



US 20110024698A1

(19) **United States**

(12) **Patent Application Publication**  
**Worsley et al.**

(10) **Pub. No.: US 2011/0024698 A1**

(43) **Pub. Date: Feb. 3, 2011**

(54) **MECHANICALLY STIFF, ELECTRICALLY  
CONDUCTIVE COMPOSITES OF POLYMERS  
AND CARBON NANOTUBES**

(76) Inventors: **Marcus A. Worsley**, Hayward, CA  
(US); **Sergei O. Kucheyev**,  
Oakland, CA (US); **Theodore F.  
Baumann**, Discovery Bay, CA  
(US); **Joshua D. Kuntz**, Livermore,  
CA (US); **Joe H. Satcher, JR.**,  
Patterson, CA (US); **Alex V.  
Hamza**, Livermore, CA (US)

Correspondence Address:

**Lawrence Livermore National Security, LLC**  
**LAWRENCE LIVERMORE NATIONAL LABO-  
RATORY, PO BOX 808, L-703**  
**LIVERMORE, CA 94551-0808 (US)**

(21) Appl. No.: **12/761,157**

(22) Filed: **Apr. 15, 2010**

**Related U.S. Application Data**

(60) Provisional application No. 61/172,363, filed on Apr.  
24, 2009.

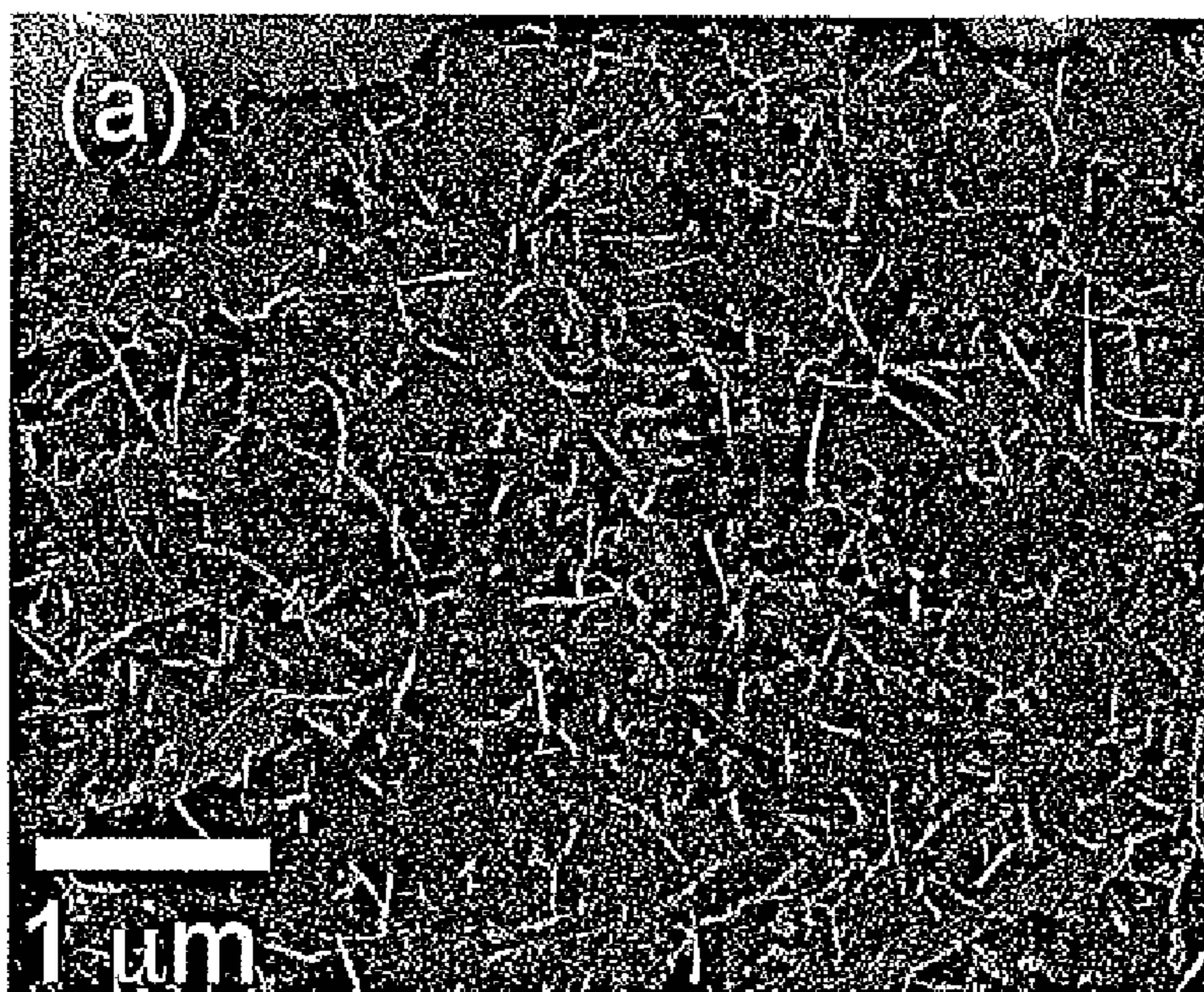
**Publication Classification**

(51) **Int. Cl.**  
**H01B 1/04** (2006.01)  
**H01B 1/12** (2006.01)  
**B82Y 30/00** (2011.01)

