



- (51) International Patent Classification:
C09C 1/44 (2006.01)
- (21) International Application Number:
PCT/US2012/026949
- (22) International Filing Date:
28 February 2012 (28.02.2012)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
61/447,305 28 February 2011 (28.02.2011) US
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- (81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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(54) Title: CARBON NANOTUBES ASSOCIATED WITH ANTIMONY PENTAFLUORIDE

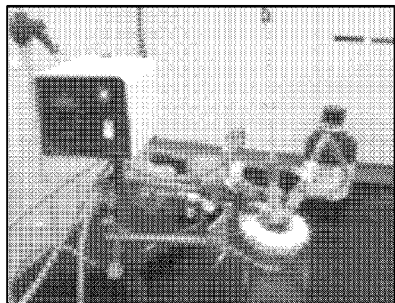


FIG. 1A

(57) Abstract: In some embodiments, the present invention pertains to compositions that include carbon nanotubes associated with antimony pentafluoride molecules. In some embodiments, the carbon nanotubes are endohedrally intercalated with the antimony pentafluoride molecules. In some embodiments, the carbon nanotubes are exohedrally intercalated with the antimony pentafluoride molecules. Additional embodiments of the present invention pertain to methods of making the above-mentioned carbon nanotube compositions. In some embodiments, the method comprises associating carbon nanotubes with antimony pentafluoride molecules by mixing. In some embodiments, the associating step occurs in an inert atmosphere. The carbon nanotube compositions of the present invention can have various arrangements. In some embodiments, the carbon nanotube compositions of the present invention can be used as part of a composite. In other embodiments, the carbon nanotube compositions of the present invention can be used as part of a carbon nanotube fiber.

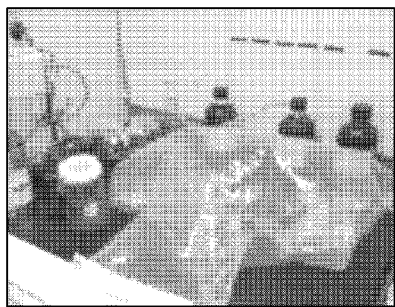


FIG. 1B



(84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS,

SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

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TITLE

CARBON NANOTUBES ASSOCIATED WITH ANTIMONY PENTAFLUORIDE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 61/447,305, filed on February 28, 2011. The entirety of the above-identified provisional application is incorporated herein by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

[0002] This invention was made with government support under Grant No. DE-AC26-07NT42677, awarded by the U.S. Department of Energy. The government has certain rights in the invention.

BACKGROUND OF THE INVENTION

[0003] Current carbon nanotube compositions have limitation in terms of stability and electrical conductivity. Therefore, a need exists for the development of more stable and electrically conductive carbon nanotube compositions for numerous applications.

BRIEF SUMMARY OF THE INVENTION

[0004] In some embodiments, the present invention pertains to compositions that include carbon nanotubes and antimony pentafluoride molecules associated with the carbon nanotubes. In some embodiments, the carbon nanotubes are at least one of single-walled carbon nanotubes, multi-walled carbon nanotubes, double-walled carbon nanotubes, few-walled carbon nanotubes, ultra-short carbon nanotubes, and combinations thereof.

[0005] In some embodiments, the carbon nanotubes are endohedrally intercalated with the antimony pentafluoride molecules. In some embodiments, the carbon nanotubes are exohedrally intercalated with the antimony pentafluoride molecules. In other embodiments, the carbon

nanotubes are exohedrally and endohedrally intercalated with the antimony pentafluoride molecules.

[0006] Additional embodiments of the present invention pertain to methods of making the above-mentioned carbon nanotube compositions. In some embodiments, the method comprises associating carbon nanotubes with antimony pentafluoride molecules. In some embodiments, the associating step comprises mixing the carbon nanotubes with the antimony pentafluoride molecules. In some embodiments, the associating step occurs in an inert atmosphere, such as non-aqueous conditions.

[0007] The carbon nanotube compositions of the present invention can also have various arrangements. For instance, in some embodiments, the carbon nanotube compositions of the present invention can be used as part of a composite. In other embodiments, the carbon nanotube compositions of the present invention can be used as part of a carbon nanotube fiber.

[0008] The carbon nanotube compositions of the present invention provide various advantageous properties, including enhanced conductivity and stability. Thus, the carbon nanotube compositions of the present invention can be used for various electrical applications, including use as conducting wires, motor windings and battery components.

BRIEF DESCRIPTION OF THE FIGURES

[0009] **FIGURE 1** shows a setup for a vacuum heating flask (**FIG. 1A**) and a nitrogen filled glove-bag (**FIG. 1B**) that were used to make antimony pentafluoride (SbF_5) intercalated, single-walled carbon nanotubes (SWNTs).

[0010] **FIGURE 2** shows the resultant SbF_5 intercalated SWNTs that were formed from the use of the setup in **FIG. 1**.

[0011] **FIGURE 3** shows scanning electron microscope (SEM) images of two types of SbF_5 intercalated SWNTs. **FIGS. 3A** and **3B** show low resolution SEM images of large diameter and small diameter SWNTs. **FIG. 3C** shows a high resolution SEM image of small diameter SWNTs.

[0012] **FIGURE 4** illustrates the characterization of SbF_5 intercalated SWNTs containing large diameter SWNTs. **FIG. 4A** is a scanning transmission electron microscopy (STEM) image of the SWNTs. **FIG. 4B** is an energy dispersive x-ray spectroscopy (EDS) of the SWNTs.

[0013] **FIGURE 5** shows STEM images of large diameter SbF_5 intercalated SWNTs.

[0014] **FIGURE 6** shows STEM images of small diameter SbF_5 intercalated SWNTs.

[0015] **FIGURE 7** is an EDS of small diameter SbF_5 intercalated SWNTs.

[0016] **FIGURE 8** shows EDS and STEM area scans of small diameter SbF_5 intercalated SWNTs. The scans confirm the presence of C, Sb and F in the compositions.

[0017] **FIGURE 9** shows thermographic analysis (TGA) data for GC100 SbF_5 intercalated SWNTs.

[0018] **FIGURE 10** shows TGA data for HiPco SbF_5 intercalated SWNTs.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0019] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only, and are not restrictive of the invention, as claimed. In this application, the use of the singular includes the plural, the word “a” or “an” means “at least one”, and the use of “or” means “and/or”, unless specifically stated otherwise. Furthermore, the use of the term “including”, as well as other forms, such as “includes” and “included”, is not limiting. Also, terms such as “element” or “component” encompass both elements or components comprising one unit and elements or components that comprise more than one unit unless specifically stated otherwise.

[0020] The section headings used herein are for organizational purposes only and are not to be construed as limiting the subject matter described. All documents, or portions of documents, cited in this application, including, but not limited to, patents, patent applications, articles, books, and treatises, are hereby expressly incorporated herein by reference in their entirety for any purpose. In the event that one or more of the incorporated literature and similar materials defines

a term in a manner that contradicts the definition of that term in this application, this application controls.

[0021] In much of the literature, intercalation is a term used to describe the reversible incorporation of a foreign molecule between two other molecules, most often in a periodic structure. For instance, intercalation is associated with the incorporation of foreign species between layers of graphite to form graphite intercalation compounds (GICs). The five main subgroups of highly electrically conductive GICs were summarized by Inagaki *et al* and shown in **Table 1**.

