular length that can reach many thousands of times their diameter. Importantly, based on different arrangements, SWNT possess different electrical properties, which are the result of the electrons moving differently in the tube depending on the SWNT arrangement. SWNH, on the other hand, are typically constituted by tubes of about 2-5 nm of diameter and 30 to 50 nm long, which associate with each other to give rise to round-shaped aggregates of 100 nm of diameter. Their large surface areas and inner nanospaces are of great importance, since they ensure a great affinity, for example, with organic electron donors.

The accomplishment of multiple-performance objectives in a single system necessitates combining these carbon allotropes with other classes of materials. Our past work has mapped out compounds that proved particularly useful: active organic materials such as porphyrins / phthalocyanines and oligomers / polymers. We have demonstrated that linking these molecular building blocks creates enormous synergisms in going much beyond just harnessing the features of the individual subunits or constituents. Eventually it enables the control over molecular arrangement – well-defined ensembles and superstructures with widely differing property values – and results in the development of the necessary tools for fine-tuning properties on the molecular, nanoscale level.

I will highlight the opportunities that rest on carbon nanostructures within the context of *charge transfer* reactions in *novel chemical* as well as *light driven* systems with *high tensile strength*. A fundamental aspect of our research is to integrate such functions without sacrificing the structural and electronic integrity of the material. In this context, I will survey our concepts to generate functional entities using the bottom up approach, that is, to design, manipulate, characterize, examine, and understand the potential of carbon materials as a novel platform for stable electron donor-acceptor hybrids and conjugates. Important aspects will include the impact, the benefits and some of the promises that evolve from charge transfer reactions involving carbon nanostructures with high tensile strength on i) the stabilization of radical ion pair states, ii) multi electron catalytic reactions, and iii) photoelectrochemical / photovoltaic solar energy conversion.

A02135-03684

Novel Natural Polymer-Carbon Nanotube Hybrid Materials: Preparation and Properties Thereof

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Owing to the peculiar one-dimension like hollow tube structure, carbon nanotubes (CNTs) hold an attractive prospect in fields such as new energy, catalysis, electricity, magnetism, field emission, selective adsorption and isolation, drug delivery systems, composites and sensors, etc. However, poor solubility, dispersibility and material compatibility of the nanotubes limit their application seriously. In recent years, covalent functionalization of the CNTs with polymers has been proved to be an effective way to solubilization of nanotubes or preparation of polymeric carbon nanocomposites. More important, the covalent techniques allow the combination of different polymers with the nanotubes to create various hybrid materials with unprecedented properties. To achieve this, it is essential to functionalize the nanotubes with ideal polymers.

Thus far, most of the studies focused on synthetic polymers, which are generally derived from nonrenewable and increasingly finite fossil resources, and some bear toxic aromatic rings. Along with the development of natural polymer science, cellulose, chitosan, and their many derivatives, which combine nontoxicity, biocompatibility, biodegradability, bioactivity with attractive physical and mechanical properties, have been increasingly significant and applied in many fields. Therefore, the opportunity to combine the CNTs and natural polymers, appears as a desirable way to develop environment friendly nanocomposites provided with properties that are inherent in both components.

As a basis of further studies aiming for potential applications, it is urgent to create natural polymer-nanotube hybrid materials. Thus, this study chose natural polymers and their derivatives, such as low molecular weight chitosan, *N,O*-carboxymethyl chitosan, *B*-cyclodextrin (*B*-CD), cellulose acetate (CA), hydroxyl ethyl cellulose (HEC) and methyl cellulose (MC) to covalently functionalize the CNTs, respectively. Consequently, six novel hybrid materials were developed, and comprehensively characterized by FTIR, ^{13}C NMR, Raman and UV spectra, as well as TEM/HRTEM, XPS, TG and XRD measurements. Crystallinity and solubility of the hybrid materials that contain rigid nanotubes have been further investigated. It should be mentioned that a strategy comprising cut, surface chain extension, introducing active groups as well as homogeneous reaction tactics, was adopted to prepare the hybrid materials. Based on the strategy and an derivative of nanotube containing active triazine groups, the study realized the homogeneous preparation of four hybrid materials. This is undoubted a breakthrough compared with the non-homogeneous modifications of the nanotubes.

Overall, the study not only improved the solubility of the CNTs effectively, but also provided several basic materials, which should be useful in the development of environment friendly nanocomposites. Furthermore, it might be helpful to develop a new research branch that crosses the nantotube chemistry, polymer chemistry and supermolecule chemistry.

Acknowledgments:
This project was supported by the National Natural Science Foundation of China (No. 50374039, 50802018), the Guangzhou Key Laboratory of Hydrogen and Green Catalyst (Contract No. 2008121106), Guangzhou University, and Key Laboratory of Cellulose and Lignocellulosics Chemistry, Guangzhou Institute of Chemistry, Chinese Academy of Sciences.

A02143-03690

Controllable Growth of Ultralong Single-Walled Carbon Nanotubes on Substrates

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The preparation of horizontally-aligned long single-walled carbon nanotube (SWNT) arrays on flat surfaces is attracting intensive attentions. Such kind of SWNT arrays may be used to build SWNT-based integrated nanodevices. Some effective chemical vapor deposition (CVD) strategies for the controllable preparation of such array were developed.