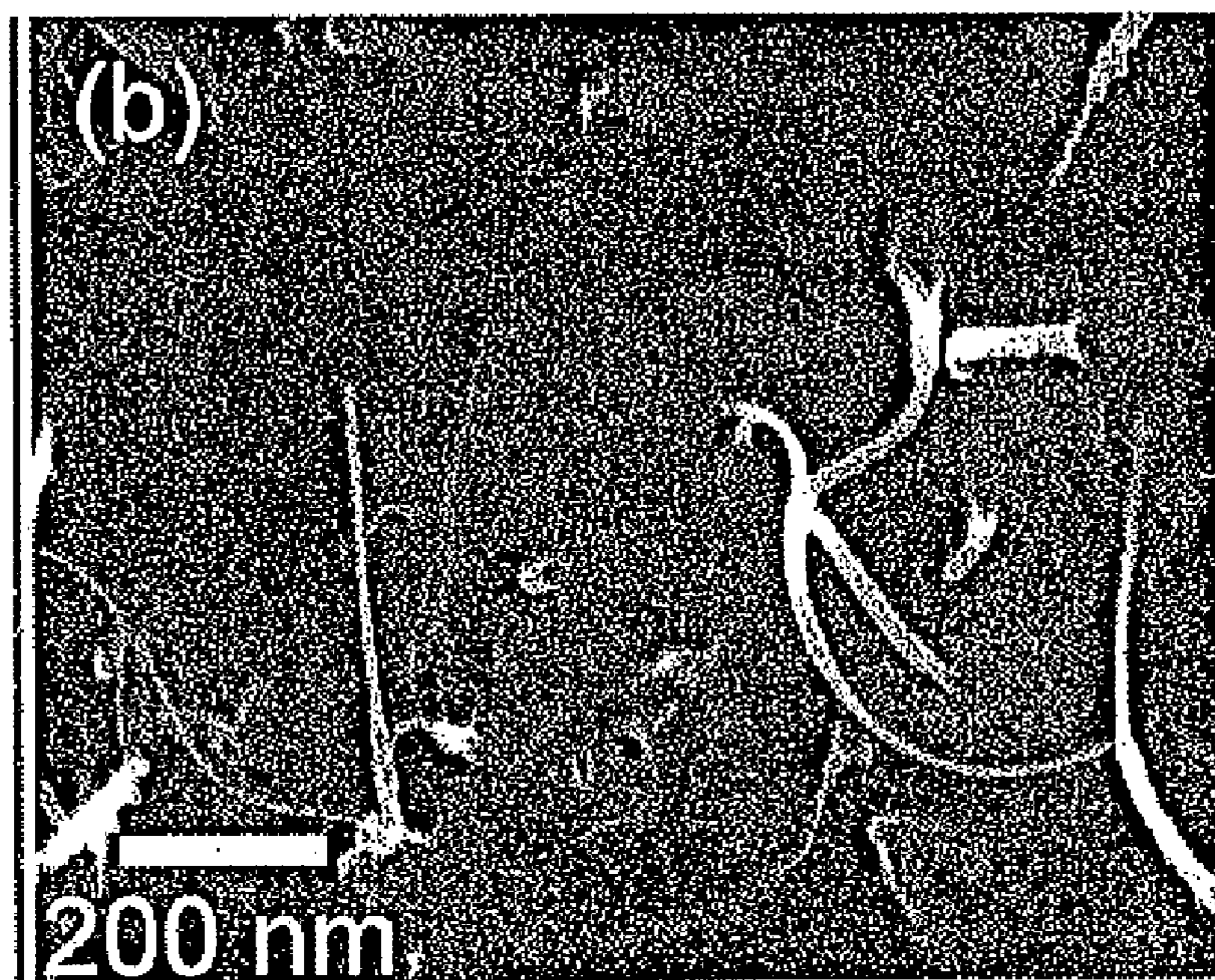
(52) **U.S. Cl. .... 252/511; 977/750**

(57) **ABSTRACT**

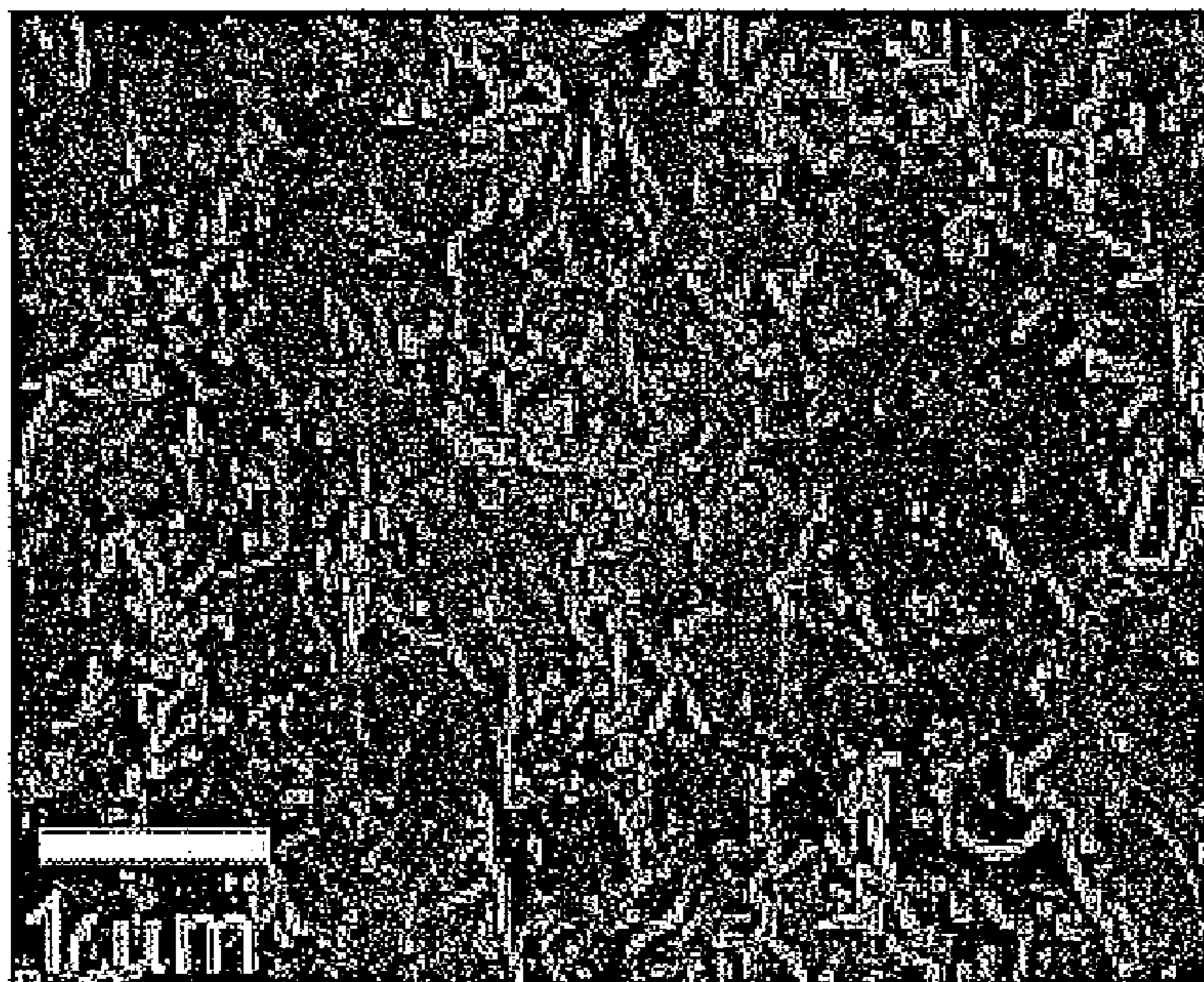
Using SWNT-CA as scaffolds to fabricate stiff, highly con-  
ductive polymer (PDMS) composites. The SWNT-CA is  
immersing in a polymer resin to produce a SWNT-CA infil-  
trated with a polymer resin. The SWNT-CA infiltrated with a  
polymer resin is cured to produce the stiff and electrically  
conductive composite of carbon nanotube aerogel and poly-  
mer.