Material	Conductivity	Comments
<u>Pentafluorides</u> AsF ₅ /HOPG and VGCF	1 X 10 ⁸ S/m	Higher than metallic copper
<u>Metal chlorides</u> CuCl ₂ /MPCF FeCl ₃ /VGCF	7.8 X 10 ⁶ S/m 1.4 X 10 ⁷ S/m	Creditable values, comparable with Cu
<u>Fluorine</u> F ₂ /HOPG and various CF's	2 X 10 ⁷ S/m	Stable in air
<u>Donor couple</u> K + Bi/HOPG	2 X 10 ⁷ S/m	Stable in air
<u>Residue Halogens</u> Br ₂ or ICl/MPCF's	1 X 10 ⁶ S/m	Very stable under severe conditions

Table 1. Summary of highly conductive graphite intercalation compounds. *Adapted from Inagaki et al., Journal of Materials Research, 1989, 4(6): p. 1560-1568.*

[0022] Electrical conductivities of 1 X 10⁶ S cm (1 X 10⁻⁶ Ω.cm) have been shown for GICs of arsenic pentafluoride (AsF₅) and antimony pentafluoride (SbF₅). However, such results have never been reproduced. In addition, conductivities between 2.1 X 10⁴ and 1.0 X 10⁵ S cm have been obtained with vapor grown carbon fibers (VGCFs) that were combined with AsF₅.

[0023] However, the above-mentioned studies focused on graphite compounds rather than carbon nanotubes. In fact, the aforementioned studies were conducted before the discovery of carbon nanotubes.

[0024] Furthermore, current carbon nanotube compositions have limitation in terms of stability and electrical conductivity. Therefore, a need exists for the development of more stable and electrically conductive carbon nanotube compositions for numerous applications. The present invention addresses these needs.

[0025] Various aspects of the present invention pertain to processes that combine two species never previously combined before: carbon nanotubes (CNTs) and SbF_5 . This process forms a novel and stable composition with improved properties, including improved stability and improved electrical conductivity of the CNTs, such as an improved electrical conductivity by a factor of ten. Thus, the compositions of the present invention provide applications where electrically conductive materials are needed, such as in batteries, motor windings and wires.

[0026] **Carbon Nanotube Compositions**

[0027] In some embodiments, the present invention pertains to compositions that include carbon nanotubes and SbF_5 molecules that are associated with the carbon nanotubes. Various carbon nanotubes may be utilized in such compositions. In addition, SbF_5 may have various forms of associations with the carbon nanotubes.

[0028] **Carbon Nanotubes**

[0029] Various carbon nanotubes may be utilized in the compositions of the present invention. Non-limiting examples of suitable carbon nanotubes include single-walled carbon nanotubes (SWNTs), double-walled carbon nanotubes (DWNTs), multi-walled carbon nanotubes (MWNTs), few-walled carbon nanotubes (FWNTs), ultra-short carbon nanotubes, and combinations thereof. In more specific embodiments, the carbon nanotube compositions of the present invention include SWNTs.

[0030] In some embodiments, the carbon nanotubes are pristine carbon nanotubes. In some embodiments, the carbon nanotubes are functionalized with various functional groups. Non-limiting examples of suitable functional groups include carboxyl groups, carbonyl groups, oxides, alcohol groups, phenol groups, aryl groups, and combinations thereof. In some

embodiments, the carbon nanotubes are combinations of pristine and functionalized carbon nanotubes.

[0031] In some embodiments, the functionalization of carbon nanotubes helps separate, de-aggregate or individualize carbon nanotubes. This in turn provides a more effective environment for associating the carbon nanotubes with SbF_5 or other dopants (such as iodine).

[0032] SbF_5 Association

[0033] In the present invention, SbF_5 molecules are associated with carbon nanotubes. To Applicants' knowledge, SbF_5 was not previously combined with carbon nanotubes.

[0034] In the present invention, SbF_5 association generally refers to the reversible or irreversible incorporation of SbF_5 molecules with carbon nanotubes. SbF_5 molecules may be associated with carbon nanotubes in various manners. For instance, in some embodiments of the present invention, the SbF_5 molecules may be intercalated with carbon nanotubes. Such intercalation may involve the reversible association of carbon nanotubes with the SbF_5 molecules. In some embodiments, the carbon nanotubes may be doped with SbF_5 molecules. Such doping may involve the reversible or irreversible incorporation of the SbF_5 molecules with the carbon nanotubes.

[0035] In some embodiments, the SbF_5 molecules may be endohedrally intercalated with SbF_5 molecules. In such embodiments, the SbF_5 molecules may be included in free spaces within carbon nanotubes.

[0036] In some embodiments, the carbon nanotubes are exohedrally intercalated with the SbF_5 molecules. In such embodiments, the SbF_5 molecules may be included between outer surfaces of carbon nanotubes.

[0037] In some embodiments, SbF_5 molecules may replace carbon atoms within a carbon nanotube structure. In further embodiments, the carbon nanotubes may be exohedrally and endohedrally intercalated with the SbF_5 molecules. In some embodiments, SbF_5 molecules may

be located near or within defective carbon nanotube sites (e.g., holes or openings within the sidewalls)

[0038] In various embodiments, the carbon nanotubes of the present invention may also be associated with one or more dopants. Non-limiting examples of suitable dopants include compounds or heteroatoms containing iodine, silver, chlorine, bromine, potassium, fluorine, gold, copper, aluminum, sodium, iron, boron, antimony, arsenic, silicon, sulfur, and combinations thereof. In some embodiments, the carbon nanotubes may be associated (i.e., doped) with one or more heteroatoms, such as AuCl_3 or BH_3 . In some embodiments, the carbon nanotubes may be associated with an acid, such as sulfuric acid or nitric acid.

[0039] In more specific embodiments, the carbon nanotubes may also be associated with arsenic pentafluoride (AsF_5), metal chlorides (e.g., FeCl_3 and/or CuCl_2), iodine, melamine, carboranes, aminoboranes, phosphines, aluminum hydroxides, silanes, polysilanes, polysiloxanes, sulfides, thiols, and combinations thereof. In more specific embodiments, the carbon nanotubes of the present invention may be associated with iodine and SbF_5 .

[0040] In some embodiments, the carbon nanotube compositions of the present invention may also be associated with one or more polymers. Non-limiting examples of suitable polymers include polyethylenes, polypropylenes, poly(methyl methacrylate) (PMMA), polyvinyl alcohols (PVA), epoxide resins, and combinations thereof.

[0041] **Methods of Making Carbon Nanotube Compositions**

[0042] Additional embodiments of the present invention pertain to methods of making the above-mentioned carbon nanotube compositions. Such methods generally comprise associating carbon nanotubes with SbF_5 molecules.

[0043] In some embodiments, the associating step comprises mixing the carbon nanotubes with the SbF_5 molecules. In some embodiments, the associating step occurs in an inert atmosphere. Such inert atmospheres may include non-aqueous environments, oxygen-free environments,

and/or environments under a steady flow of an insert gas (e.g., Ar, N₂, and combinations of such gases).