Based on the rational analysis about the fluidic property of the system, an ultra-low gas flow CVD process was designed to prepare large-scale horizontally aligned ultralong SWNT arrays. SWNT arrays could be well obtained under extremely low feeding flow of 1.5 sccm in a one-inch quartz tube reactor. It was confirmed that the tubes grew floatingly and could cross micro-trenches or climb over micro-obstacles in ultra-slow gas flow. Both the buoyancy effect induced by gas temperature/density difference and gas flow stability played dominant roles. More attractively, simultaneous batch-scale preparation of SWNT arrays was realized by the ultra-low gas flow strategy. This new strategy turns to be more abstemious, efficient, promising and flexible comparing with the high gas flowrate fast-heating CVD processes.

Metallic copper was found to be an efficient catalyst to grow SWNTs under suitable conditions. It showed very high catalytic activity for the growth of both random SWNT networks and horizontally aligned SWNT arrays. Especially, high quality SWNT arrays were obtained when monodispersed copper nanoparticles were used. The weaker interaction between copper and silica surface plays an important role in the growth of high quality horizontally aligned SWNT arrays. Experimental data and theoretical analysis all proved that copper is advantageous over the normally used iron catalyst in obtaining individually presented small diameter SWNTs with fewer amorphous carbon.

IVA group metal Pb was also found to be an efficient catalyst to grow SWNTs under suitable conditions. It showed very high catalytic activity for the growth of horizontally aligned SWNT arrays. Especially the volatility of Pb made it feasible to realize the growth of SWNTs with no metallic catalyst residues. These directly prepared SWNTs with no metallic residues will greatly benefit the study of the intrinsic properties of SWNTs, and is also very important for making use of SWNTs in nanodevices and in biological systems.

A02148-03701

Composites of Carbon Nanotubes and Calcium Carbonate from Eggshell Waste and its Properties

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The biomineralization process in eggshells completes within 24 hours and is controlled by a number of biomacromolecules. These biomacromolecules helps to induce hierarchical crystal growth process and termination process during the biomineralization of the eggshell. *In vitro* calcium carbonate ($CaCO_3$) crystallization studies in presence of these biomacromolecules resulted in various crystal shape modulations. Recently water dispersible carboxylic acid modified multi/single walled carbon nanotubes (SWCNT/MWCNT) also showed crystal shape and structure modulation which is dependent on the concentration of the carbon nanotubes to the calcium ions present. In this study, we have prepared calcium carbonate and MWCNT composites. We were able to produce highly porous uniform sized micro crystals in presence of low concentration of MWCNT. The crystal morphology was studied by scanning electron micrograph (SEM) and characterized by Fourier transformed infrared spectroscopy (FTIR) and X-ray powder diffraction (XRD). The mechanism of the crystal formation was investigated by analyzing the crystals using transmission electron microscopy (TEM), SEM, FT-IR, XRD and thermo gravimetric analysis (TGA) and differential scanning calorimetry (DSC).

A02184-03745

Performance Enhancement in the Organic Solar Cell with Chemical-doped Carbon Nanotube as Interpenetrating Electrode

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The photovoltaic efficiency of organic solar cell has been hampered by the excitons dissociation and slow charge carriers transport. Recently, the organic solar cells based on bulk-heterojunction (BHJ) structure, comprising blends of donor and acceptor molecules, has exhibited improved efficiency by providing nanoscaled dissociation center near the photo-generated excitons to suppress charge recombination. However, the transport of separated charge carriers still remains an issue due to low carrier mobility, particularly that of holes in the organic materials.

In this work, we have demonstrated the increase of the power conversion efficiency (PCE) in a bulk-heterojunction organic solar cell using single-walled carbon nanotubes network(SWNT-network) as interpenetrating electrodes for extracting hole carriers. High quality of SWNT-network were firstly synthesized via alcohol catalytic chemical vapor deposition (ACCVD), and then transfered on to a patterned ITO galss by using a transfer process. An active layer of P3HT:PCBM blends were spin-coated onto this SWNT-network, followed by a top electrode deposition of LiF/Al .In order to investgate the influence of chemical doping on the as-grown SWNT-network,and further realize the enhancement factors in device performance. The SWNT-network are treated with nitric acid, sulfuric, and hydrazine before the deposition of active layer. The scanning electron microscopy(SEM) and transmission electron microscopy(TEM) are carried out to characterize the morphological features and nanostructure of as-grown materials, respectively. In addition, the quality and optical transmittance were characterized respectively by Raman spectra and UV-Vis-IR spectrophotometer.The device properties, such as short-circuit current (J_{sc}) and open-circuit voltage (V_{oc}), and filled factor *(FF*), are measured with a solar simulator under AM 1.5 illumination (100 mW/cm^2).

Consequently, we have observed that the PCE is silghtly increased from 3.4%(reference device without SWNT-network) to ~3.6% by introducing the SWNT-network in the device. In the case of hytrazine-treated SWNT-network, the device performance is boosted to ~ 4%. It is worthy to note that short-curcuit current shows an increase of ~20% (from 10 to 12 mA/cm^2)by comparing with refernce device. It is believed that CNTs enhance the hole transport

by providing conducting pathways to the electrode,while maximizing the surface area for the collection of charges. Moreover, the charge transport model between CNT and polymer will be discussed.