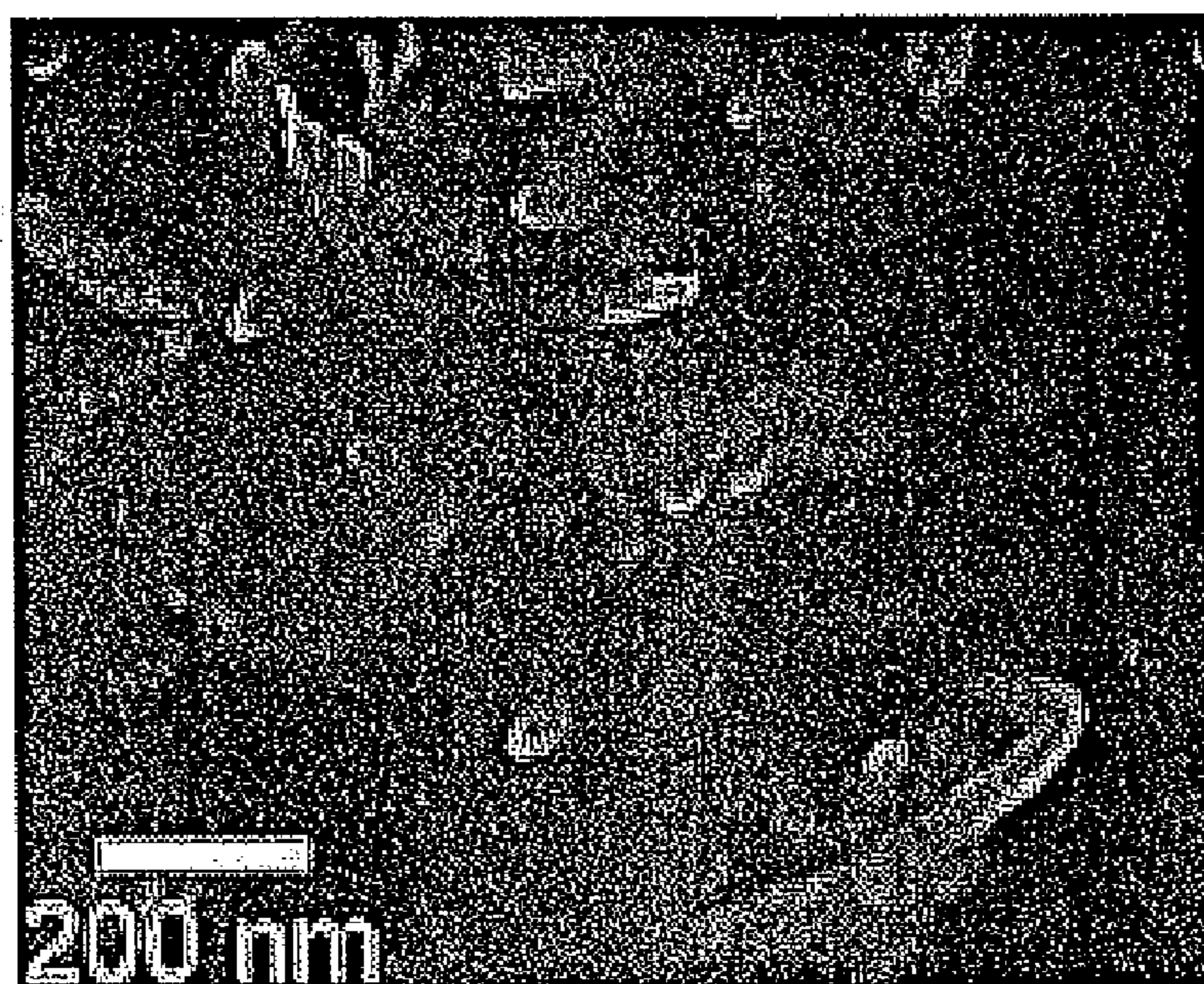
**FIG. 1 A**



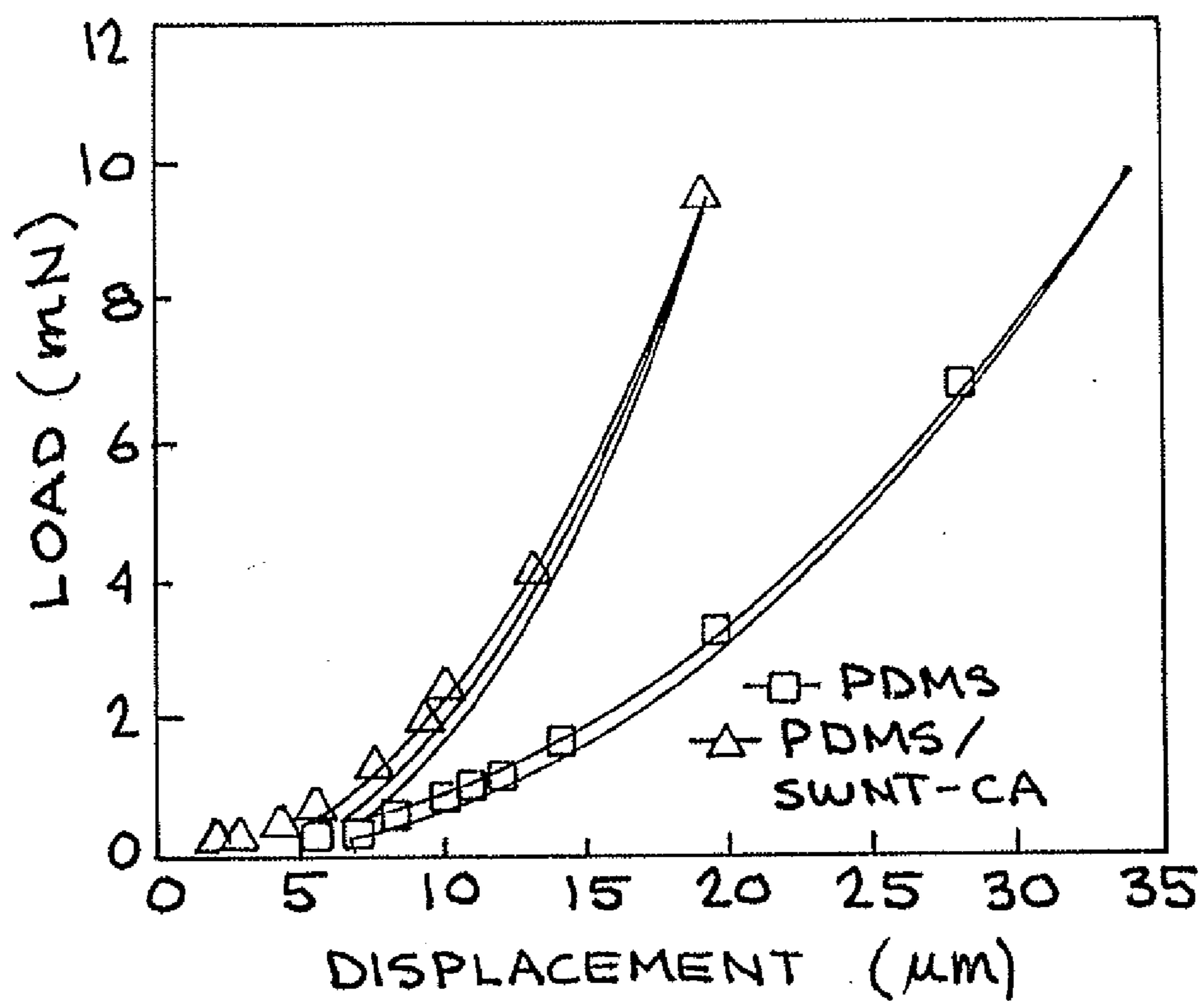
**FIG. 1 B**



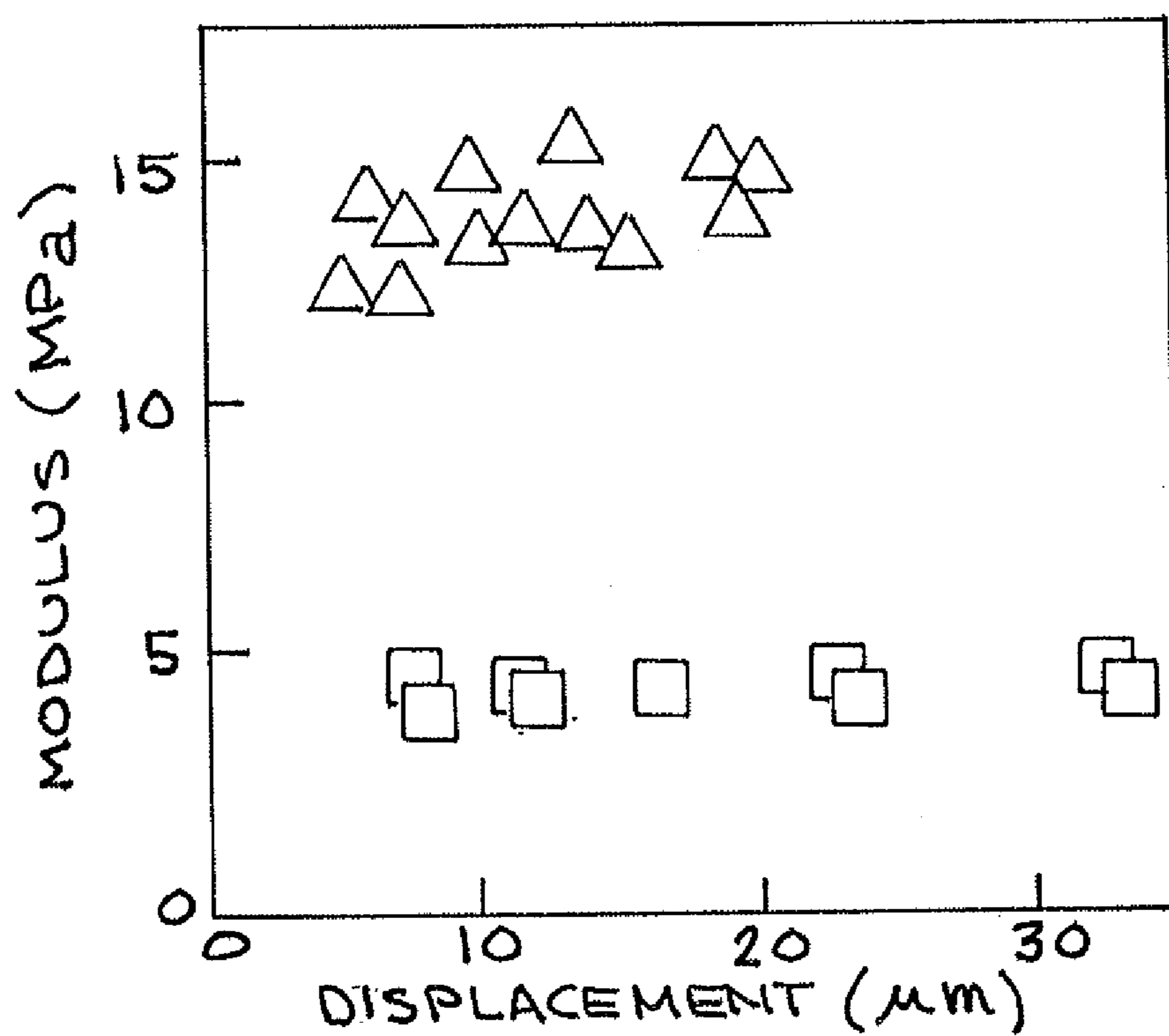
**FIG. 1 C**



**FIG. 1 D**



**FIG. 2A**



**FIG. 2B**

# MECHANICALLY STIFF, ELECTRICALLY CONDUCTIVE COMPOSITES OF POLYMERS AND CARBON NANOTUBES

## CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** The present application claims benefit under 35 U.S.C. §119(e) of U.S. Provisional Patent Application No. 61/172,363 filed Apr. 24, 2009 entitled "Route to mechanically stiff, electrically conductive composites of polymers and carbon nanotubes," the disclosure of which is hereby incorporated by reference in its entirety for all purposes.

## STATEMENT AS TO RIGHTS TO INVENTIONS MADE UNDER FEDERALLY SPONSORED RESEARCH AND DEVELOPMENT

**[0002]** The United States Government has rights in this invention pursuant to Contract No. DE-AC52-07NA27344 between the United States Department of Energy and Lawrence Livermore National Security, LLC for the operation of Lawrence Livermore National Laboratory.

## BACKGROUND

**[0003]** 1. Field of Endeavor

**[0004]** The present invention relates to and more particularly to a composite of polymers and carbon nanotubes, and more particularly, to a mechanically stiff, electrically conductive composites of polymers and carbon nanotubes.

**[0005]** 2. State of Technology

**[0006]** The treatise, *Introduction to Nanotechnology*, by Charles P. Poole, Jr., and Frank J. Owens, John Wiley & Sons, 2003, states: "Nanotechnology is based on the recognition that particles less than the size of 100 nanometers (a nanometer is a billionth of a meter) impart to nanostructures built from them new properties and behavior. This happens because particles which are smaller than the characteristic lengths associated with particular phenomena often display new chemistry and physics, leading to new behavior which depends on the size. So, for example, the electronic structure, conductivity, reactivity, melting temperature, and mechanical properties have all been observed to change when particles become smaller than a critical size."

