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(72) **Inventeurs/Inventors:**
STOLTZ, RICHARD, US;
BULLINGTON, JEFF, US
(73) **Propriétaire/Owner:**
GARMOR, INC., US
(74) **Agent:** AVENTUM IP LAW LLP

(54) **Titre : ENTRAINEMENT DE GRAPHENE DANS UN HOTE**
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(57) **Abrégé/Abstract:**

This is generally a method of producing graphene-containing suspensions of flakes of high quality graphene/graphite oxides and method of producing graphene/graphite oxides. Both the exfoliating graphite into flakes and oxidizing the graphite flakes and the preparation and suspension of the flakes can be done with high volume production and at a low cost.

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(71) Applicant: **GARMOR, INC.** [US/US]; 6317 McCoy Road, Suite 100, Orlando, FL 32822 (US).

(72) Inventor; and

(71) Applicant : **BLAIR, Richard** [US/US]; 3034 Moore Drive, Oviedo, FL 32765 (US).

(74) Agents: **FLORES, Edwin, S.** et al.; Chalker Flores, LLP, 14951 North Dallas Parkway, Suite 400, Dallas, TX 75254 (US).

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(54) Title: GRAPHENE ENTRAINMENT IN A HOST

(57) Abstract: This is generally a method of producing graphene-containing suspensions of flakes of high quality graphene/graphite oxides and method of producing graphene/graphite oxides. Both the exfoliating graphite into flakes and oxidizing the graphite flakes and the preparation and suspension of the flakes can be done with high volume production and at a low cost.



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GRAPHENE ENTRAINMENT IN A HOST

TECHNICAL FIELD OF THE INVENTION

The present invention relates in general to the field of graphene, and more particularly, to transitioning graphene into a variety of macroscale mechanical structures.

5 BACKGROUND OF THE INVENTION

Without limiting the scope of the invention, its background is described in connection with composite materials.

United States Patent No. 8,216,541, issued to Jang, et al. is directed to a process for producing dispersible and conductive nano-graphene platelets from non-oxidized graphitic materials.

10 Briefly, these inventors are said to teach a process for producing nano-graphene platelets (NGPs) that are both dispersible and electrically conducting. The process is said to include: (a) preparing a pristine NGP material from a graphitic material; and (b) subjecting the pristine NGP material to an oxidation treatment to obtain the dispersible NGP material, wherein the NGP material has an oxygen content no greater than 25% by weight. The conductive NGPs are said
15 to find applications in transparent electrodes for solar cells or flat panel displays, additives for battery and supercapacitor electrodes, conductive nanocomposite for electromagnetic wave interference (EMI) shielding and static charge dissipation.

United States Patent Publication No. 20120298620, filed by Jiang, et al., is directed to a method for making graphene composite structure. Briefly the method is said to include providing a
20 metal substrate including a first surface and a second surface opposite to the first surface, growing a graphene film on the first surface of the metal substrate by a CVD method, providing a polymer layer on the graphene film and combining the polymer layer with the graphene film, and forming a plurality of stripped electrodes by etching the metal substrate from the second surface.

25 Finally, United States Patent Publication No. 20120228555, filed by Cheng, et al., is directed to a method of making graphene. Briefly, the application is said to disclose a method for making graphene by providing a starting material and heating the starting material for a time and to a temperature effective to produce graphene. In certain embodiments the applicants are said to use starting materials that include carbonaceous materials used in conjunction with, or
30 comprising, sulfur, and essentially free of a transition metal. The graphene produced by the current method is said to be used to coat graphene-coatable materials.

SUMMARY OF THE INVENTION

In accordance with an aspect of at least one embodiment, there is provided a method of making a graphene suspension, comprising: preparing graphene flakes with a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, by mechanically milling
5 graphite and exfoliating the graphite into graphene flakes in a stirred media mill, an attrition mill, an attritor mill, or a ball mill without concentrated acid to produce oxidized graphene, wherein the graphene flakes are planar, have no significant physical surface distortions or corrugations, have only edge oxidation, and have a surface polarity; preparing a polar or nonpolar fluid having the same polarity as said graphene flakes; and suspending said graphene flakes in said fluid by mixing
10 until the suspension is uniform.