[0044] In addition, various methods may be used to associate carbon nanotubes with SbF₅ molecules. In some embodiments, the association occurs by sputtering or spraying the SbF₅ molecules onto carbon nanotubes. In some embodiments, the association may occur by chemical vapor deposition. Additional association methods can also be envisioned.

[0045] Furthermore, the carbon nanotube compositions of the present invention can have various arrangements. For instance, in some embodiments, the carbon nanotube compositions of the present invention can be used as part of a composite. In other embodiments, the carbon nanotube compositions of the present invention can be used as part of a carbon nanotube fiber. Examples of such carbon nanotube fibers are disclosed in Applicants' co-pending Provisional Patent Application No. 61/449,309 and the corresponding PCT Application entitled "Doped Multi-walled Carbon Nanotube Fibers and Methods of Making the Same", which is concurrently being filed herewith.

[0046] **Applications and Advantages**

[0047] The carbon nanotube compositions of the present invention also provide various advantageous properties. In particular, by combining a highly unstable acid (SbF₅) with carbon nanotubes, Applicants have produced a composition that is stable and resistant to normal atmospheric conditions. The formed carbon nanotube composition also has a higher electrical conductivity than that of the carbon nanotubes alone. In fact, an improved electrical conductivity by a factor of ten has already been observed.

[0048] Thus, the carbon nanotube fibers of the present invention provide numerous applications. For instance, the carbon nanotube compositions of the present invention can be assembled into one dimensional, two dimensional or even three dimensional macroscopic engineering components. Such structures could in turn be used as conducting wires, sensors, diodes, battery components, reinforcement fabrics in composites, thermal conductors, microwave absorption materials, motor windings, and components in energy harvesting or conversion systems. In more

specific embodiments, the carbon nanotube compositions of the present invention can be utilized as hall-effect devices, infrared detectors, antifriction compositions, lead-free solders, fire retardant materials, and hardeners for lead in batteries. In additional embodiments, the carbon nanotube compositions of the present invention may be used as fluorinating agents.

[0049] Additional Embodiments

[0050] Reference will now be made to more specific embodiments of the present disclosure and experimental results that provide support for such embodiments. However, Applicants note that the disclosure below is for exemplary purposes only and is not intended to limit the scope of the claimed invention in any way.

[0051] In this study, SbF_5 molecules were intercalated with SWNTs. SbF_5 was chosen as the intercalate or dopant species due to its high conductivity, its ease of use relative to AsF_5 , and the novelty of the combination.

[0052] Example 1. Intercalation of SWNTs with SbF_5 Molecules

[0053] SWNTs and SbF_5 molecules were combined in a method based on one from Lalancette et al. Journal of the Chemical Society-Chemical Communications, 815 (1973). The SWNTs were supplied by SouthWest NanoTechnologies, Inc. (CG 100 grade). These SWNTs were produced by a catalytic CVD process utilizing CO disproportionation at 700-950 °C in the presence of a Co-Mo catalysts. 250 mg of as-produced SWNTs were dried by heating under vacuum in a boiling flask for 72 hours at a temperature range of 90-110°C. The setup is shown in **FIG. 1A**.

[0054] The SWNTs were then transferred to a plastic glove bag for processing under an atmosphere of dry nitrogen. See **FIG. 1B**. About 0.084 mL of SbF_5 (Sigma Aldrich) was pipetted onto the SWNTs inside a boiling flask to provide a 50% by weight concentration.

[0055] This preliminary experiment showed the preference for dry inert conditions, as some residual moisture was clearly present in the glove bag that reacted with the SbF_5 molecules to produce hydrogen fluoride (HF) gas. These reactions and the products they presented also produced the preference to complete the experiment in an expedited fashion. The resultant

material was sealed in its flask, placed under vacuum and heated at 90-120°C for 72 hours. The initial application of vacuum, applied to the boiling flask while inside the glove bag, led to a deposition of black material on the inner surface of the vacuum line. *See FIG. 2.* The end product was a dry black powder, similar to the starting SWNTs, which appeared stable under normal atmosphere and resistant to hydrolysis. The bulk of the material remained inside the boiling flask.

[0056] Example 2. Conductivity of SbF₅ Intercalated SWNTs

[0057] In order to measure the electrical conductivity of the SbF₅ intercalated SWNTs, a small amount of the product was used in a two-point probe measurement. The product was placed inside a Teflon tube. A probe was then attached at each end. Two-point electrical probe measurements were obtained using a Commercial Electrical HDM350 Multimeter. The results are summarized in **Table 2.**

Nanotube	Resistance (Si)
Raw SWNT	55.3
SWNT-SbF ₅	2.3

Table 2. 2-point resistance measurements for raw and SbF₅-doped SWNTs.

[0058] With additional samples, 4-point tests were also prepared. In addition, a simple procedure of iodine doping was explored. The results are summarized in **Table 3.**

Nanotube	Dopant	Initial Resistivity (Ω•cm)	Post-Doping Resistivity (Ω•cm)
SWNT CG100	Iodine	0.014	0.0027
SWNT CG100	Iodine & SbF ₅	0.014	0.0027
SWNT CG100	SbF ₅	0.014	0.0038
HiPco SWNT	SbF ₅	0.01	0.0003

Table 3. Summary of 4-point resistance measurements.

[0059] The SbF₅-treated SWNT showed over an order of magnitude improvement in conductivity. This is in keeping the typical factor of ten improvement noted by Inagaki et al.'s

review. Given the difficult processing conditions, and the correlation of packing density of SWNTs to electrical resistance, the aforementioned data should be considered preliminary. Applicants envision further improvements in conductivity.

[0060] The iodine samples also showed an impressive improvement. It is envisioned that the use of more than one dopant can lead to synergistic effects. Both methods yielded stable doping, which had consistent resistivity results, even 6 months after doping.

[0061] **Example 3. Characterization of SbF₅ Intercalated SWNTs**

[0062] Scanning electron microscopy (SEM) and scanning transmission electron microscopy (STEM) was performed on both the main sample and the materials found deposited inside the vacuum line (Hitachi S-5500). Simultaneous energy dispersive x-ray spectroscopy (EDS) was also carried out (Hitachi-Bruker).

[0063] Fourier transform infrared spectroscopy (FTIR) was performed on the original sample (Nicolet). XPS data was also collected and analyzed (PHI Quantera). Two primary materials were studied using SEM and scanning transmission electron microscopy (STEM): materials recovered from inside the vacuum line, and the main body of materials produced. The specimens shared a number of key characteristics, while some differences were also observed. The materials from the vacuum line contained two types of tube structures: one similar in size to the starting SWNTs but with clear additions to the sidewalls; and a second tube type in the size range of 20-40nm. *See FIG. 3* (and herein referred to as large diameter and small diameter SWNTs).

[0064] Furthermore, energy dispersive x-ray spectroscopy (EDS) data confirmed the presence of carbon (C), antimony (Sb) and fluorine (F) with the vacuum line sample. *See FIG. 4B*. One key difference noted when compared to the bulk material produced was that the large diameter tubes were neither as rigid-looking, nor as straight as those found in the main sample.