**[0007]** Carbon nanotubes (CNTs) possess a number of intrinsic properties that make them promising candidates as filler material in the design of new composite systems. CNTs can have electrical conductivities as high as  $1 \times 10^6 \text{ S m}^{-1}$ , thermal conductivities as high as  $3000 \text{ W m}^{-1}\text{K}^{-1}$ , elastic moduli of the order of 1 TPa, and are extremely flexible. Unfortunately, the realization of these properties in macroscopic forms, such as conductive polymer/CNT composites, has been limited. In these composites, CNTs are typically dispersed throughout the polymeric matrix by addition of the individual nanotubes or bundles to precursor formulations. Since the loading levels and distribution of the CNTs in the polymer determine the conductivity of the composite, one of the challenges associated with the fabrication of conductive polymer composites is attaining uniform dispersion of the CNTs within the matrix. In addition, dispersion methods can vary greatly depending on the characteristics of matrix material. While measurable increases in electrical conductivity can be achieved through addition of as little as 0.007 wt % CNTs to polymer matrices, preparation of composites with conductivities  $>1 \text{ S cm}^{-1}$  requires either higher loadings of

CNTs ( $>10 \text{ wt } \%$ ) or specially-designed CNTs that facilitate dispersion in the matrix. Thus, the fabrication of CNT-polymer composites with conductivities on par with highly conductive semiconductors and metals for applications such as electromagnetic interference shielding can be an expensive endeavor. An attractive alternative to the dispersion approach for the design of conductive polymer composites would be the use of a low-density, electrically conductive CNT foam as a scaffold that can be filled or infiltrated with the polymer matrix. With this approach, the uniformity of the dispersed phase, and hence the conductivity of the composite, is established by the pre-formed CNT network of the scaffold. In addition, this approach could be general and utilized with a wide variety of polymer matrices.

## SUMMARY

**[0008]** Features and advantages of the present invention will become apparent from the following description. Applicants are providing this description, which includes drawings and examples of specific embodiments, to give a broad representation of the invention. Various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this description and by practice of the invention. The scope of the invention is not intended to be limited to the particular forms disclosed and the invention covers all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims.

**[0009]** Many challenges remain in the effort to realize the exceptional mechanical and electrical properties of carbon nanotubes in composite materials. Applicants have developed highly electrically conductive and mechanically stiff composites of polymers and single-walled carbon nanotubes (SWNT). Conductive SWNT-based nanofoams (aerogels) are used as scaffolds to create polymer [poly(dimethylsiloxane)] composites. The resulting composites possess electrical conductivities over  $1 \text{ S cm}^{-1}$  and exhibit an  $\sim 300\%$  increase in the elastic modulus with as little as 1 vol % nanotube content.

## DEFINITION OF TERMS

**[0010]** Various terms used in this patent application are defined below.

- [0011]** CA=Carbon Aerogel
- [0012]** CNT=Carbon Nanotubes
- [0013]** CA-CNT=Carbon Aerogel & Carbon Nanotube Composite
- [0014]** Nanofoam=Aerogel
- [0015]** SWNT=Single-Walled Carbon Nanotubes
- [0016]** DWNT=Double-Walled Carbon Nanotubes
- [0017]** SDBS=Sodium Dodecylbenzene Sulfonate
- [0018]** MESOPORPOUS=Pore Dia. 2 & 5 nm
- [0019]** PVA=Polyvinyl Alcohol
- [0020]** CVD=Chemical Vapor Deposition
- [0021]** TEM=Transmission Electron Microscopy
- [0022]** SEM=Scanning Electron Microscopy
- [0023]** R/C=Resorcinol to Catalyst Ratios
- [0024]** RF=Resorcinol and Formaldehyde Solids
- [0025]** BET=Brunauer-Emmett-Teller
- [0026]** Mechanically Robust=Can withstand strains greater than 10% before fracture
- [0027]** Electrically Conductive=Exhibits an electrical conductivity of  $10 \text{ S/m}$  or greater

- [0028] Mechanically Stiff=Elastic modulus greater than 10 MPa
- [0029] Ultralow-Density=Exhibits densities less than 50 mg/cc
- [0030] Carbon Nanotube-Based Aerogel=Porous carbon material consisting of 5 to 95% carbon nanotubes by weight
- [0031] SWNT-CA=Single-Walled Carbon Nanotubes/Carbon Aerogel
- [0032] PDMS/SWNT-CA=Polydimethylsiloxane (PDMS)/Single-Walled Carbon Nanotubes/Carbon Aerogel
- [0033] Applicants used SWNT-CAs as scaffolds to fabricate stiff, highly conductive polymer (PDMS) composites via the infiltration method with little to no degradation of the conductive network of the CNT-based scaffold. Conductivities as high as  $1 \text{ S cm}^{-1}$  have been observed for SWNT loadings as low as 1 vol % (1.2 wt %) in polymer/SWNT-CA composites. In addition to excellent electrical conductivity, the polymer composite exhibited an ~300% increase in Young's modulus, producing not only a highly conductive, but a stiffer composite as well. The exceptional properties of this polymer composite and the general nature of the fabrication method provide the potential for a whole new class of composites based on the SWNT-CA scaffold.
- [0034] The invention is susceptible to modifications and alternative forms. Specific embodiments are shown by way of example. It is to be understood that the invention is not limited to the particular forms disclosed. The invention covers all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims.

#### BRIEF DESCRIPTION OF THE DRAWINGS

- [0035] The accompanying drawings, which are incorporated into and constitute a part of the specification, illustrate specific embodiments of the invention and, together with the general description of the invention given above, and the detailed description of the specific embodiments, serve to explain the principles of the invention.
- [0036] FIGS. 1A, 1B, 1C, and 1D are SEM images under different magnifications of conductive PDMS/SWNT-CA composites.
- [0037] FIGS. 2A and 2B show partial load-displacement curves for PDMS and PDMS/CNT composite.

#### DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

- [0038] Referring to the drawings, to the following detailed description, and to incorporated materials, detailed information about the invention is provided including the description of specific embodiments. The detailed description serves to explain the principles of the invention. The invention is susceptible to modifications and alternative forms. The invention is not limited to the particular forms disclosed. The invention covers all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the claims.
- [0039] Applicants synthesized ultralow-density SWNT-based foams (SWNT-CA) with exceptional electrical and mechanical properties. In these foams, carbon nanoparticles were used as a binder to crosslink randomly oriented bundles of single-walled CNTs. These SWNT-CAs simultaneously exhibited increased stiffness and high electrical conductivity

even at densities approaching  $10 \text{ mg cm}^{-3}$ . The foams are stable to temperatures approaching  $1000^\circ \text{C}$ . and have been shown to be unaltered by exposure to extremely low temperatures during immersion in cryogenic liquids (such as liquid hydrogen). Therefore, in addition to use as catalyst supports, sensors, and electrodes, these ultra-light and robust foams can serve as scaffolds for the preparation of novel CNT composites. As the conductive network is already established, the CNT foam can simply be impregnated through the wicking process with the matrix of choice, ranging from inorganic sols to polymer melts to ceramic pastes, to prepare a variety of conductive CNT composites. Applicants used SWNT-CA foam scaffolds for the synthesis of a highly conductive poly (dimethylsiloxane) (PDMS) composite. This polymer composite exhibits ~300% increase in the elastic modulus relative to the unloaded PDMS elastomer and electrical conductivity over  $1 \text{ S cm}^{-1}$ , the highest conductivity reported for a polymer/SWNT composite at this CNT loading level (1.2 wt % or 1 vol %).