In accordance with an aspect of at least one embodiment, there is provided a method of making a graphene suspension, comprising: preparing graphene flakes with a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, by mechanically milling
15 graphite and exfoliating the graphite into graphene flakes in a stirred media mill, an attrition mill, an attritor mill, or a ball mill without concentrated acid to produce oxidized graphene, wherein the graphene flakes are planar, have no significant physical surface distortions or corrugations, have only edge oxidation, and have a surface polarity; and suspending said graphene flakes in a fluid by mixing until the suspension is uniform.

In accordance with an aspect of at least one embodiment, there is provided a graphene suspension
20 made by a method comprising: preparing graphene flakes with a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, by mechanically milling graphite and exfoliating the graphite into graphene flakes in a stirred media mill, an attrition mill, an attritor mill, or a ball mill without concentrated acid to produce oxidized graphene, wherein the
25 graphene flakes are planar, have no significant physical surface distortions or corrugations, have only edge oxidation, and have a surface polarity; preparing a polar or nonpolar fluid having the same polarity as said graphene flakes; and suspending said graphene flakes in said fluid by mixing until the suspension is uniform.

In accordance with an aspect of at least one embodiment, there is provided a graphene suspension made by a method comprising: preparing graphene flakes with a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, by mechanically milling graphite without concentrated acid and exfoliating the graphite into graphene flakes in a stirred media mill, an attrition mill, an attritor mill, or a ball mill without concentrated acid to produce oxidized graphene, wherein the graphene flakes are planar, have no significant physical surface distortions or corrugations, have only edge oxidation, and have a surface polarity; and suspending said graphene flakes in a fluid by mixing until the suspension is uniform.

In one embodiment the present invention includes a method of making a graphene suspension, comprising: preparing graphene flakes with a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, wherein the graphene flakes have no significant physical surface distortions and have a surface polarity; preparing a polar or nonpolar fluid having the same polarity as said graphene flakes; and suspending said graphene flakes in said fluid by mixing until the suspension is substantially uniform. In one aspect, the suspension is a carbon allotrope. In another aspect, 95% of the flakes are from about 0.8 to 16 nanometers in thickness. In another aspect, 95% of the flakes have a surface area to thickness ratio of a minimum of 300 Angstroms. In another aspect, the maximum dimension of the flakes between 220 Angstroms and 100 microns. In another aspect, the Graphene flake has only edge oxidation. In another aspect, the method further comprises adding a bonding host and the flake surfaces have the same polarity as the bonding host. In another aspect, the mechanically exfoliating graphite into graphene flakes is done in a stirred media mill, and the stirred media mill is an Attrition mill or ball mill. In another aspect, the method outputs are substantially limited to substantially flat graphene flakes and water.

Another embodiment the present invention includes a method of making a graphene suspension, comprising: preparing graphene flakes with a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, wherein the graphene flakes are substantially planar and have a surface polarity; and suspending said graphene flakes in a fluid by mixing until the suspension is substantially uniform. In one aspect, the suspension is a carbon allotrope. In another aspect, 95% of the flakes are from about 0.8 to 16 nanometers in thickness. In another aspect, 95% of the flakes have a surface area to thickness ratio of a minimum of 300

Angstroms. In another aspect, the maximum dimension of the flakes between 220 Angstroms and 100 microns. In another aspect, the Graphene flake has only edge oxidation. In another aspect, the method further comprises adding a bonding host and the flake surfaces have the same polarity as the bonding host. In another aspect, the mechanically exfoliating graphite into graphene flakes
5 in done in a stirred media mill, and the stirred media mill is an Attrition mill or ball mill. In another aspect, the method outputs are substantially limited to substantially flat graphene flakes and water.

Yet another embodiment of the present invention includes a graphene suspension made by a method comprising: preparing graphene flakes with a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, wherein the graphene flakes have no

significant physical surface distortions and have a surface polarity; preparing a polar or nonpolar fluid having the same polarity as said graphene flakes; and suspending said graphene flakes in said fluid by mixing until the suspension is substantially uniform. In one aspect, 95% of the flakes are from about 0.8 to 16 nanometers in thickness. In another aspect, 95% of the flakes have a surface area to thickness ratio of a minimum of 300 Angstroms. In another aspect, the maximum dimension of the flakes between 220 Angstroms and 100 microns.