[0065] Furthermore, the main body of the sample showed a similar mix of two tube types, but the microscopy consistently found very rigid and straight nanotubes in the 20-40nm range. *See*

FIG. 5. High-resolution STEM images of the smaller (i.e., ~2nm) nanotubes suggest that the SWNTs are modified or functionalized SWNTs. *See FIG. 6.* In addition, EDS data shows the presence of C, Sb and F on these smaller nanotubes. *See FIGS. 7-8.*

[0066] The results indicate the formation of a complex morphology of materials at the nanoscale. Furthermore, thermogravimetric analysis (TGA) data confirmed that the CNTs suffered damage, as the oxidation peak has been broadened and shifted. *See FIGS. 9-10.* Without being bound by theory, the production of large diameter, straight tubular structures is envisioned. It is also envisioned that a considerable amount of metallic species has been added by the process (i.e., >40%).

[0067] However, X-ray photoelectron spectroscopy (XPS) data did not provide a concrete answer to the species present. It appeared from the literature that no XPS standard for SbF₅ currently exists. The data collected showed the presence of C, Sb and F. Analysis software suggested numerous forms of Sb present, including KSbF₅ and KSbF₆.

[0068] Future experiments can use more robust nitrogen atmosphere glove boxes. The use of an actual vacuum furnace might also be beneficial. Experimenting with additional types of CNTs may also be useful. SWNTs were used in this Example, although MWNTs or other types of CNTs could have also been used. For instance, DWNTs may provide a more robust nanotube surface, as STEM and TEM analyses of the GC 100 SWNTs showed a rough surface morphology of carbon.

[0069] Without further elaboration, it is believed that one skilled in the art can, using the description herein, utilize the present invention to its fullest extent. The embodiments described herein are to be construed as illustrative and not as constraining the remainder of the disclosure in any way whatsoever. While the preferred embodiments have been shown and described, many variations and modifications thereof can be made by one skilled in the art without departing from the spirit and teachings of the invention. Accordingly, the scope of protection is not limited by the description set out above, but is only limited by the claims, including all equivalents of the subject matter of the claims. The disclosures of all patents, patent applications

and publications cited herein are hereby incorporated herein by reference, to the extent that they provide procedural or other details consistent with and supplementary to those set forth herein.

WHAT IS CLAIMED IS:

1. A composition comprising:

carbon nanotubes; and

5 antimony pentafluoride molecules associated with the carbon nanotubes.

2. The composition of claim 1, wherein the carbon nanotubes are selected from the group consisting of single-walled carbon nanotubes, multi-walled carbon nanotubes, double-walled carbon nanotubes, few-walled carbon nanotubes, ultra-short carbon nanotubes, and
10 combinations thereof.

3. The composition of claim 1, wherein the carbon nanotubes comprise single-walled carbon nanotubes.

15 4. The composition of claim 1, wherein the carbon nanotubes are functionalized.

5. The composition of claim 4, wherein the carbon nanotubes are functionalized with functional groups selected from the group consisting of carboxyl groups, carbonyl groups, oxides, alcohol groups, phenol groups, and combinations thereof.

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6. The composition of claim 1, wherein the carbon nanotubes are endohedrally intercalated with the antimony pentafluoride molecules.

7. The composition of claim 1, wherein the carbon nanotubes are exohedrally intercalated
25 with the antimony pentafluoride molecules.

8. The composition of claim 1, wherein the composition is a composite, and wherein the carbon nanotubes are dispersed in the composite.

30 9. The composition of claim 1, wherein the composition is a carbon nanotube fiber, and wherein the carbon nanotubes are aggregated in the carbon nanotube fiber.

10. The composition of claim 1, wherein the carbon nanotubes are also associated with iodine molecules.

11. A method of making a carbon nanotube composition, wherein the method comprises
5 associating carbon nanotubes with antimony pentafluoride molecules.

12. The method of claim 11, wherein the associating comprises mixing the carbon nanotubes with the antimony pentafluoride molecules.

10 13. The method of claim 11, wherein the associating occurs in an inert atmosphere.

14. The method of claim 11, wherein the associating causes the carbon nanotubes to become endohedrally intercalated with the antimony pentafluoride molecules.

15 15. The method of claim 11, wherein the associating causes the carbon nanotubes to become exohedrally intercalated with the antimony pentafluoride molecules.

16. The method of claim 11, wherein the carbon nanotubes are selected from the group consisting of single-walled carbon nanotubes, multi-walled carbon nanotubes, double-walled
20 carbon nanotubes, few-walled carbon nanotubes, ultra-short carbon nanotubes, and combinations thereof.

17. The method of claim 11, wherein the carbon nanotubes comprise single-walled carbon nanotubes.

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18. The method of claim 11, further comprising a step of associating the carbon nanotubes with iodine molecules.

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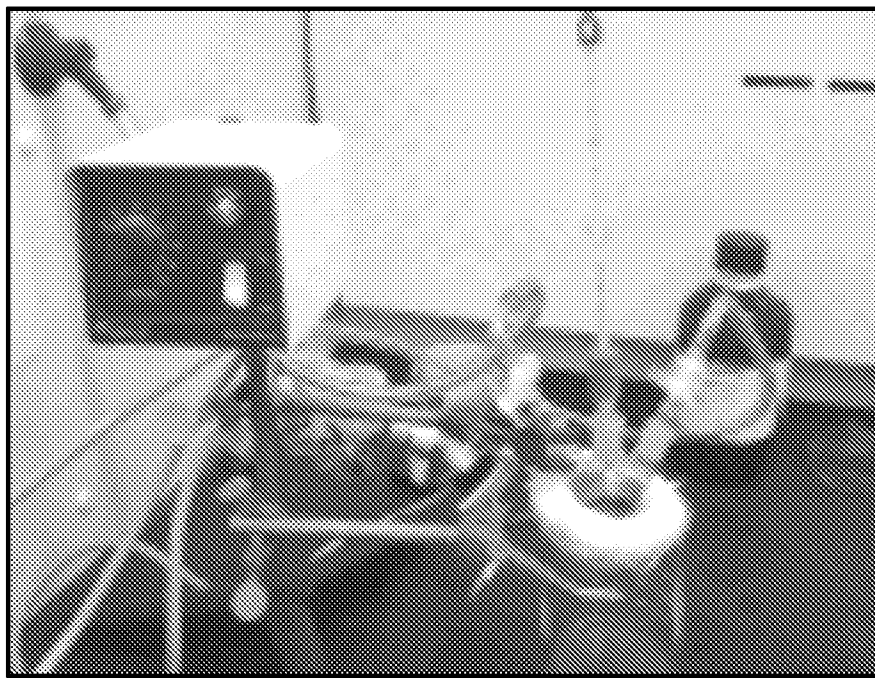


FIG. 1A



FIG. 1B

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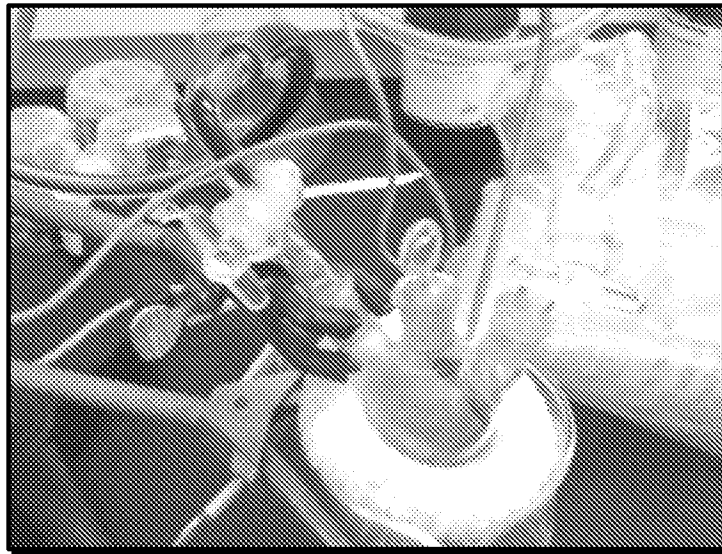