A02206-03772

Effect of Reaction Temperature on the Production of Carbon Nanotubes on a Silicon Dioxide Wafer

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Carbon nanotubes (MWCNTs), carbon nanofibers (CNFs) and other type of carbon nanostructure materials have been synthesized on silicon dioxide substrate at different reaction temperature by using floating catalyst chemical vapor deposition (FC-CVD) method. The effect of the reaction time on the purity and yield of carbon nanomaterilas was studied from 500 °C to 1200 °C. By controlling the growth temperature, carbon nanotubes (CNTs), carbon nanofibers (CNFs) and vapor grown carbon fiber with different structures were produced. Increasing the temperature has a remarkable effect on the size and shape of the catalyst and this in turn affected the diameter distribution and structure of the carbon materials. The carbon nanotubes were produced from 600 °C to 850 °C with maximum yield at 850 °C, while for the production of carbon nanofibers the reaction temperature was from 900 °C to 1000 °C with a maximum yield at 1000 °C. Vapor grown carbon fibers were produced at 1050 °C to 1200 °C with maximum yield at 1050 °C.

A02219-03794

Properties of Copper Coated with Carbon Nanotubes

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A thick layer of multi-wall carbon nanotubes (CNTs) has been deposited on copper surface by gravity from a solution containing dispersed CNTs in water. Scanning electron microscopy (SEM) has been utilized to characterize the morphology, uniformity and thickness of the CNTs coating. A low magnification examination shows a uniform coating. However, a close look at the SEM images reveals that the coating consists of clumps of CNTs deposited rather irregularly on the surface. The CNT coating exhibits a strong adhesion onto the copper surface as revealed by adhesion test. A corrosion test has been carried out to investigate the effect of CNTs coating on the corrosion rate of copper. The results have clearly indicated that the corrosion rate has been reduced by almost 50%.

A02220-03795

Effect of Hydrogen Flowrate and Carbon Source on Production of Carbon Nanotubes by Chemical Vapor Deposition

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Multi wall carbon nanotubes (CNTs), carbon nanofibers (CNFs) and other types of carbon nanostructure materials have been synthesized by a fabricated floating catalyst chemical vapor deposition (FC-CVD) method by using two different types of hydrocarbon and different hydrogen flow rates. The hydrocarbons used were benzene and acetylene. The procedure involved the pyrolysis of benzene-ferrocene and acetylene-ferrocene vapor mixture. The CVD parameters like reaction time, reaction temperature and amount of ferrocene catalyst were fixed at 30 minutes, 800 °C and 100 mg, respectively, while the hydrogen flow rate was varied at 100, 150 and 200 ml/min. The hydrogen gas was varied to study the effect of the hydrogen as reacting and carrier gas on the production, purity, quality and quantities of carbon nanomaterials. Hydrogen flow rate plays a significant role in the formation of carbon nanotubes and carbon nanofibers, as being the carrier and reactant gas in the floating catalyst method. During the process of synthesis of CNTs, hydrogen gas carried along benzene vapour in to the reaction chamber. The hydrogen flow rate influenced the concentration of benzene and acetylene and its absorption on the catalyst particles. The two different hydrocarbon sources were used to study the effect of carbon atoms on the growth of the carbon nanomaterials. Carbon nanotubes films with a diameter of 10-70 nm and nanofiber with a diameter range of 100-200 nm were synthesized in a benzene/hydrogen and acetylene/hydrogen atmosphere. Samples were analyzed using SEM and TEM. The results show that by increasing the hydrogen flow rate associated with benzene vapor the number and also the diameter range of the CNTs were increased. Most of the CNTs have been observed to have small diameters. At the minimum hydrogen flow rate, i.e. 100 ml/min, CNFs were formed. At the maximum flow rate of 200 ml/min, the observed range of CNTs diameter varied from 10-60 nm. However, when the acetylene was used the diameter of the CNTs was reduced due to the excess amount of the hydrogen flow rate which inhibits the carbon atoms to deposit on the surface of the catalyst. The results indicate that by increasing the hydrogen flow rate the purity of the product increased in both hydrocarbons. Further investigation of the effect of hydrogen flow rate and the carbon source on the purity, quality and quantities of CNTs is detailed in this paper.

A02234-03955

Preparation and Properties of Carbon Nanotubes-TiO_2 Nanocomposites

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Nano-TiO_2 catalyst is of considerable interest due to their excellent characteristics such as high photocatalytic property, low consume energy, easily operate etc. Preparation of different structure inorganic materials supported TiO_2 overcomes the shortcomings of TiO_2 nano powder, such as agglomeration and beyond reclaim. Carbon nanotubes (CNTs) could be considered as a good support for materials with photocatalytic properties due to their high mechanical and chemical stability and their mesoporous character which favors the diffusion of reacting species. On the other hand, a dispersion of TiO_2 on the CNTs surface could create many active sites for the photocatalytic degradation. In the present study, CNTs-TiO_2 nanocomposites were prepared by sol-gel method using $Ti(OBu)_4$ as raw material and the CNTs as the carrier. The morphological structure of the photocatalyst particles was characterized by XRD and TEM. Absorbency was analysed by the UV-Vis diffuse reflection spectra of TiO_2 and CNT-TiO_2 photocatalysts. The photocatalytic activities of the materials heat-treated at different reaction temperatures have been tested on decomposable substrate methyl orange solution under UV-light illumination. The results showed that the nanocomposites had excellent photocatalytic ability. When the wavelength was between 200~800 nm, CNT-TiO_2 nanocomposites had good absorbency. TEM micrographs showed that TiO_2 was closely coated on the surface of carbon nanotubes. The best heat treatment temperature of CNT-TiO_2 nanocomposites was 450°C. The crystal form of TiO_2 was anatase and the diameter of crystal was 7.3 nm. The photodegradation rate of CNT-TiO_2 nanocomposites was better than that of pure TiO_2 under sunlight.