Yet another embodiment of the present invention includes a graphene suspension made by a method comprising: preparing graphene flakes with a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, wherein the graphene flakes are substantially planar and have a surface polarity; and suspending said graphene flakes in a fluid by mixing until the suspension is substantially uniform. In one aspect, 95% of the flakes are from about 0.8 to 16 nanometers in thickness. In another aspect, 95% of the flakes have a surface area to thickness ratio of a minimum of 300 Angstroms. In another aspect, the maximum dimension of the flakes between 220 Angstroms and 100 microns.

DETAILED DESCRIPTION OF THE INVENTION

While the making and using of various embodiments of the present invention are discussed in detail below, it should be appreciated that the present invention provides many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed herein are merely illustrative of specific ways to make and use the invention and do not delimit the scope of the invention.

To facilitate the understanding of this invention, a number of terms are defined below. Terms defined herein have meanings as commonly understood by a person of ordinary skill in the areas relevant to the present invention. Terms such as “a”, “an” and “the” are not intended to refer to only a singular entity, but include the general class of which a specific example may be used for illustration. The terminology herein is used to describe specific embodiments of the invention, but their usage does not delimit the invention, except as outlined in the claims.

Despite these nanoscale mechanical properties, graphene previously had not been able to be transitioned to a macro-scale mechanical structure. The process of producing a loaded host did not translate to a viable composite structure. The inability to translate the technology to a viable composite structure was a combination of technical issues and cost factors, including uniform distribution of the suspension in the host material. The technical limitation included stochastic processes in the curing of the host while obtaining a distribution of the suspension. Curing of

the host material resulted in random shrinkage phenomena, which was exacerbated in larger composite structures/devices. If a suspension was added to the host prior to curing, polymerization, hydrolyzation or other thermal, mechanical, chemical processes that initiation either long-range or short-range ordering bonding the distribution of the non-uniform suspension
5 creating weak regions and failure points in the loaded host material.

Graphene is an allotrope of carbon. Graphene's purest form is a one-atom-thick planar sheet of sp^2 -bonded carbon atoms that are densely packed in a honeycomb or hexagonal crystal lattice. Graphene used as an additive have been shown superior mechanical, chemical, thermal, gas barrier, electrical, flame retardant and other properties compared to the native host.
10 Improvement in the physicochemical properties of the host depends on: 1) a uniform distribution and entrainment of the graphene flake, 2) optimizing the interfacial bonding between the graphene flake and host's matrix, 3) removal of gasses entrained in the host during processing, 4) optimizing the additive's innate properties, e.g. flatness, and/or 5) optimizing the thickness to surface-area ratio of the graphene flake.

15 Optimal properties of the graphene flake: We have found that the performance of a graphene flake is dominated by both the texture and the surface and edge oxidation/functionalization. A Hummer's based process produces graphene flakes that have both a surface and edge oxidation. The degree of oxidation and exfoliation inherent in the Hummer's or modified based Hummer's process results in permanent corrugated disfiguration of the graphene flake. The combination
20 low yield, high cost and inconsistent performance makes the approach not viable. The permanent corrugated structure degrades the chemical, mechanical, electrical and thermal properties of graphene flake. Hence a surface oxidized graphene flake has lower performance than the single-layer graphene originally demonstrated when the graphene was first discovered in 2007. This can explain by simple theoretical analysis where the corrugated structure induces
25 different shearing and loading forces to the surrounding host as the corrugated structure gives a third dimension to the ideal two dimension graphene structure. In the transmission of phonons or electrons the ideal structure is a uniform flat large area graphene structure. This is illustrated by the development activities of the semiconductor industry as they focused chemical vapor deposition thin film generated graphene material. A corrugated structure induces resistance and
30 inductance to the transmission of phonons and electrons hence a planar flake has higher performance in the electron and phonon transmission relative to a corrugated structure in the surface oxidized graphene flake.

This can be a method of making a graphene suspension, comprising: preparing graphene flakes with a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, wherein the graphene flakes have no significant physical surface distortions and have a surface polarity; preparing a polar or nonpolar fluid having the same polarity as said graphene flakes; suspending said graphene flakes in said fluid by mixing until the suspension is substantially uniform.

