Title: IMPROVED EXPLOSIVE MATERIALS BY STABILIZATION IN NANOTUBES

Abstract: A nanotube containing an explosive compound, including a nanotube having an internal cavity defined by walls of the nanotube; and an explosive compound contained within the internal cavity of the nanotube and a method of forming the explosive compound containing nanotube. A process of providing energy to a predetermined location, including providing a nanotube at a predetermined location on a substrate, exposing the nanotube to an explosive compound; and detonating the explosive compound within the nanotube to release energy at the predetermined location. A process of stabilizing an explosive compound, including providing an explosive compound, in which the explosive compound has a first sensitivity to shock and/or friction; exposing a nanotube cavity to the explosive compound, so that the explosive compound enters the cavity; in which, in the cavity, the explosive compound has a second sensitivity to shock and/or friction reduced in relation to the first sensitivity.
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IMPROVED EXPLOSIVE MATERIALS BY STABILIZATION IN NANOTUBES

BACKGROUND

TECHNICAL FIELD

[0001] This invention relates to the field of explosives, and in particular to stabilization of explosive compounds by placing such compounds within the confines of nanotubes to make explosive nanotubes, and to the use of explosive nanotubes in novel applications.

DESCRIPTION OF RELATED ART

[0002] Fullerenes are spheroidal, closed-cage molecules consisting essentially of sp²-hybridized carbons typically arranged in hexagons and pentagons. Fullerenes, such as C₆₀, also known as Buckminsterfullerenes, more commonly, "buckyballs," and C₇₀, have been produced from vaporized carbon at high temperature. Carbon nanotubes, a discovery originating from work on fullerenes, were first disclosed by lijima et al., first in "Helical microtubules of graphitic carbon", NATURE, 354, 56 (1991) and later in "Single-shell carbon nanotubes of 1-nm diameter", NATURE, 363, 605-606 (1993). As reported by lijima et al. in the earlier NATURE article, graphitic carbon needles, ranging from 4 to 30 nm in diameter and up to 1 micrometer in length, were grown on the negative end of the carbon electrode used in the d.c. arc-discharge evaporation of carbon in an argon-filled vessel, at a pressure of 100 Torr. Nanotubes having from two to seven walls were reported by lijima et al. in this NATURE article. Since that time, single-wall as well as multi-wall tubular structures which may be open at both ends, or may be sealed at one or both ends, with a semifullerene dome forming the end seal, have been made. Both the single-walled carbon cylindrical structures, known as single-wall carbon nanotubes (SWCNTs) or more commonly, "buckytubes", and multi-walled carbon nanotubes (MWCNTs), have extraordinary properties, including both electrical and thermal conductivity and high strength. As used herein, the fullerene or buckyball, including multi-walled fullerenes, are included within the definition of nanotubes. Thus, any reference herein to nanotube, unless specifically directed to a particular form of nanotube, includes all of these forms.
Nanotubes, and in particular, carbon nanotubes, have been developed, in which single-walled varieties have an internal diameter ranging from 1 to about 100 nanometer (nm). Single-walled nanotubes (SWNTs) are composed of rolled sheets of sp² graphene carbon, and may be terminated at one end, both ends or neither end by a fullerenic carbon hemisphere. Thus, a nanotube may be considered, in essence, as an elongated fullerene. SWNTs form well-defined cylindrical cavities within a relatively limited range of diameters, when prepared by catalytic arc vaporization or laser ablation. Large quantities of SWNTs can be produced by a variety of catalyst-assisted decomposition techniques, such as by pyrolysis of carbon monoxide in the presence of iron and/or other catalysts.

Explosive materials are often unstable due to their very nature. Well known examples include, e.g., nitroglycerin, TATP and metal azides. In the past, these explosive materials have been stabilized by incorporation into an inert or less reactive carrier, e.g., of nitroglycerin into sawdust to make dynamite or by use of materials such as diatomaceous earth, such that the shock sensitivity of the explosive compound is suppressed. Additional examples of such stabilization include freezing or use with a solvent or inert carrier, such as a thermoplastic polymer. Such methods produce a relatively stable material, but it is still a bulk material, and known methods all include some problems and are not entirely successful. Furthermore, being a bulk material, there is little provision for use in a micro- or nano-environment.