A02356-04061

Preparation of the Multifunctional Films Based on Carbon Nanotubes: Conductive, Transparent, Superhydrophobic, Photocatalytic Films

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Recently, several attempts have been made to fabricate transparent superhydrophobic coatings, which can be applied in architecture or automobile windows, eyeglasses, optical windows for electronic devices, etc. If the wettability of the conductive, transparent CNT films can be controlled by TiO_2 photocatalysis from superhydrophobicity to superhydrophilicity under UV illumination, this technology will meet the needs of a wide range of applications requiring multifunctional coatings (e.g., in optoelectronic devices, solar energy conversion, photocatalysis, and so on). In this paper, we studied a effective method for multifunctional films based on multi-walled carbon nanotubes (MWCNTs), which were prepared that the hydroxyl functionalized multi-walled carbon nanotubes and TiO_2 nanoparticle were dispersed in fluorited silane sol binder and then were spin coated on the glass substrates.. The CNTs and the composite films were characterized by a range of analytical techniques including X-ray photoelectron spectroscopy (XPS), raman spectra, scanning electron microscopy (SEM). As a result, the films showed multi properties, such as superhydrophobicity, conduction, transparency, and photocatalysis.

A02379-04070

Carbon Nanotubes as Reactors and Containers for Diverse Functional Nanomaterials

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Ever-since the discovery of carbon nanotubes (CNT) in 1991 by Iijima, intense research has been carried out in understanding its useful physical and electronic properties as well as exploring its use in many device concepts. Many of its unique properties such as tunable electrical resistance, mechanical robustness, super-hydrophobicity and opacity to visible light, when combined with that of the other functional materials could lead to heterostructures with diverse functionality that would otherwise not exist. We have been recently exploring general methods for mass production of such materials wherein CNT forms core-shell heterostructures with metals, semiconductors, insulators and even metal-semiconductor heterojunctions. Some of the examples include Ga filled CNT which works as a nanothermometer, In filled CNT heterostructure where In is superconducting, Ga-doped ZnS nanowires inside CNT that acts as precursor for composite heterostructure nanotubes of ZnO and $ZnGa_2O_4$, In-ZnS heterojunctions and certain exotic and unstable materials such as Mg_3N_2 that can not be otherwise exposed to air if not encapsulated, due to high reactivity. The emerging strategy employs high temperature chemical vapor deposition technique with rapid heating rate. The mechanism involved in such synthesis are being investigated in details. Due to high temperature stability, and hydrophobicity, CNT can be used a nanoreactor for producing exotic materials (inside it) in nanostructured forms which is otherwise quite challenging. The properties of the materials inside CNT vary due to

high interface area. Additionally, since light also can not penetrate into a CNT, it is an excellent system for storing photo-degradable nanomaterials. Recently, CNT has been proposed as an ideal tool for not only storing materials, but also for delivering substances at the nanoscale level for a variety of applications. Our experiments demonstrate promising strategy for the slow and controlled release of the CNT encaptulated materials. Finally, the effect of filling materials on the mechanical and electrical properties of this type of single CNT heterostructure is also estimated.

A02397-04238

Wafer-scale Synthesis and Electrochemical Properties of Few-layer Graphene for Energy Applications

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The recent experimental breakthroughs on graphene-based nanoelectronics have triggered enormous academic activities. Among the production methods of graphene, mechanical exfoliation of graphite and surface evaporation of SiC are widely used. Despite the successful fabrication in surface evaporation of SiC, process integration of graphene into the well-established Si-based technology remains a challenging task. In view of this, it is also desirable to develop a reliable and large-scale (or wafer-based) production of graphene for practical applications. In this presentation, we will demonstrate a novel synthetic route for graphene growth on silicon substrate by microwave plasma enhanced chemical vapor deposition (MPECVD). The resultant nanoarchitecture exhibits a wall-like morphology with a high density of sharp edges. Structure wise, each nanowall is composed of SiC decorated by a few layer of graphene (i.e. concrete paint on concrete wall). Moreover, direct deposition of Pt nanostructures onto these graphene samples is also performed to explore their potentials for electrochemical energy applications. Preliminary cyclic voltammetry studies for electro-oxidation of methanol show a high ratio of forward anodic peak current to reverse peak current, suggesting an efficient oxidation of methanol to CO_2 on the Pt/graphene electrode. The effective suppression in the reverse cathodic peak current probably suggests a selective growth of Pt on graphene. Other electrochemical properties (such as electron-transfer kinetics and chemical reactivity) of MPECVD-grown graphene will also be addressed in this presentation. Our synthetic approach offers an alternative route toward wafer-scale fabrication of graphene for fundamental research and opens up various potential applications in nanoelectronics, sensing, catalysis, and energy production.

A02415-04127

Ink-jet Printing of Nano-carbon Materials

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Nano-carbon materials, such as single-walled carbon nanotube (SWCNT) and graphene, demonstrate a significant advantage in transport properties and chemical stability. It is only natural to apply solution-based method to them because it opens a route for large area electronics on virtually any surface. Herein, we have investigated ink-jet printing of SWCNT and graphene from their dispersions. Both nano-carbon materials were successfully printed by ink-jet technique. In particularly, we fabricated SWCNT thin-film transistors using ink-jet printing. For this end, we prepared SWCNT films with high and moderated coverage for all of the conducting (i.e., source and drain electrodes) and semiconducting layers, respectively, since it is well known that the transport characteristics of SWCNT films strongly depend on coverage. The transport characteristics of printed SWCNT films have been perfectly controlled by coverage, which was precisely tuned by the number of printing. As a result, we achieved to make a high-performance SWCNT-TFT (on/off current ratio of 1×10^5 and a field-effect mobility of 6.5 cm^2/Vs).