In one embodiment, the suspension is a carbon allotrope; 95% of the flakes are from about 0.1 to 16 nanometers in thickness; 95% of the flakes have a surface area to thickness ratio of a minimum of 300 Angstroms; the maximum dimension of the flakes between 220 Angstroms and 100 microns; the Graphene flake has only edge oxidation; the flake surface has the same polarity as the bonding host; the mechanically exfoliating graphite into graphene flakes is done in a stirred media mill, and the stirred media mill is an Attrition mill or ball mill; and/or the method outputs are substantially limited to substantially flat graphene flakes and water.

The present invention also includes a method of making a graphene suspension, comprising: Preparing graphene flakes with a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, wherein the graphene flakes are substantially planar and have a surface polarity; Suspending said graphene flakes in said fluid by mixing until the suspension is substantially uniform.

Recent publications have shown one possible route to produce a non corrugated graphene through the use of ball milling crystalline graphite with dry ice the chemo-mechanical processing of the crystalline graphite produces edge oxidized graphene flakes. This process shows the feasibility of an edge-only oxidized graphene flake but cost of this processing is more expensive as required by a commodity additive market. Note that planar graphene graphite for research has also been produced by manually separating one layer at a time from a piece of crystalline graphite. Needless to say this is far too slow and too expensive for commercial production. The Hummer's based process produces graphene that is not planar, generally weakens the graphite in a host.

Optimizing the interfacial bonding between the graphene flake and host's matrix. Optimizing the interfacial bonding requires the two critical aspects, first is the providing of a planar pristine surface that is not distorted through the graphene production process. Secondly is the modification of the chemistry of the additive to allow full entrainment of the additive in host's matrix. For graphene this can be the modifying the OOH group with other chemical functionality to tailor the additive to be hydrophilic or hydrophobic and/or create a functional

group on the additive that is similar to the host's chemistry (i.e., polarity, hydrophilicity, etc.). Creating the correct hydrophobicity allows the graphene additive to be maintained in suspension in a variety of common solvent hosts prior to long or short range ordering or bonding (e.g. a solid). Functionalizing the graphene additive with a similar chemistry to the host allows the
5 graphene additive to be directly incorporated in the long or short range ordering or bonding. The fluids can include plastics, metals, ceramics and glass.

Thickness to surface area ratio of the graphene flake: Using a planar graphene flake the next issue of implementing in a host is the thickness to surface-area of the graphene flake. The thickness to surface-area ratio of the graphene flake plays a significant ability in the graphene
10 flakes ability to positively impact the host's properties.

This large surface with a modest thickness is conceptually comparable to the ideal larger area monolayer need by the semiconductor industry. A large flat flake will conduct better phonons and electrons better than the host alone. A multi-layer graphene flake held bonded even by with van der Waal forces is more desirable than a thin flake surround by an insulating host. This is
15 true for mechanical applications as well. As long as there is a larger surface area to thickness ratio the graphene can mitigate and distribute a mechanical load giving the host enhanced mechanical properties, increased tensile, shear, and flexural strength. The ability to achieve substantial enhancement of the host's mechanical properties can e.g. be obtained with a flake with an area of $48,400 \text{ \AA}^2$ with a flake thickness to 160Å to 200 Angstroms. A $48,400 \text{ \AA}^2$ area
20 flake with a thickness of 160 Å has a surface area to thickness ratio of about 300 Angstroms can also provide enhancement to the host's mechanical properties (preferably 95% of the graphene flakes of the present invention have a surface area to thickness ratio of a minimum of 300 Angstroms).

In some embodiments our flake thicknesses are 16 nanometers or less as too many layers
25 significantly reduce the tensile strength (preferably 95% of the graphene flakes of the present invention are from about 0.8 to 16 nanometers), and our surface area to thickness ratio is greater than 48400 to 1 Angstroms. Preferably, the maximum dimension of the flake varies between 220 Angstroms and 100 microns. This requires precise process control or a process that allows separation of the graphene flakes by surface area and/or thickness.