#### [0040] Method of Preparation

[0041] SWNT-CA nanofoams, with a SWNT loading of 55 wt % (1 vol %) and a monolith density of  $28 \text{ mg cm}^{-3}$ , were prepared as described in:

[0042] (1) Co-Pending patent application Ser. No. 12/652, 616 titled "Mechanically Robust, Electrically Conductive Ultralow-Density Carbon Nanotube-Based Aerogels," filed Jan. 5, 2009 which is incorporated herein in its entirety by this reference;

[0043] (2) the journal article, "Mechanically robust and electrically conductive carbon nanotube foams," by Marcus A. Worsley, Sergei O. Kucheyev, Joe H. Satcher, Jr., Alex V. Hamza, and Theodore F. Baumann, in APPLIED PHYSICS LETTERS 94, 073115 (2009) which is incorporated herein in its entirety by this reference; and

[0044] (3) "Properties of single-walled carbon nanotube-based aerogels as a function of nanotube loading," by Marcus A. Worsley, Peter J. Pauzauskie, Sergei O. Kucheyev, Joseph M. Zaug, Alex V. Hamza, Joe H. Satcher Jr., and Theodore F. Baumann, in Acta Materialia 57 (2009) 5131-5136, which is incorporated herein in its entirety by this reference.

[0045] Once the SWNTs are dispersed, organic sol-gel chemistry is used crosslink the CNT bundles. Typically, organic sol-gel chemistry involves the polymerization of organic precursors to produce highly crosslinked organic gels that can be dried and pyrolyzed to yield porous carbon structures. In this case, low concentrations of the sol-gel precursors (resorcinol, formaldehyde) and catalyst (sodium carbonate) are added to the CNT suspension to induce polymerization primarily on the walls of the CNT bundles and, more importantly, at the junctions between adjacent bundles to form an organic binder.

[0046] The resulting gel is then dried and subsequently pyrolyzed to convert the organic binder to carbon, yielding the SWNT-CA nanofoam. The volume percent of SWNTs in each sample was calculated from the initial mass of SWNTs added, a CNT density of  $1.3 \text{ g cm}^{-3}$ , and the final volume of the sample. The synthesis process for the SWNT-CA allows for a range of possible shapes and sizes. SWNT-CA right cylinders with diameters of ~1 cm and heights of ~2 cm have been fabricated.

[0047] Composites were prepared by immersing the as-prepared SWNT-CA in the polymer resin prior to cure. The immersed SWNT-CA is placed under vacuum until no more air escaped from the scaffold, suggesting full infiltration of

the resin. The infiltrated SWNT-CA is then cured at 60° C. to produce the composite. The dimensions of the composite are approximately equal to those of the initial SWNT-CA.

**[0048]** Referring now to the drawings and in particular to FIGS. 1A, 1B, 1C, and 1D, scanning electron microscopy (SEM) images of PDMS/SWNT-CA composites show that the SWNTs are homogeneously distributed throughout the polymer matrix, suggesting that there is good wetting at the PDMS/SWNT-CA interface and that the CNT-based scaffold is intact after infiltration and curing. FIG. 1A is a SEM image under low magnification of the conductive PDMS/SWNT-CA composite. FIG. 1B is a SEM image under high magnification of the conductive PDMS/SWNT-CA composite.

TABLE 1

Physical properties of SWNT-CA scaffold, polymers and conductive polymer composites				
Material	CNT (vol %), (wt %)	Density/g cm <sup>-3</sup>	E/MPa	/S cm <sup>-1</sup>
SWNT-CA	1, 55	0.028	1.0	1.12
PDMS	0, 0	1.04	4.2	<0.001
PDMS/SWNT-CA	1, 1.2	1.01	14	1.00

**[0049]** This observation is supported by the fact that the electrical conductivity of the SWNT-CA scaffold is maintained even in a fully dense insulating matrix as shown by Table 1. To Applicant's knowledge, the conductivity of these polymer composites (1 S cm<sup>-1</sup>) represents the highest conductivity reported for a polymer/SWNT composite prepared at such a low CNT loading level (1.2 wt % or 1 vol %). Interestingly, the electrical conductivity of this composite is on par with the highest reported value for a polymer/MWNT at a similar ~1 wt % MWNT loading. As SWNTs typically contain some fraction of semiconducting tubes, as compared to MWNTs, which presumably are all metallic, one might expect a higher conductivity in the MWNT composite with similar CNT loadings. This observation highlights the need for further study in this area and suggests that even larger improvements in the conductivity of polymer composites are possible.

**[0050]** Referring now to FIGS. 2A and 2B, nanoindentation measurements show that the PDMS/SWNT-CA experiences very elastic behavior with an ~300% increase in Young's modulus as compared to the case of PDMS. The observed enhancement in modulus is consistent with the increase expected based on the Halpin-Tsai model for a nanotube bundle aspect ratio of ~100. A similar increase in modulus was observed by Dyke and Tour for a PDMS/SWNT composite prepared with 1 wt % loading of surface-functionalized SWNT. The improved modulus is also consistent with the observation of a polymer shell that coats the CNT bundles in the SEM images as shown in FIG. 1. The presence of the polymer shell suggests strong bonding at the PDMS/SWNT-CA interface, a key element in successful reinforcement. These results highlight the effectiveness of using a pre-made CNT scaffold for structural reinforcement.

#### Example 1

**[0051]** SWNT-CA nanofoams, with a SWNT loading of 55 wt % (1 vol %) and a monolith density of 28 mg cm<sup>-3</sup>, were

prepared as previously reported. Briefly, purified SWNTs were suspended in deionized water and thoroughly dispersed via sonication.

**[0052]** Once the SWNTs were dispersed, organic sol-gel chemistry was used to crosslink the CNT bundles. Typically, organic sol-gel chemistry involves the polymerization of organic precursors to produce highly crosslinked organic gels that can be dried and pyrolyzed to yield porous carbon structures. In this case, low concentrations of the sol-gel precursors (resorcinol, formaldehyde) and catalyst (sodium carbonate) were added to the CNT suspension to induce polymerization primarily on the walls of the CNT bundles and, more importantly, at the junctions between adjacent bundles to form an organic binder.

**[0053]** The resulting gel was then dried and subsequently pyrolyzed to convert the organic binder to carbon, yielding the SWNT-CA nanofoam. The volume percent of SWNTs in each sample was calculated from the initial mass of SWNTs added, a CNT density of 1.3 g cm<sup>-3</sup>, and the final volume of the sample. The synthesis process for the SWNT-CA allows for a range of possible shapes and sizes. In this report, SWNT-CA right cylinders with diameters of ~1 cm and heights of ~2 cm were fabricated.

**[0054]** Composites were prepared by immersing the as-prepared SWNT-CA in the PDMS polymer resin prior to cure. The immersed SWNT-CA was placed under vacuum until no more air escaped from the scaffold, suggesting full infiltration of the resin. The infiltrated SWNT-CA was then cured at 60° C. to produce the composite. The dimensions of the composite were approximately equal to those of the initial SWNT-CA.