FIG. 2

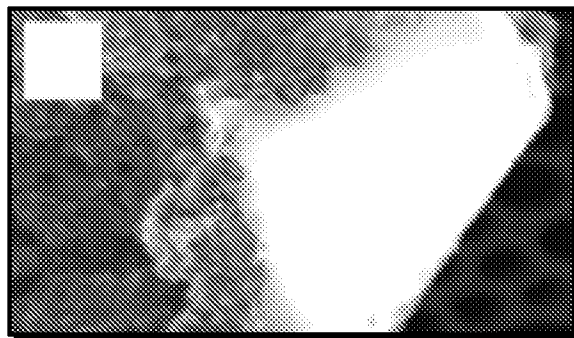


FIG. 3A

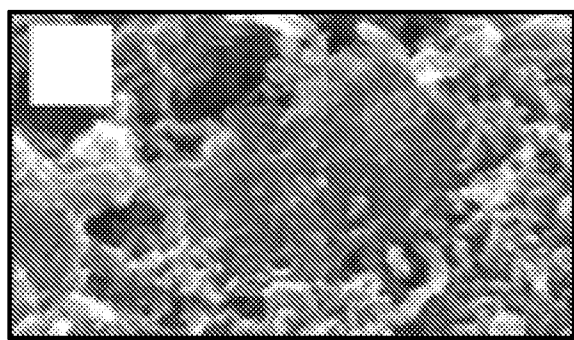


FIG. 3B

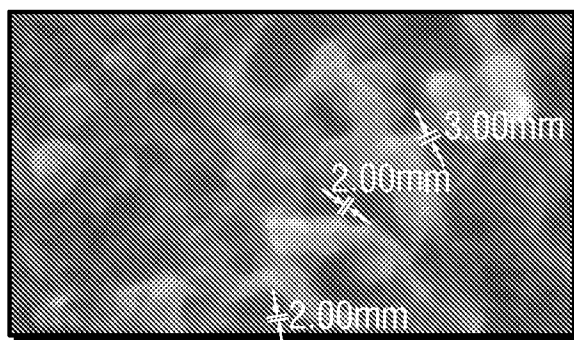
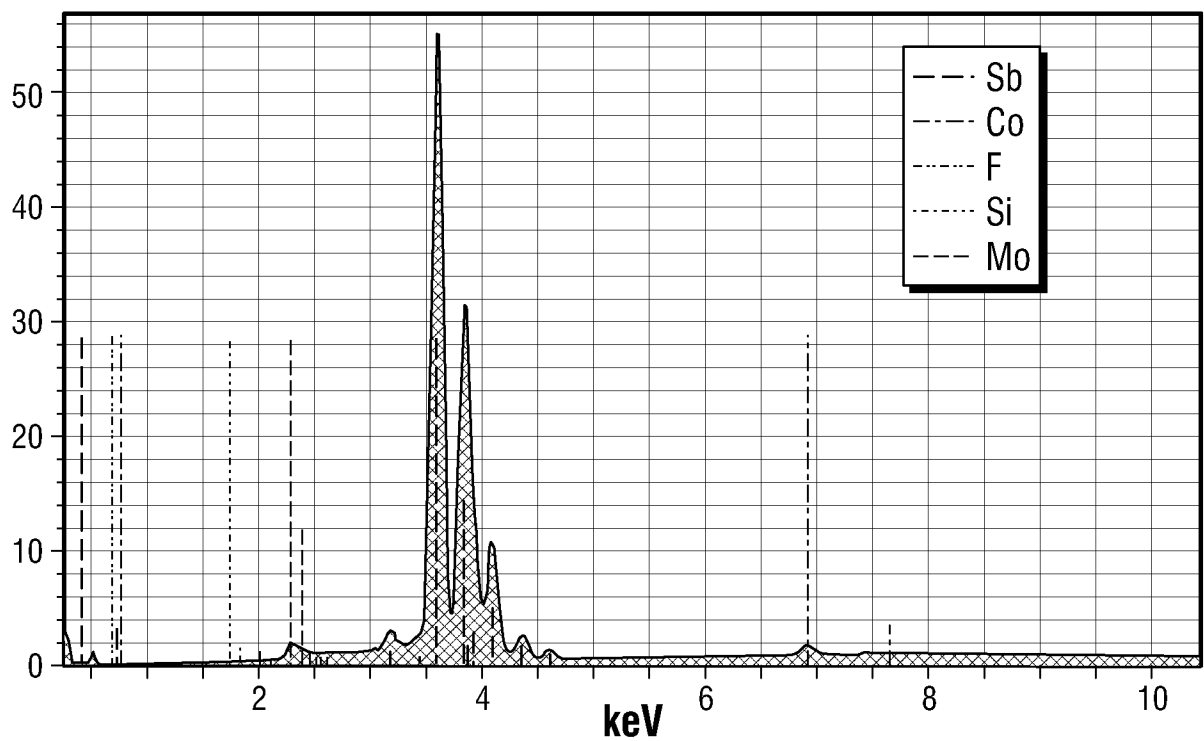


FIG. 3C

3/9**FIG. 4A****FIG. 4B**

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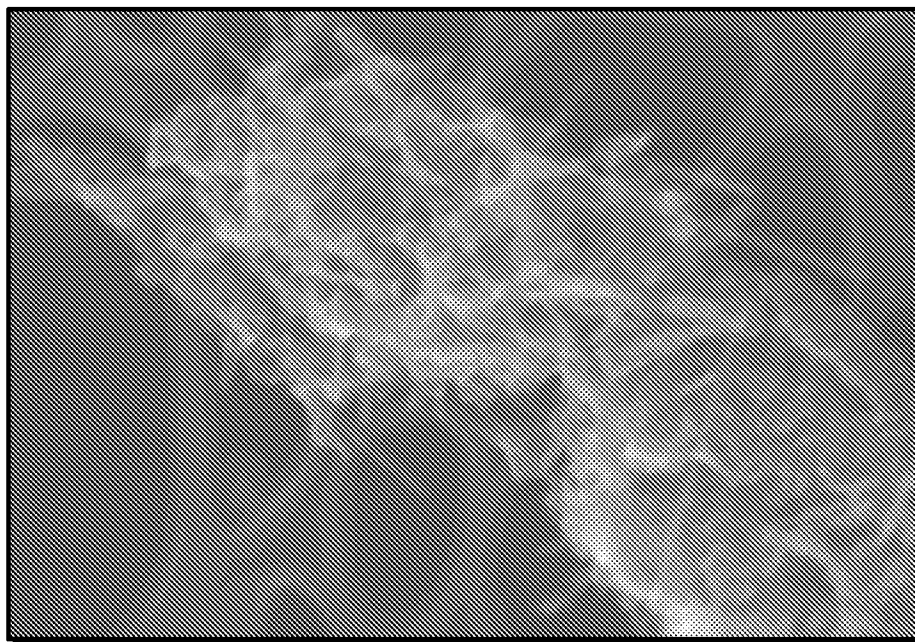