30 Uniform distribution and entrainment: The third aspect of obtaining an effective uniform distribution and entrainment of graphene flake as an additive in the host fluid is the aggressively mixing the flake into the host fluid (for example, under an at least partial vacuum), prior to reacting, casting or otherwise causing the host to become ordered by thermal, chemical,

electrical or other processes that induce order or bonding in the host, e.g. solidified or gelled. In some embodiments, epoxy that is dried is used, and then thermally set after mixing. In one embodiment of the present invention, greater than 6% loading of graphene is used (e.g. between 6 and 35%). Studies on attaining increased potency of fillers by using different mixing techniques, modification of polymer backbone or filler surface, use of functional polymers and coupling agents, etc. Graphene, has low surface energy as compared with crystalline graphite (the cost-effective precursor for graphene/graphene oxide). One of the routes to overcome this limitation is the functionalization of flake surface, which results in significant enhancement of the mechanical and electrical properties of polymer composites. As graphene is being entrained in a host a mild vacuum may be applied to prevent gasses from being incorporated in the host. The formation of gas bubbles increase resistance to phonon and electron transpiration in addition creating light scattering centers and mechanical defect sites in a host.

Obtaining consistent size and thickness can require controlled pre-processing (e.g., milling and separation) of the crystalline graphite. Chemo-mechanical processing can use crystalline graphite with a mild oxidizing agent in conjunction with mechanical energy (milling) for synthesis of graphene.

The mechanical energy in conjunction with a mild oxidizing environment can produce edge oxidation of the graphene minimizing the surface oxidation and mechanical defects generated in a Hummer's based process.

Graphite (TC306, 30g) can be used as the starting material for the graphene chemo-mechanical process. Chemo-mechanical process can be done in what is generically referred to as a "stirred ball mill." A useful and simple equation describing the grinding momentum is $M \times V$ (mass x velocity), which enables us to see how a ball milling use up to 6 lbs (2.7 Kg) (or ~2,600 stainless steel balls) of 0.25" diameter stainless steel balls weighing 1 g each. Milling in a closed chamber for 360 minutes at 2,000 RPM or less. When grinding in the ball milling as the balls (media) in their random movement are spinning in different rotation and, therefore, exerting shearing forces on the crystalline graphite. The resulting graphene preferably has edge-only oxidized flakes with a pristine surface free of distortions or corrugations with low surface energies allowing for easier incorporation and entrainment in a host with enhance graphene physical properties.

The oxidation of the graphene can occur from a wide range of methods of making graphene oxide, comprising: Putting crystalline graphite and an atomizer or aerosolized oxidizing agent in a mill, wherein the atomizer or aerosolized oxidizing exfoliating agent contains only carbon,

oxygen, hydrogen and combinations thereof; Milling said crystalline graphite and atomizer or aerosolized oxidizing exfoliating agent to produce planar graphene flakes having a thickness of less than 160 Angstroms; and Suspending said graphene flakes in a fluid to remove the graphene flakes from the mill.

- 5 This can be a technique for low cost, mass-production of a partially oxidized to fully oxidized graphite/graphene using mechanical processing (Attritor Mill) in conjunction with a water soluble exfoliating agent, such as kaolin clay powder and at least one of atomizer or aerosolized carbolic acid or oxalic acid ($C_2H_2O_4$), acetic acid, carbonic acid or ethanoic (CH_3CO)₂O, and citric acid. Aerosolization can be accomplished by an Ultrasonic Atomizer Processor, ultrasonic
- 10 spray & atomization system made by U&STAR Ultrasonic Technology. An ultrasonic spray system, uses an ultrasound technology to atomize liquid or powders generated from ultrasonic energy that scattered the liquid forming droplets ranging microns to more than 100 microns. Liquid droplets that may contain powders and soluble matter, promoting chemical reaction, and spraying. This ultrasonic spray atomization has low power, large volume. An ultrasonic spray
- 15 system widely applied on kinds of industrial applications including ultrasonic spraying liquid, metal power water nebulization or atomization. The controlled small droplet sizes provide a high surface to volume ratio enhancing efficiency and control chemical reactions.

The atomizer or aerosolized oxidizing agent is injected into a mill in addition to the crystalline graphite. Directly milling of graphite powder without concentrated acid, for aerosolized

20 oxidizing, to produce high quality oxidized graphene. After milling the crystalline graphite with an aerosolized oxidizing agent is injected into the attritor mill for a minimum of 30 min to produce an aqueous slurry. The aqueous slurry contains a mild acid that breaks down into water and graphite. The water can dissolve the water-soluble exfoliating agent. An example of a water-soluble exfoliating agent is kaolin clay powder. The mild aerosolized oxidizing agent

25 produces oxidized graphene with no distortion or texturing. Textured graphene oxide produces significant problems when depositing the graphene oxide, using the graphene oxide in a suspension or as an additive to other materials.