**[0055]** Materials and Methods

**[0056]** Materials. All reagents were used without further purification. Resorcinol (99%) and formaldehyde (37% in water) were purchased from Aldrich Chemical Co. Sodium carbonate (anhydrous) was purchased from J. T. Baker Chemical Co. Highly purified SWNTs were purchased from Carbon Solutions, Inc.

**[0057]** SWNT-CA preparation. The SWNT-CAs were prepared using traditional organic sol-gel chemistry [1]. In a typical reaction, purified SWNTs (Carbon Solutions, Inc.) were suspended in deionized water and thoroughly dispersed using a VWR Scientific Model 75T Aquasonic (sonic power ~90 W, frequency ~40 kHz). The concentration of SWNTs in the reaction mixture was 1.3 wt %. Once the SWNTs were dispersed, resorcinol (1.235 g, 11.2 mmol), formaldehyde (1.791 g, 22.1 mmol) and sodium carbonate catalyst (5.95 mg, 0.056 mmol) were added to the reaction solution. The resorcinol-to-catalyst ratio (R/C) employed was 200. The amount of resorcinol and formaldehyde (RF solids) used was 4 wt %. The sol-gel mixture was then transferred to glass molds, sealed and cured in an oven at 85° C. for 72 h. The resulting gels were then removed from the molds and washed with acetone for 72 h to remove all the water from the pores of the gel network. The wet gels were subsequently dried with supercritical CO<sub>2</sub> and pyrolyzed at 1050° C. under a N<sub>2</sub> atmosphere for 3 h. The SWNT-CAs materials were isolated as black cylindrical monoliths. Foams with a SWNT loading of 55 wt % (1 vol %) were prepared by this method.

**[0058]** Characterization. Scanning electron microscopy (SEM) characterization was performed on a JEOL 7401-F at 5-10 keV (20 mA) in secondary electron imaging mode with a working distance of 2-8 mm. Electrical conductivity was measured using the four-probe method with metal electrodes

attached to the ends of cylindrical samples. The amount of current transmitted through the sample during measurement was 100 mA, and the voltage drop along the sample was measured over distances of 3 to 6 mm. Seven or more measurements were taken on each sample, and results were averaged. Mechanical properties were studied by indentation in an MTS XP Nanoindenter with a Berkovich diamond tip. A series of both continuous and partial load-unload indents (with 5 cycles and an unloading percentage of 100% for each cycle) was carried out in laboratory air at room temperature. The loading rate was continuously adjusted to keep a constant representative strain rate of  $10^{-3} \text{ s}^{-1}$ , defined as  $(dP/dt)/\cot\theta/4P$ , where  $P$  is load,  $t$  is time, and  $\theta=72.1^\circ$  is the equivalent cone angle of the Berkovich tip used. For every cycle, the unloading rate was kept constant and equal to the maximum loading rate of the cycle. The Oliver-Pharr method [2] was used to analyze partial load-unload data in order to calculate the indentation elastic modulus as a function of the indenter penetration.

#### Example 2

**[0059]** SWNT-CA nanofoams, with a SWNT loading of 55 wt % (1 vol %) and a monolith density of  $28 \text{ mg cm}^{-3}$ , were prepared as previously reported. Briefly, purified SWNTs were suspended in deionized water and thoroughly dispersed via sonication.

**[0060]** Once the SWNTs were dispersed, organic sol-gel chemistry was used to crosslink the CNT bundles. Typically, organic sol-gel chemistry involves the polymerization of organic precursors to produce highly crosslinked organic gels that can be dried and pyrolyzed to yield porous carbon structures. In this case, low concentrations of the sol-gel precursors (resorcinol, formaldehyde) and catalyst (sodium carbonate) were added to the CNT suspension to induce polymerization primarily on the walls of the CNT bundles and, more importantly, at the junctions between adjacent bundles to form an organic binder.

**[0061]** The resulting gel was then dried and subsequently pyrolyzed to convert the organic binder to carbon, yielding the SWNT-CA nanofoam. The volume percent of SWNTs in each sample was calculated from the initial mass of SWNTs added, a CNT density of  $1.3 \text{ g cm}^{-3}$ , and the final volume of the sample. The synthesis process for the SWNT-CA allows for a range of possible shapes and sizes. In this report, SWNT-CA right cylinders with diameters of  $\sim 1 \text{ cm}$  and heights of  $\sim 2 \text{ cm}$  were fabricated.

**[0062]** Composites were prepared by immersing the SWNT-CA in the epoxy polymer resin prior to cure. The immersed SWNT-CA was placed under vacuum until no more air escaped from the scaffold, suggesting full infiltration of the resin. The infiltrated SWNT-CA was then cured at elevated temperature of  $150^\circ \text{ C}$ . to produce the epoxy/SWNT-CA composite.

**[0063]** Materials and Methods

**[0064]** Materials. All reagents were used without further purification. Resorcinol (99%) and formaldehyde (37% in water) were purchased from Aldrich Chemical Co. Sodium carbonate (anhydrous) was purchased from J. T. Baker Chemical Co. Highly purified SWNTs were purchased from Carbon Solutions, Inc.

**[0065]** SWNT-CA preparation. The SWNT-CAs were prepared using traditional organic sol-gel chemistry [1]. In a typical reaction, purified SWNTs (Carbon Solutions, Inc.) were suspended in deionized water and thoroughly dispersed

using a VWR Scientific Model 75T Aquasonic (sonic power  $\sim 90 \text{ W}$ , frequency  $\sim 40 \text{ kHz}$ ). The concentration of SWNTs in the reaction mixture was 1.3 wt %. Once the SWNTs were dispersed, resorcinol (1.235 g, 11.2 mmol), formaldehyde (1.791 g, 22.1 mmol) and sodium carbonate catalyst (5.95 mg, 0.056 mmol) were added to the reaction solution. The resorcinol-to-catalyst ratio (R/C) employed was 200. The amount of resorcinol and formaldehyde (RF solids) used was 4 wt %. The sol-gel mixture was then transferred to glass molds, sealed and cured in an oven at  $85^\circ \text{ C}$ . for 72 h. The resulting gels were then removed from the molds and washed with acetone for 72 h to remove all the water from the pores of the gel network. The wet gels were subsequently dried with supercritical  $\text{CO}_2$  and pyrolyzed at  $1050^\circ \text{ C}$ . under a  $\text{N}_2$  atmosphere for 3 h. The SWNT-CAs materials were isolated as black cylindrical monoliths. Foams with a SWNT loading of 55 wt % (1 vol %) were prepared by this method.

**[0066]** Characterization. Scanning electron microscopy (SEM) characterization was performed on a JEOL 7401-F at 5-10 keV (20 mA) in secondary electron imaging mode with a working distance of 2-8 mm. Electrical conductivity was measured using the four-probe method with metal electrodes attached to the ends of cylindrical samples. The amount of current transmitted through the sample during measurement was 100 mA, and the voltage drop along the sample was measured over distances of 3 to 6 mm. Seven or more measurements were taken on each sample, and results were averaged.