FIG. 5A

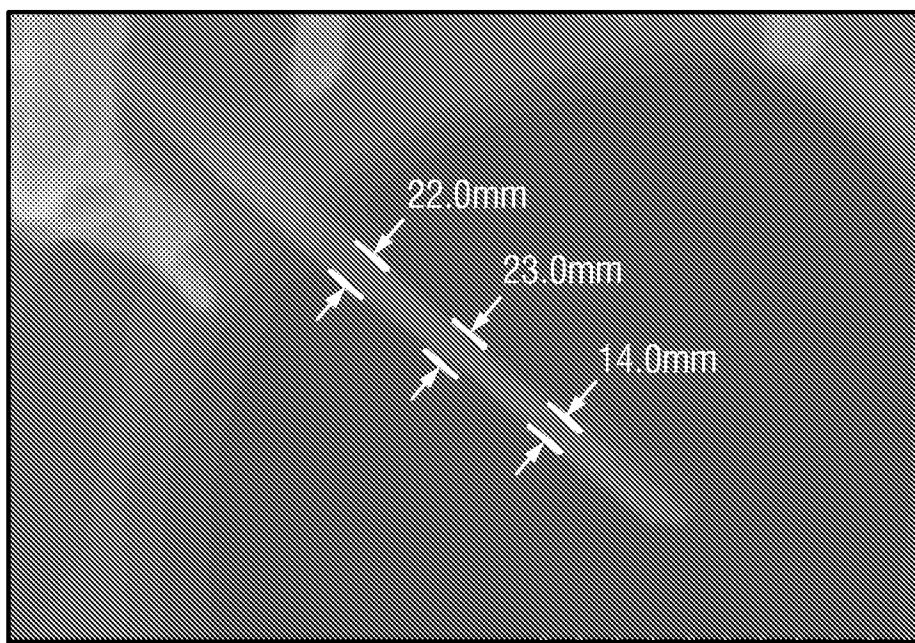


FIG. 5B

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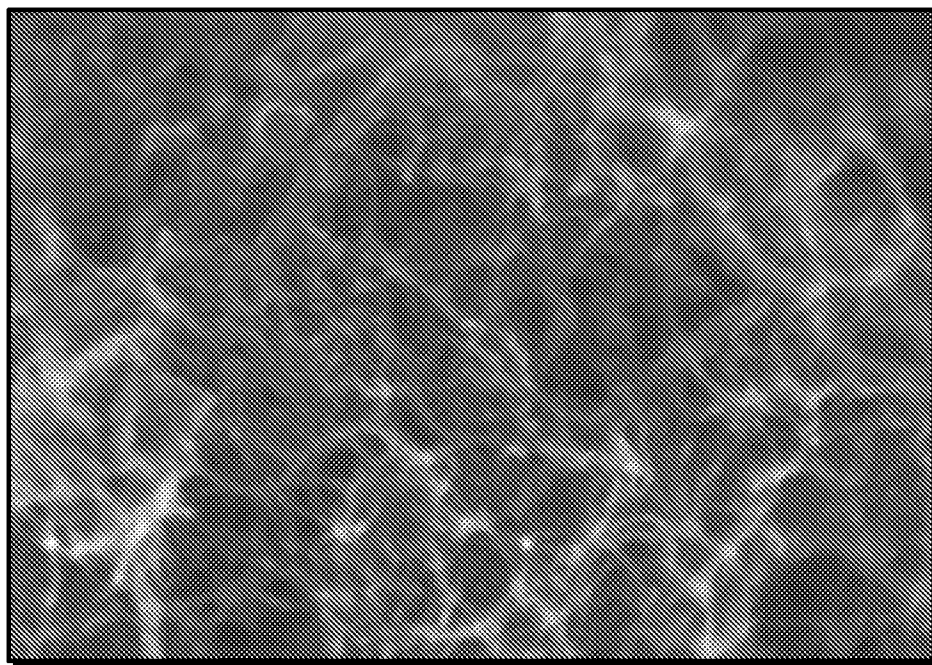