Directly milling of graphite powder with a chemically stable gaseous oxidizing agent in addition to the gaseous oxidizing agent a water-soluble exfoliating agent, such as kaolin clay powder can

30 be added to process to produce high quality edge oxidized graphene. After exfoliating the crystalline graphite in the Attritor mill for 90 min with steel balls and chemically stable gaseous oxidizing agent is introduced. Once the carbon dioxide is released and the pressure in the Attritor exceeds two atmospheres the chemo-mechanical processing initiate graphene oxidation

resulting edge oxidized graphene. As the chemo-mechanical processing continues pressure in the chamber decreases in the Attritor mill. Keeping the Attritor mill at an elevated pressure during the oxidation process enables a higher level of oxidation of the graphene flakes.

5 Additionally graphene oxide may be made, by: Putting crystalline graphite, and vapor phase oxidizing agent in a mill, wherein the oxidizing agent comprises nitrogen, carbon, oxygen, hydrogen and/or combinations thereof; Milling said crystalline graphite and vapor phase oxidizing agent to produce planar graphene flakes having a thickness of less than 160 Angstroms; and Suspending said graphene flakes in a fluid to remove the graphene flakes from the mill.

10 This can also be a method of making graphene oxide, comprising: Putting crystalline graphite, mineral-based exfoliating media and vapor phase oxidizing agent in a mill, wherein the oxidizing agent comprises nitrogen, carbon, oxygen, hydrogen and/or combinations thereof; Milling said crystalline graphite, mineral-based exfoliating media and vapor phase oxidizing agent where water vapor or liquid is combined to produce a mild acidic slurry where the slurry
15 enhances the exfoliation of the graphite to produce planar graphene flakes having a thickness of less than 160 Angstroms; and additional water is added at the end of the process to remove the water soluble exfoliating agent leaving water and graphene flakes.

This can be a method of making graphene oxide, comprising: Putting crystalline graphite and anhydrous oxidizing exfoliating agent in a mill, wherein the anhydrous oxidizing exfoliating
20 agent contains only carbon, oxygen, hydrogen and combinations thereof; Milling said crystalline graphite and anhydrous oxidizing exfoliating agent to produce planar graphene flakes having a thickness of less than 160 Angstroms; and Suspending said graphene flakes in a fluid to remove the graphene flakes from the mill.

Preferably, the milling is done in a stirred mill; the stirred mill is an Attrition mill or Attritor; the
25 method outputs are substantially limited to substantially flat graphene flakes and carbon, oxygen, hydrogen and combinations thereof; and/or the anhydrous oxidizing exfoliating agent is at least one of crystal carboic acid or anhydrous oxalic acid ($C_2H_2O_4$), Acetic anhydride, or ethanoic anhydride (CH_3CO)₂O, and anhydrous citric acid powder.

If the suspension application requires a narrow size distribution the edge oxide graphene can be
30 chemically separated via acidic precipitation by titrating hydrochloric acid into the bath the larger (thicker/heavier) material comes out of suspension first creating a narrow graphene oxide flake distribution. The particle size can be monitored during this process by Dynamic Light

Scattering measurement tool. Dynamic Light Scattering tools can resolve particle sizes down to 30Å.

Preferably, the surface area to thickness ratio should be greater than about 300 to have a positive impact on the host as a suspension. The pH of the water containing the oxidized graphite/graphene can range from 5 to 9 while maintaining the suspension of the media the pH of the resulting water/graphene mixture is typically is about 7. A chemo-mechanical can be controlled to process graphene with oxidization of from 1% to 35%. Unless otherwise indicated or produced by the Hummer process, the term “graphene” as used herein means graphene with oxidization of from 1% to 35%. The functionalization can be COOH on the edge carbons preserving the graphene structure.

Oxidized graphite produced by this method is typically hydrophilic and easily suspended in a neutral aqueous solution. The oxidized graphite can be kept in suspension until varying the pH of the solution.

A ball mill operating with less than or equal to 2,000 RPM can be generally sufficient to prevent agglomeration of the graphene adhering to the milling balls or tank.

The graphene can be combined with the host material in a mechanical agitation process.