This study was supported by Industrial Technology Research Grant Program in 2006 from New Energy and Industrial Technology Development Organization (NEDO) of Japan.

A02451-04184

Laser-Induced Pyrolysis: In-Situ Modulation of Carbon Black Morphology

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Laser-induced pyrolysis of a gas/vapor reactants is a versatile and reproducible technique to synthesize numerous nanostructured materials. The nature and composition of the reactive gas mixture as well as the appropriate experimental parameters allows to modulate the characteristics of the material in the view of foreseen functional properties. Carbon nanomaterials could interface naturally both with electronic and biologic systems and, due to their morphological flexibility, high specific area and chemical activity, present an extended potential of applicability. The size, structure, composition and aggregation as well as chemical functionalization of the surface define the interaction with other systems. Also, carbon nanoparticles existing in environment are

an important factor on healthy, either by their toxicity or by interaction with pathogen microorganisms, which can make them more resistant or induce a specific muthagenesis. Through the variation of the experimental parameters and gas composition, the method of laser-induced pyrolysis allows obtaining carbon nanoparticles with different morphologies. The work presents the attempts to drive the synthesized nanocarbon into a regime where it can naturally interface with the surrounding matter and investigates how to modulate, through laser induced pyrolysis, the characteristics of carbon nanopowders in order to achieve functional properties claimed by specific applications. Carbon blacks with different morphologies, from almost amorphous to those presenting a high degree of curvature like fullerenes or anion-like were synthesized by laser-induced pyrolysis of hydrocarbon-based mixtures and characterized by FTIR, Raman and XPS spectroscopy, X-ray diffraction spectrometry, transmission electron microscopy and its related techniques (EDAX, SAED, EELS), scanning electron microscopy and dynamic light scattering. The results confirm experimentally their particular behavior during interaction with different chemical and biological systems.

The authors gratefully acknowledge financial support from the Romanian Ministry of Education and Research, under Project 71-125

A02529-04330

Development of Carbon Nanotube-Filled Lead Free Sac Alloy Solder Paste

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Carbon nanotube-filled materials have motivated a lot of researchers to venture for a range of possible applications over the last few years. This includes the further improvement of the SAC alloy solder alloys which are considered to be the most viable alternative to the tin-lead as the electronics industry undergoes transition on coming lead-free. This study aims to impregnate SAC 405 (95.5 Sn/4.0 Ag/0.5 Cu) based composite solder with Multi-walled Carbon Nanotubes (MWCNT) with 0.8 wt. % concentration under two different atmosphere. This was done through the Powder Metallurgy Route. The morphological, elemental composition, mechanical, thermal and wetting properties of this solder composite were taken into account as to compare its difference to the existing lead-free SAC alloy solder paste used in the assembly on the microelectronics industry. The microstructures and morphology of the specimens were analyzed through the Field-Emission Scanning Electron Microscope (FE-SEM) and Atomic Force Microscope (AFM). Elemental Composition characteristics were verified through the X-ray Fluorescence Spectrometer (XRF). The hardness of the specimens was tested through the Rockwell Superficial Hardness Tester. Thermal Properties on the other hand, were analyzed through the Differential Scanning Calorimetry (DSC), and the wetting properties were observed through the wetting balance. From the results gathered, it was verified that there was a significant improvement on the mechanical and thermal properties. Morphological analysis also revealed that MWCNTs were dispersed within the solder matrix. However, a more homogeneous dispersion was achieved in the SAC-MWCNT solder specimen milled under inert (Ar) atmosphere. Solder specimens were subjected to actual Surface Mount Technology (SMT) processes to verify the efficiency of the manufactured solder paste to actual applications and to build a data base of comparison to the existing solder paste used in the microelectronics industry nowadays. The gathered data implied that the manufactured solder paste passed the qualification criteria since the capability index (CPk) was greater than 1.66, thus, proving that the SAC-MWCNT solder paste manufactured in this research is a viable alternative to the existing solder pastes with more outstanding characteristics.

A02538-04347

Production of High Quality Aligned Carbon Nanotubes by One Step Method

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High quality Multi wall carbon nanotubes (MWNTs) have produced by a simple one step technique. The production of CNTs is based on thermal decomposition of the mixture of a liquid phase organic compound and ferrocene. Different characterization tools were employed for the structural analysis. High degree of alignment is noticed under scanning electron microscope (SEM). The aspect ratio of CNTs is quite high ~ 4000. TEM analysis shows the presence of the catalytic iron nanorods at various lengths of CNTs. In fact an attempt of varying the iron content in the CNTs has been made and EDAX analysis shows that Fe content changes in different samples which have made by varying the ferrocene weight in the precursor mixture. XPS spectrum reveals that iron is present in CNTs in two chemical states namely singlet and triplet. Raman spectroscopy is been used to know the quality of CNTs. The ratio of intensity of the G-peak to the D-peak is very high. Magnetotransport studies is carried out at low temperature and a negative MR is noticed.

A02699-04643

Nanostructured Carbon Electrodes for Energy Storage

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Energy harvesting or 'passive' conversion of energy brings about with it a new set of system challenges on energy conditioning to enable practical use of the the collected energy. Continuous conditioning and connection is not efficient for very small amounts of power. Therefore, energy storage and modes of utilisation have become key issues for the realization, for example, of a PV energy harvesting scheme.