FIG. 6A

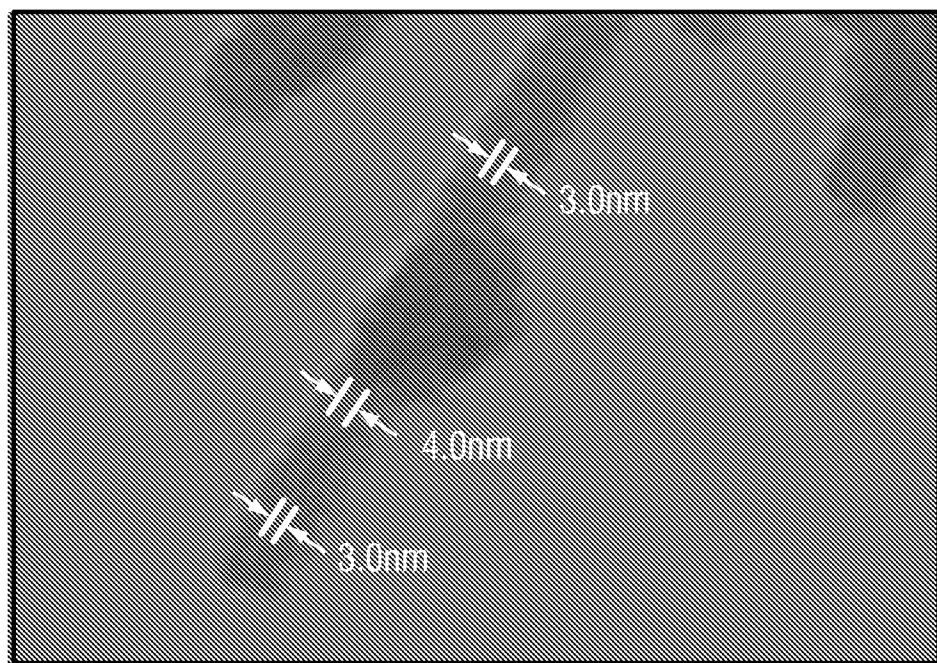
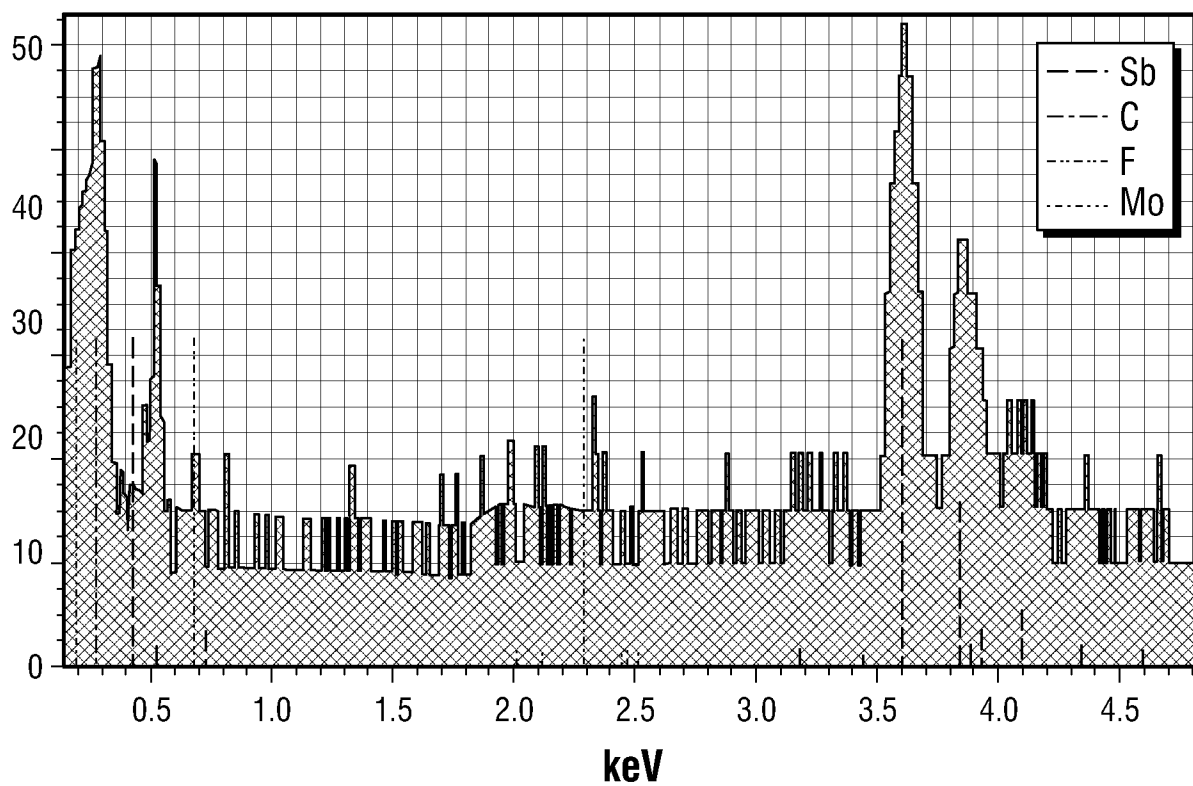
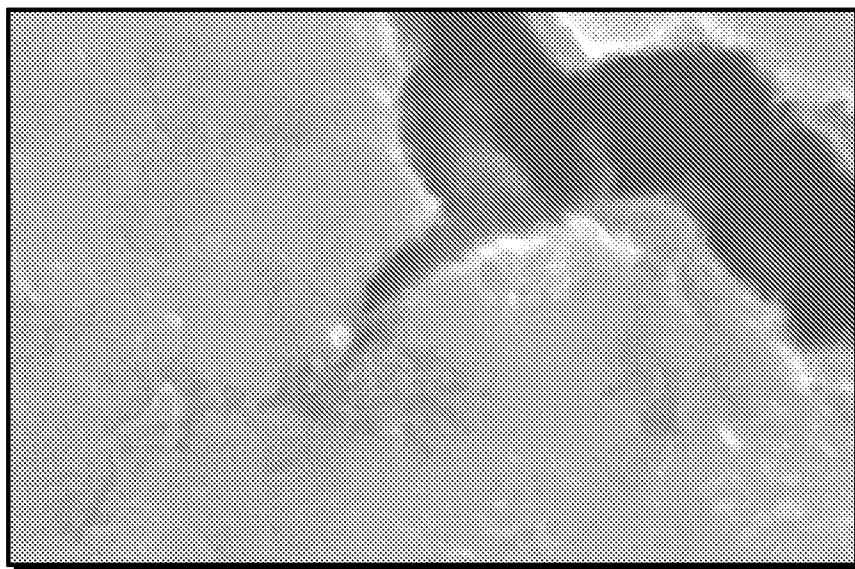


FIG. 6B

6/9**FIG. 7****FIG. 8A**

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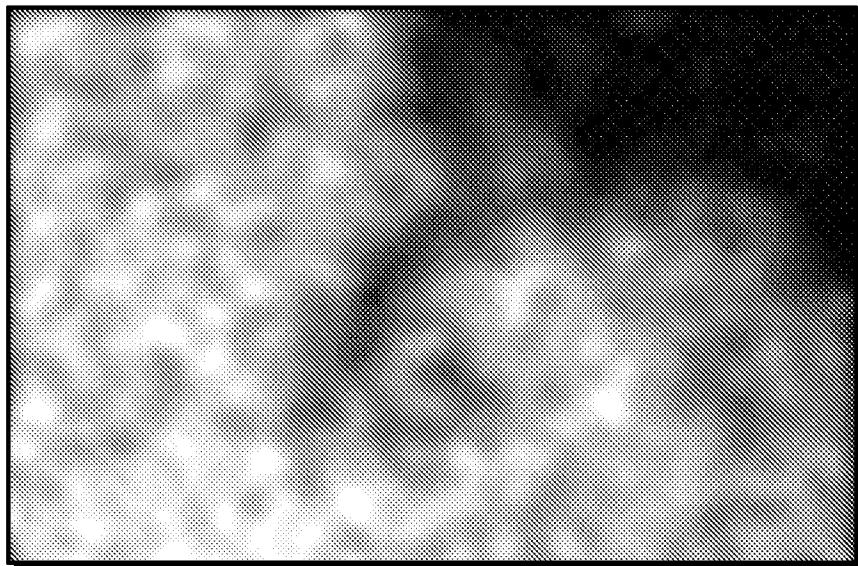