Graphene is diamagnetic and as such dynamic magnetic fields can be used to enhance orientation and mixing along in addition other method such as: melt blending, counter rotating screw, sonication or other mixing processes of the graphene additive into the host material prior to inducing ordering or bonding in the host. The entrainment and uniform dispersement preferably uses a minimum of 30 minutes of and less than 600 minutes in a ball mill.

The resulting graphene entrained host can be the cast, extruded or otherwise processed into the final product by inducing long or short range ordering or bonding through chemical, thermal, electrical, shearing, or mechanical treatments.

Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the scope of the invention as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure of the present invention, processes, machines, manufacture, compositions of matter, means,

methods, or steps, presently existing or later to be developed, that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the present invention. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

It is contemplated that any embodiment discussed in this specification can be implemented with respect to any method, kit, reagent, or composition of the invention, and vice versa. Furthermore, compositions of the invention can be used to achieve methods of the invention.

It will be understood that particular embodiments described herein are shown by way of illustration and not as limitations of the invention. The principal features of this invention can be employed in various embodiments without departing from the scope of the invention. Those skilled in the art will recognize, or be able to ascertain using no more than routine experimentation, numerous equivalents to the specific procedures described herein. Such equivalents are considered to be within the scope of this invention and are covered by the claims.

All publications and patent applications mentioned in the specification are indicative of the level of skill of those skilled in the art to which this invention pertains.

The use of the word “a” or “an” when used in conjunction with the term “comprising” in the claims and/or the specification may mean “one,” but it is also consistent with the meaning of “one or more,” “at least one,” and “one or more than one.” The use of the term “or” in the claims is used to mean “and/or” unless explicitly indicated to refer to alternatives only or the alternatives are mutually exclusive, although the disclosure supports a definition that refers to only alternatives and “and/or.” Throughout this application, the term “about” is used to indicate that a value includes the inherent variation of error for the device, the method being employed to determine the value, or the variation that exists among the study subjects.

As used in this specification and claim(s), the words “comprising” (and any form of comprising, such as “comprise” and “comprises”), “having” (and any form of having, such as “have” and “has”), “including” (and any form of including, such as “includes” and “include”) or “containing” (and any form of containing, such as “contains” and “contain”) are inclusive or open-ended and do not exclude additional, unrecited elements or method steps. In embodiments of any of the compositions and methods provided herein, “comprising” may be replaced with “consisting essentially of” or “consisting of”. As used herein, the phrase “consisting essentially

of” requires the specified integer(s) or steps as well as those that do not materially affect the character or function of the claimed invention. As used herein, the term “consisting” is used to indicate the presence of the recited integer (e.g., a feature, an element, a characteristic, a property, a method/process step or a limitation) or group of integers (e.g., feature(s), element(s), characteristic(s), propertie(s), method/process steps or limitation(s)) only.

The term “or combinations thereof” as used herein refers to all permutations and combinations of the listed items preceding the term. For example, “A, B, C, or combinations thereof” is intended to include at least one of: A, B, C, AB, AC, BC, or ABC, and if order is important in a particular context, also BA, CA, CB, CBA, BCA, ACB, BAC, or CAB. Continuing with this example, expressly included are combinations that contain repeats of one or more item or term, such as BB, AAA, AB, BBC, AAABCCCC, CBBAAA, CABABB, and so forth. The skilled artisan will understand that typically there is no limit on the number of items or terms in any combination, unless otherwise apparent from the context.

As used herein, words of approximation such as, without limitation, “about”, “substantial” or “substantially” refers to a condition that when so modified is understood to not necessarily be absolute or perfect but would be considered close enough to those of ordinary skill in the art to warrant designating the condition as being present. The extent to which the description may vary will depend on how great a change can be instituted and still have one of ordinary skilled in the art recognize the modified feature as still having the required characteristics and capabilities of the unmodified feature. In general, but subject to the preceding discussion, a numerical value herein that is modified by a word of approximation such as “about” may vary from the stated value by at least $\pm 1, 2, 3, 4, 5, 6, 7, 10, 12$ or 15%.

All of the compositions and/or methods disclosed and claimed herein can be made and executed without undue experimentation in light of the present disclosure. While the compositions and methods of this invention have been described in terms of preferred embodiments, it will be apparent to those of skill in the art that variations may be applied to the compositions and/or methods and in the steps or in the sequence of steps of the method described herein without departing from the scope of the invention. All such similar substitutes and modifications apparent to those skilled in the art are deemed to be within the scope of the invention as defined by the appended claims. The scope of the claims should not be limited by the preferred embodiments set forth in the examples, but should be given the broadest interpretation consistent with the description as a whole.