Current work on using nanostructured carbon surfaces in supercapacitors and batteries to enable enhanced performance is discussed. In particular the emphasis is on solid electrolyte based batteries and supercapcitors which can be flexible and change form factor. This is a new concept for energy storage systems driven by the requirements of next generation mobile communication devices which will be designed to supplement regular battery power with power from harvested energy. It will be shown that a new class of flexible suprecapacitors and batteries can be realised through use of carbon electrodes with enhanced nanostructure. The power density of a flexible supercapacitor , for example, can be increased very significantly by designing nanostructure based around carbon nanotubes into the electrodes.

A02731-04704

Purification of Carbon Nanotubes by NaOH Leaching and Froth Flotation

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The as-prepared SWNTs from deposition of carbon on supported catalysts always contain significant amounts of impurities such as metallic catalysts, catalyst support, and other unwanted forms of carbon. Therefore the purification of SWNTs is required prior to bring them to use. In this study, the SWNTs produced by the CO disproportionation over a CoMo/silica catalyst was purified by first using NaOH solution to dissolve the silica support. The froth flotation was subsequently applied to further recover and concentrate the total carbon. To achieve a high purity of total carbon, the effects of operating parameters were investigated in order to minimize the entrainment of undissolved silica with the froth. At the optimum operating conditions: 3 h of sonication time, 30 mg/l of surfactant dosage, 1.0 g/l of pulp density, 100 ml/min of air flow rate, and 22 cm of froth height, the purity of total carbon was found to increase to 30% after the NaOH treatment and to 78% after the froth flotation as compared to the initial carbon content of only 4% of the as-prepared SWNTs. From the temperature programmed oxidation results, the Raman spectra and the scanning electron microscope images, the physical and chemical structures of SWNTs are not damaged by NaOH treatment and froth flotation.

A02777-04744

Carbon Nanofibers

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Carbon nanofibers have been attracted many attentions for their potential applications in nanocomposites and electromagnetic wave-absorbing materials due to their remarkable mechanical, electrical and other properties. Ethanol as carbon source not only possesses low toxicity, easier storage and transportation, but also does not tend to form amorphous carbon on dissociation. So in our experiments, we use ethanol as carbon source to synthesize carbon nanofibers. In this paper, we report ethanol catalytic chemical vapor deposition (ECCVD) for synthesizing carbon nanofibers. We utilized ferrocene as catalyst precursor to synthesize carbon nanofibers by ethanol chemical vapor deposition. The ECCVD setup consists of two-stage furnace fitted with independent temperature controllers, carbon source supply system, carrier gas supply system and pump system. The ethanol was introduced into furnace tube by bubbling liquid ethanol under carrier gas flow of 100sccm 3%H_2/Ar and 100sccm N_2. Catalyst precursor ferrocene was place at low temperature (300°C) region. Then ferrocene gas was introduced into high temperature (800°C) region by carrier gas. Ferrocene was decomposed to form iron nano-particles as catalysts. These catalysts catalyzed the growth of carbon nanotubes which were deposited on substrates and the wall of furnace tube. After about 1h synthesis time, we obtained mass production of carbon nanofibers. The deposits were characterized by employed scanning electron microscopy, transmission electron microscopy, and Raman spectroscopy.

A02799-04790

Effect of Carbon Nanotube Fillers on the Electrical Conductivity of High Density Polyethylene - Carbon Black Composites

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Carbon nanotubes (CNTs) have been widely used in various applications due to their unique structure and important characteristics. Conducting polymers characterized by attractive features that include good corrosion resistance and controllable conductivity, these properties make conducting polymers good shielding material against electromagnetic interference (EMI). In this paper the conducting polymer nanocomposites have been fabricated using a high density polyethylene (HDPE) with 20 wt % of carbon black (CB) and different wt % of multiwalled carbon nanotubes (MWNTs). The volume and surface conductivity of these composite materials are measured by varying current, temperature and time. The volume and surface conductivity depends on the concentration of fillers. It was noticed that incorporating the MWNTs in HDPE-CB composites can enhance the electrical properties of the nanocomposites. The nanocomposite is found to have good conductive behavior can find its application as electromagnetic interference shielding material. A theoretical model of conductivity was also developed for the sake of comparison with the measured data. The data reveals that a good correlation exists in respect of experimental conductivity value with that of the theoretical one.

A02809-04907

Adsorption of $MgCl_2$ on Surface-Modified Multi-Walled Carbon Nanotubes

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Carbon nanotubes are expected to be an effective reinforcing filler for polymer that will provide exceptional mechanical properties. The nanotubes, however, tend to aggregate into bundles, leading to impractical applications. In this study, multi-walled carbon nanotubes (MWCNTs) were chemically treated by various types of acid, such as HCl, HNO_3, H_2SO_4, and a mixture of H_2SO_4 and HNO_3. The morphology and functional groups of the treated MWCNTs were observed by SEM and FT-IR. The results showed that MWCNTs treated by the mixture of diluted H_2SO_4 and HNO_3 contain a high amount of functional hydroxyl groups with good morphology. Subsequently, the adsorption of $MgCl_2$ on these surface-treated MWCNTs were studied and compared with other fillers such as silica and carbon black.

A02846-04873

Thermal Kinetics of Multiwall Carbon Nanotube Prepared by Floating Catalyst Chemical Vabor Deposition (FC-CVD)

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Well aligned multi wall carbon nanotubes (MWCNTs) materials have been synthesized by a fabricated floating catalyst chemical vapor deposition (FC-CVD) method. Carbon nanotubes films with a diameter of 2-50 nm were synthesized in a benzene/hydrogen atmosphere. Iron clusters that were produced from the thermal decomposition of ferrocene films were used as catalyst for the synthesis of the carbon structures.