TABLE 2

Material	CNT, vol % (wt %)	$\sigma$ , $\text{Scm}^{-1}$
Epoxy	0	<0.001
Epoxy/SWNT-CA	1 (1.2)	1.01

**[0067]** Additional information about Applicants' invention is disclosed in the journal article, "Stiff and electrically conductive composites of carbon nanotube aerogels and polymers," by Marcus A. Worsley, Sergei O. Kucheyev, Joshua D. Kuntz, Alex V. Hamza, Joe H. Satcher, Jr., Theodore F. Baumann, in *J. Mater. Chem.*, 2009, 19, 3370-3372. The *J. Mater. Chem.*, 2009, 19, 3370-3372, is incorporated herein in its entirety by this reference.

**[0068]** While the invention may be susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and have been described in detail herein. However, it should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the following appended claims.

The invention claimed is:

1. A method of making a stiff and electrically conductive composite of carbon nano tube aerogel and polymer, comprising the steps of:

providing a single-walled carbon nanotubes carbon aerogel,

immersing said single-walled carbon nanotube carbon aerogel in a polymer resin to produce a single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin, and

curing said single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin to produce the stiff and electrically conductive composite of carbon nanotube aerogel and polymer.

2. The method of making a stiff and electrically conductive composite of carbon nanotube aerogel and polymer of claim 1 wherein said step of immersing said single-walled carbon nanotube carbon aerogel in a polymer resin to produce a single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin includes placing said single-walled carbon nanotube carbon aerogel immersed in a polymer resin under vacuum.

2. The method of making a stiff and electrically conductive composite of carbon nanotube aerogel and polymer of claim 1 wherein said step of curing said single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin to produce the stiff and electrically conductive composite of carbon nanotube aerogel and polymer comprises curing said single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin at 60 or 150° C.

3. The method of making a stiff and electrically conductive composite of carbon nanotube aerogel and polymer of claim 1 wherein said step of providing a single-walled carbon nanotubes carbon aerogel comprises providing SWNT-CA nanofoams with a SWNT loading of 55 wt % (1 vol %) and a monolith density of 28 mg cm<sup>-3</sup>.

4. The method of making a stiff and electrically conductive composite of carbon nanotube aerogel and polymer of claim 1 wherein said step of immersing said single-walled carbon nanotube carbon aerogel in a polymer resin to produce a single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin comprises immersing said single-walled carbon nanotube carbon aerogel in polydimethylsiloxane resin.

5. The method of making a stiff and electrically conductive composite of carbon nanotube aerogel and polymer of claim 4 wherein said step of curing said single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin comprises curing said single-walled carbon nanotubes carbon aerogel infiltrated with said polydimethylsiloxane resin to produce the stiff and electrically conductive composite of carbon nanotube aerogel and polymer.

6. The method of making a stiff and electrically conductive composite of carbon nanotube aerogel and polymer of claim 1 wherein said step of immersing said single-walled carbon nanotube carbon aerogel in a polymer resin to produce a single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin comprises immersing said single-walled carbon nanotube carbon aerogel in epoxy polymer resin.

7. The method of making a stiff and electrically conductive composite of carbon nanotube aerogel and polymer of claim 4 wherein said step of curing said single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin comprises curing said single-walled carbon nanotubes carbon aerogel infiltrated with said epoxy polymer resin to produce the stiff and electrically conductive composite of carbon nanotube aerogel and polymer.

8. The method of making a stiff and electrically conductive composite of carbon nanotube aerogel and polymer of claim 1 wherein said step of immersing said single-walled carbon nanotube carbon aerogel in a polymer resin to produce a single-walled carbon nanotubes carbon aerogel infiltrated

with said polymer resin comprises immersing said single-walled carbon nanotube carbon aerogel in polydimethylsiloxane or epoxy resin.

9. The method of making a stiff and electrically conductive composite of carbon nanotube aerogel and polymer of claim 4 wherein said step of curing said single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin comprises curing said single-walled carbon nanotubes carbon aerogel infiltrated with said polydimethylsiloxane or epoxy resin to produce the stiff and electrically conductive composite of carbon nanotube aerogel and polymer.

10. A method of making a stiff and electrically conductive composite of carbon nanotube aerogel and polymer, comprising the steps of:

dispersing nanotubes in an aqueous media or other media to form a suspension,

adding reactants and catalyst to said suspension to create a reaction mixture,

curing said reaction mixture to form a wet gel,

drying said wet gel to produce a dry gel,

pyrolyzing said dry gel to produce a single-walled carbon nanotubes carbon aerogel,

immersing said single-walled carbon nanotube carbon aerogel in a polymer resin to produce a single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin, and

curing said single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin to produce the stiff and electrically conductive composite of carbon nanotube aerogel and polymer.

11. The method of making a stiff and electrically conductive composite of carbon nanotube aerogel and polymer of claim 10 wherein said step of immersing said single-walled carbon nanotube carbon aerogel in a polymer resin to produce a single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin includes placing said single-walled carbon nanotube carbon aerogel immersed in a polymer resin under vacuum.

12. The method of making a stiff and electrically conductive composite of carbon nanotube aerogel and polymer of claim 10 wherein said step of curing said single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin to produce the stiff and electrically conductive composite of carbon nanotube aerogel and polymer comprises curing said single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin at 60 or 150° C.

13. The method of making a stiff and electrically conductive composite of carbon nanotube aerogel and polymer of claim 10 wherein said step of providing a single-walled carbon nanotubes carbon aerogel comprises providing SWNT-CA nanofoams with a SWNT loading of 55 wt % (1 vol %) and a monolith density of 28 mg cm<sup>-3</sup>.

14. A mechanically stiff, electrically conductive composite of polymer and carbon nanotubes comprising:

a porous carbon material having 5 to 95% by weight carbon nanotubes and 5 to 95% carbon binder, and

a polymer infiltrated within said porous carbon material having 5 to 95% by weight carbon nanotubes and 5 to 95% carbon binder.

15. The mechanically stiff, electrically conductive composite of polymer and carbon nanotubes of claim 14 wherein said polymer infiltrated within said porous carbon material having 5 to 95% by weight carbon nanotubes and 5 to 95% carbon binder is polydimethylsiloxane or epoxy.

16. A mechanically stiff, electrically conductive composite of polymers and carbon nanotubes comprising:

a mechanically stiff, electrically conductive composite prepared by the method of

providing a single-walled carbon nanotubes carbon aerogel,  
immersing said single-walled carbon nanotube carbon aerogel in a polymer resin to produce a single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin, and

curing said single-walled carbon nanotubes carbon aerogel infiltrated with said polymer resin to produce the stiff and electrically conductive composite of carbon nanotube aerogel and polymer.

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