What is claimed is:

1. A method of making a graphene suspension, comprising:
preparing graphene flakes with a surface area to thickness ratio greater than 300
Angstroms, and thickness of less than 160 Angstroms, by mechanically milling graphite and
5 exfoliating the graphite into graphene flakes in a stirred media mill, an attrition mill, an attritor
mill, or a ball mill without concentrated acid to produce oxidized graphene, wherein the graphene
flakes are planar, have no significant physical surface distortions or corrugations, have only edge
oxidation, and have a surface polarity;
preparing a polar or nonpolar fluid having the same polarity as said graphene flakes; and
10 suspending said graphene flakes in said fluid by mixing until the suspension is uniform.
2. The method of claim 1, wherein the suspension comprises a carbon allotrope.
3. The method of claim 1, wherein 95% of the flakes are from 0.8 to 16 nanometers in
thickness.
4. The method of claim 1, wherein 95% of the flakes have a surface area to thickness ratio of
15 a minimum of 300 Angstroms.
5. The method of claim 1, wherein a maximum dimension of the flakes is between 220
Angstroms and 100 microns.
6. The method of claim 1, wherein a bonding host is added and the flake surfaces have the
same polarity as the bonding host.
- 20 7. The method of claim 1, wherein the solvent is water.
8. A method of making a graphene suspension, comprising:
preparing graphene flakes with a surface area to thickness ratio greater than 300
Angstroms, and thickness of less than 160 Angstroms, by mechanically milling graphite and
exfoliating the graphite into graphene flakes in a stirred media mill, an attrition mill, an attritor
25 mill, or a ball mill without concentrated acid to produce oxidized graphene, wherein the graphene
flakes are planar, have no significant physical surface distortions or corrugations, have only edge
oxidation, and have a surface polarity; and
suspending said graphene flakes in a fluid by mixing until the suspension is uniform.
9. The method of claim 8, wherein 95% of the flakes are from 0.8 to 16 nanometers in
30 thickness.

10. The method of claim 8, wherein 95% of the flakes have a surface area to thickness ratio of a minimum of 300 Angstroms.

11. The method of claim 8, wherein a maximum dimension of the flakes is between 220 Angstroms and 100 microns.

5 12. The method of claim 8, wherein the solvent is water.

13. A graphene suspension made by a method comprising:

preparing graphene flakes with a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, by mechanically milling graphite and exfoliating the graphite into graphene flakes in a stirred media mill, an attrition mill, an attritor mill, or a ball mill without concentrated acid to produce oxidized graphene, wherein the graphene flakes are planar, have no significant physical surface distortions or corrugations, have only edge oxidation, and have a surface polarity;

preparing a polar or nonpolar fluid having the same polarity as said graphene flakes; and

suspending said graphene flakes in said fluid by mixing until the suspension is uniform.

15 14. The method of claim 13, wherein 95% of the flakes are from 0.8 to 16 nanometers in thickness.

15. The method of claim 13, wherein 95% of the flakes have a surface area to thickness ratio of a minimum of 300 Angstroms.

20 16. The method of claim 13, wherein a maximum dimension of the flakes is between 220 Angstroms and 100 microns.

17. A graphene suspension made by a method comprising:

preparing graphene flakes with a surface area to thickness ratio greater than 300 Angstroms, and thickness of less than 160 Angstroms, by mechanically milling graphite without concentrated acid and exfoliating the graphite into graphene flakes in a stirred media mill, an attrition mill, an attritor mill, or a ball mill without concentrated acid to produce oxidized graphene, wherein the graphene flakes are planar, have no significant physical surface distortions or corrugations, have only edge oxidation, and have a surface polarity; and

suspending said graphene flakes in a fluid by mixing until the suspension is uniform.

30 18. The method of claim 17, wherein 95% of the flakes are from 0.8 to 16 nanometers in thickness.

19. The method of claim 17, wherein 95% of the flakes have a surface area to thickness ratio of a minimum of 300 Angstroms.
20. The method of claim 17, wherein a maximum dimension of the flakes is between 220 Angstroms and 100 microns.