Thermal degradation of multi wall carbon nano tubes (MWCNTs) was studied using thermogravimetric analysis. Degradation of MWCNT was completed in one step. Single heating rate (10°C/min), and first order (n=1) method was applied in this study. The TG thermgrams was carried out in air and there were some residual remains of the sample, when it was heated to about 900°C. Major degradation step of MWCNT was at 660°C. Activation energy achieved for MWCNT was 160.618 kJ/mol. While pre-exponential factor was found to be $2.7\times10^6\ min^{-1}$

A02895-04948

Optical Properties of Purified Carbon Nanotube-polymer Composites

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The development of new purification routes for nanotube solutions using organic solvents and semiconducting polymers allows us to produce highly selected species specific solutions. Studies of the interband transition energies in these solutions allows us to perform a detailed fitting of the contribution from Coulomb effects to the transition energies and hence deduce the single particle band gaps and the magnitude of the carbon-carbon overlap integral for a range of semiconducting carbon nanotubes. The interband transitions are all consistent with a value for Γ of 2.75eV, while the net Coulomb contribution to the band gap is found to vary relatively slowly with diameter with the factor $d^{-0.55}$.

In addition to acting as solubilising agents semiconducting polymers also lead to electronic interactions between the nanotubes and the surrounding material. This causes modification of the excitonic properties of the nanotubes, charge and energy transfer between the polymers and the nanotubes and in some cases to the formation of novel hybrid nanostructures. Variation of the polymer allows the formation of both type I and type II excitonic structures which lead to significantly different properties for the different heterostructures, with significant implications for the production of organic photovoltaic cells.

A02899-04957

Selective Growth of Well Aligned Semiconducting Single-walled Carbon Nanotubes

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Even though the devices made from individual nanotubes have shown outstanding performances such as high mobility[1], high current[2-4], high thermal conductivity[5], good chemical[6] and mechanical stability[7], the high hope for the next generation of carbon nanotube based electronics is hampered by several major problems. Among them are the lack of reliable methods to control the alignment and position of nanotubes as well as and perhaps most problematically, the simultaneous growth of nanotubes with different chiralities, yielding random mixtures of metallic and semiconducting nanotubes[8]. Even though the post-growth separation of metallic from semiconducting SWNTs have made good progress[9-16], the alignment and assembly of the separated nanotubes into devices are still challenging and not suitable for large scale fabrication. Consequently, a method that can directly produce well aligned arrays of pure semiconducting nanotubes is thought to be the ideal choice for large scale fabrication of nanotubes FETs. In this talk, we show that such a method is not a dream. We developed a chemical vapor deposition (CVD) approach, which allows selective growth of high-density arrays of well-aligned SWNTs with almost exclusively semiconducting SWNTs. Analysis of the samples shows that at least over 95% of nanotubes are semiconducting. This method demonstrates great promise to solve two of the most difficult problems which limit application of carbon nanotubes in nanoelectronics – the coexistence of metallic and semiconducting nanotubes in samples produced by most, if not all, growth methods and the simultaneous control of the alignment of the nanotubes.

A02924-04999

Solution-processed Transparent and Conducting Single Walled Carbon Nanotube and Graphene Thin Films

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Low-density random networks of SWNTs have received significant attention for applications such as transparent electrodes for solar cells and active layers in field-effect transistors. We will briefly review the optoelectronic properties of SWNT networks. The morphology, optical properties and the electronic performance of solution-processed SWNT networks will be correlated to the type and age of the starting suspensions by means of spectroscopic ellipsometry and Raman spectroscopy combined with electrical transport measurements. The utilization of SWNT thin films in thin film electronics via incorporation in transistors and organic photovoltaics will also be discussed. In addition to SWNT networks, we will also present our results on thin film electronics based on graphene obtained by chemical reduction of graphite oxide. These results represent a route for translating the interesting fundamental properties of graphene into technologically significant devices.

A02963-05071

Reinforcement of Alginate Hydrogels using Carbon Nanotubes

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Carbon nanotubes (CNT) are materials which possess high aspect ratio and good mechanical properties making them useful as additives in materials where structural support is needed. Recently, CNTs have shown promise in improving the mechanical properties of biopolymers for tissue engineering applications. One typical example is alginate, which is a natural, anionic polysaccharide and alginate hydrogels have been applied in cell encapsulation studies. However, alginate hydrogel is mechanically weak and its mechanical strength is also not compatible to that of natural tissues and organs. In our study, a series of homogenous alginate/CNT hydrogels were made by using calcium carbonate ($CaCO_3^{2+}$) and D-glucono- δ -lactone (GDL) with the addition of different amount of CNT. Purified CNT dispersed in a biopolymerwas incorporated, with a loading of between 0.5 to 2.5 wt% with respect to the alginate, to the mixture of alginate, $CaCO_3^{2+}$ and GDL. The mechanical properties of the resultant alginate/CNT hydrogels, formed after in-situ gelation of one day, were characterized using tensile testing. An improvement in mechanical strength was observed for the carbon nanotube - reinforced gels compared to the gel without reinforcement. The Young modulus (measured at compressive strain from 20-40%) increased with higher CNT content, *i.e.* from 30.7 ± 11.2 kPa to 84.6 ± 14.4 kPa. The ultimate compressive stress generally increased, from 14.6 ± 4.82 kPa to 20.3 ± 2.93 kPa, with higher CNT content while the ultimate compressive strain decreased, from 57.8 ± 5.39 to 49.2 ± 1.99 kPa. This result suggests that CNT can be used to strengthen the alginate hydrogels prepared via the $CaCO_3^{2+}$/GDL system.