FIG. 8B

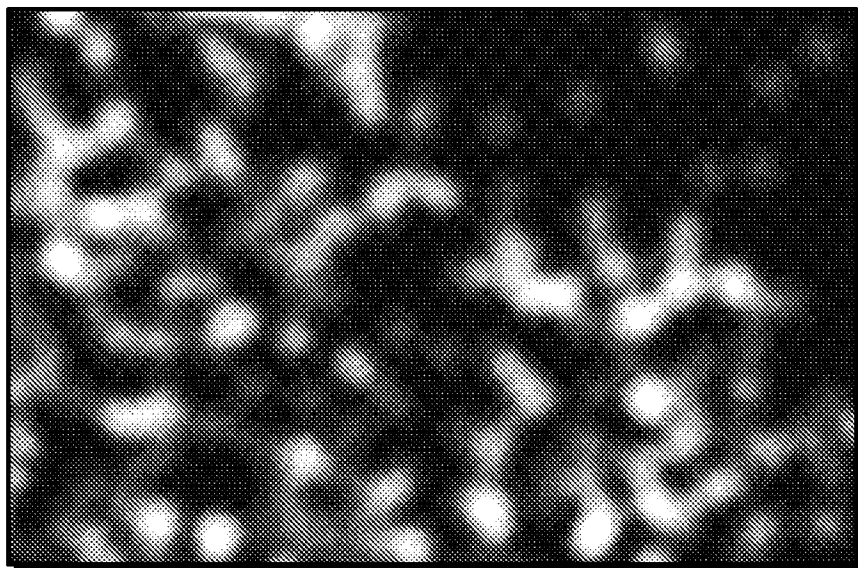


FIG. 8C

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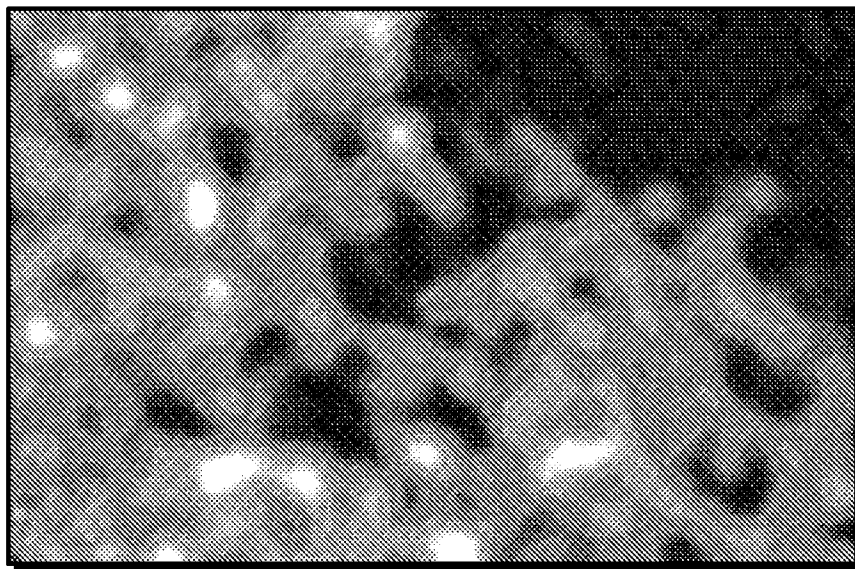


FIG. 8D

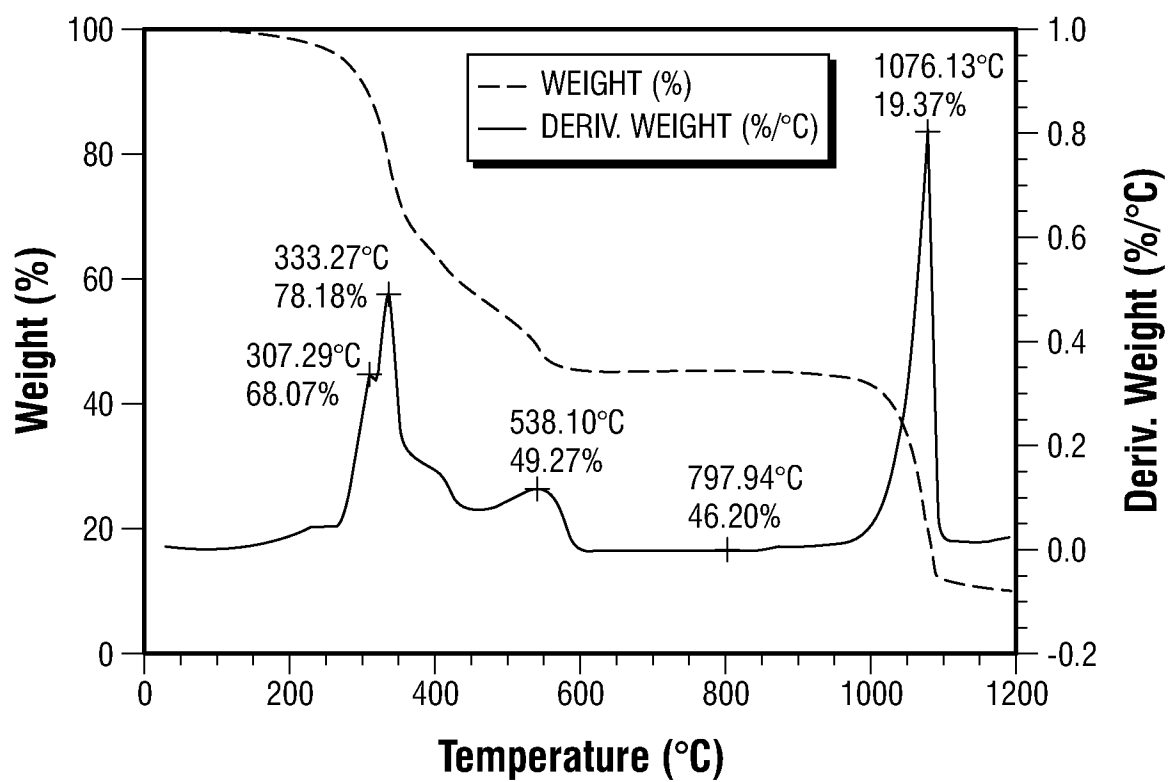
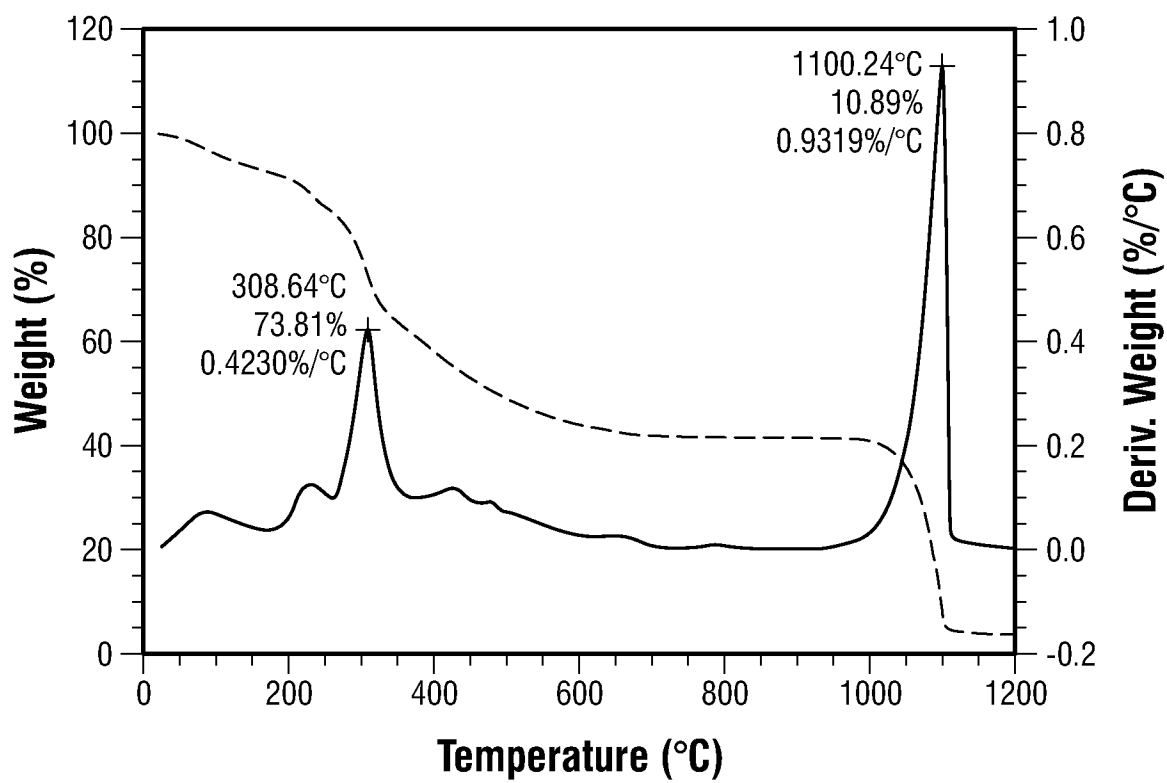


FIG. 9

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