A02964-05072

Carbon Nanotubes as Physical and Biological Platforms for Technology Applications

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Since 1991 carbon nanotubes (CNT) have generated much interest and excitement in the science and technology community due to its unique physical and materials properties. Its physical structure, and high aspect ratios have given rise to quantum phenomena being observed at room temperatures, and given new insight to device physics. In this talk, I will discuss some of the research we have conducted in the growth, nano-manipulation and functionalisation of carbon nanotubes, and by suitable design how novel platforms can be created for technological applications including nano-biology.

The mixing of CNT with organics also opens a plethora of applications in solution processable hybrid structures, which could be exploited for the production of large area solar cells and lighting devices. Issues associated with low charge carrier mobilities and low diffusion lengths of excitons in the organics can be overcome within the hybrid structures by having 'inorganics-in-organics' to improve on the efficiency of the devices. The electronic properties of CNT are fundamentally dependent on its atomic structure, and understanding the interactions at this level through STM studies has allowed us to better design systems that incorporate CNTs as active materials. The ability to functionalise CNTs inside and outside its tubular structure allows this material great flexibility than most in providing a platform for future technology applications in electronics, optical and biological fields.

A02965-05073

Reactive Spinning of Thermoset Composite Fibers Reinforced with Aligned and Functionalized Single-walled Carbon Nanotubes

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A new approach of reactive spinning to fabricate thermosetting composite fibers with aligned single-walled carbon nanotubes (SWNTs) was reported. The composite fibers were produced by first dispersing SWNTs in thermosetting polymer matrix, followed by pre-polymerization to achieve a suitable viscosity, spinning, and then multi-stage curing. Composite fibers were fabricated by two types of thermosetting matrices, namely cyanate ester (CE) and epoxy (EP). In the first case, amino-functionalized SWNTs were used as filler which were prepared via reaction between acid-treated SWNTs with toluene 2,4-diisocyanate and then ethylenediamine. In the second case, SWNTs were functionalized with generation (n) 0 to 2 dendric poly(amidoamine) (denoted as SWNTs-G_0-NH_2, n = 0, 1, or 2). The composite fibers were characterized for SWNTs dispersion by optical and scanning electron microscope (SEM). Alignment of SWNTs in thermosetting matrices was confirmed by SEM and polarized Raman spectroscopy. Significant enhancement of the mechanical properties is obtained for two types of composite fibers. Amino-functionlized SWNTs reinforced CE composite fibers show 85, 140, and 420% increase over neat CE in tensile strength, elongation, and toughness. EP composite fibers reinforced with SWNTs-G_2-NH_2 show high tensile strength and Young's modulus per unit weight fraction ($d\sigma/dW_{NT}$ = 7022MPa and dE/dW_{NT} = 118.0GPa). Spinning of SWNTs/polymer composite fibers

using thermosetting resin is novel and would be useful for making mechanically strong composites.

A02967-05075

Stability and Dispersibility of Single-Walled Carbon Nanotube Dispersion using Polysaccharides and Surfactants

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Biopolymers (specifically chitosan and O-carboxymethylchitosan (OCMCS) and surfactants (sodium dodecylbenzene sulfonate (SDBS) and Triton® X-100) were used as dispersants for single walled carbon nanotubes (SWNTs) in water. The single-walled carbon nanotubes (SWNTs)-dispersants solutions were observed over a time period of one month under different temperatures and standing times. The nanotubes were dispersed in water using these dispersants by sonication and then left standing for up to 1 month. The solutions were then centrifuged. Analysis was then carried out on the supernatant obtained from centrifugation of the resulting SWNTs solutions. The quantitative method which uses ultraviolet visible near infra-red (UV-vis-NIR) spectroscopy was employed to evaluate the dispersibility and stability of the biopolymers and surfactants. The relative dispersibility was obtained by comparing area ratios calculated within wavelength range S_{22} from the spectroscopy data. In addition, photoluminescence (PL) of the SWNTs surfactant dispersion was used as an affirmative evaluation method to UV-vis-NIR. Observation of changes in UV-vis-NIR spectroscopy was monitored for 1 month to ascertain the stability. Our results provide understanding about the mechanism of debundling with different structure dispersants and the stability performance of carbon nanotube solutions. These solution behaviors shall give more information which will be useful in potential applications in bioelectronics area.

A02998-05120

Carbon Electronics Based on Wafer-Scale Aligned Carbon Nanotubes and Graphene

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Nanoscale materials rank among the most exciting new developments in modern science and engineering. This talk will focus on our recent work on carbon electronics based on massive aligned carbon nanotubes and wafer-scale chemical vapor deposition (CVD) of graphene. We have pioneered the synthesis of massively aligned single-walled carbon nanotubes atop sapphire and quartz substrates, and developed a nanotube-on-insulator (NOI) technique to tackle the challenging issues of nanotube assembly and integration. Wafer-scale synthesis, transfer, and integration of aligned carbon nanotubes have been successfully developed to produce nanotube transistors and defect-tolerant integrated circuits such as inverter, NAND, and NOR. In addition, we have recently developed a highly scalable wafer-scale CVD approach to grow few and single layer graphene atop polycrystalline and single-crystalline nickel surfaces. We have further developed ways to transfer the graphene films to arbitrary substrates and used the graphene for both electronic devices and transparent conductive films.

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