A need exists for new methods of stabilizing explosive materials. In addition, a need exists for explosive materials that can be used in a micro- or nano-environment, and which can be used as well in bulk, as a more standard explosive material.

SUMMARY

According to an aspect of the invention, a nanotube having a cavity filled or partially filled with an explosive compound is provided. The explosive compound may be stabilized by its presence in the cavity of the nanotube. The explosive compound may have other characteristics altered by its presence in the nanotube, such as its crystal structure or other physical properties, as well as having its reactivity modified. The explosive-laden nanotube can be used to provide a small charge of energy to a selected or predetermined location, which location may be on
a micro- or nano-scale. Alternatively, the explosive-laden nanotubes can be used en masse to form a bulk explosive composition useful on a macro-scale, such as dynamite is conventionally used. As a further alternative, the explosive-laden nanotubes can be used by mixing with a mass of conventional explosive material and used as a detonation source, whereby when electromagnetic radiation such as microwave radiation is applied, the explosive nanotubes may be caused to detonate substantially simultaneously, there by allowing for substantially simultaneous detonation of the entire mass of conventional explosive material.

[0007] In one embodiment, the present invention includes a nanotube containing an explosive compound, including a nanotube having an internal cavity; and an explosive compound contained within the internal cavity of the nanotube. In one embodiment the nanotube is a single-walled carbon nanotube. In one embodiment, the nanotube of the present invention has an internal diameter ranging from about 1 nanometer (nm) to about 20 nm. In another embodiment, the internal diameter of the nanotube of the present invention is in the range from about 1 nm to about 15 nm, and in another embodiment, the internal diameter of the nanotube of the present invention is in the range from about 1 nm to about 10 nm, and in another embodiment, the internal diameter of the nanotube of the present invention is in the range from about 1 nm to about 5 nm. The nanotubes of the present invention may have a length of at least 20 microns, and may be as long as 100 microns, under presently known preparation methods.

[0008] In one embodiment, the nanotube of the present invention is a multi-walled nanotube, having any known number of wall layers, for example, ranging from 2 to about 10 or more. In a multi-walled nanotube, the explosive compound may be retained within the cavity in the innermost nanotube, or may be retained between any of the respective layers of the multi-walled nanotube. As will be understood, in multi-walled nanotubes, a range of internal diameters will be present, with the internal diameter of the innermost nanotube being in the foregoing ranges. Multi-walled nanotubes may be in the form of concentric cylinders, for example, a (0,8) single-walled nanotube within a larger (0,1 0) single-walled nanotube, and so on, for the total number of walls in the multi-walled nanotube. It is also possible for a multi-walled nanotube to resemble a single sheet of graphite rolled up around itself, resembling a scroll of parchment or a rolled up newspaper, in which there are
no concentric cylinders. The outside diameter of the multi-walled nanotube may have any known diameter, ranging up to about 150 nm or more, for example. As will be understood, the outside diameter of a multi-walled nanotube depends on the number of wall layers as well as the diameter of the outermost nanotube.

Since, as noted above, the fullerene (or buckyball) is a species of nanotube, the internal diameter of a fullerene generally will fall within the above-disclosed ranges. Like multi-walled nanotubes, fullerenes can be nested one inside another, with the innermost fullerene or one of the shells containing the explosive compound. In another embodiment, a fullerene or a nested fullerene can be nested inside a single- or multi-walled nanotube. Thus, in one embodiment, an explosive compound can be placed inside a fullerene (or a nested fullerene) and one or more such fullerenes (or nested fullerenes) can be nested inside a single- or multi-walled nanotube. In one embodiment, the fullerene can be nested inside a nanotube to act as an isolating agent or separator for providing separation of compounds which, when mixed together either react, e.g., to form an explosive compound or form a spontaneously exploding mixture (i.e., upon mixing the previously separated compounds react explosively) or combine to reach a critical amount or volume resulting in rupture of the nanotube and release of the compound(s).

In one embodiment, the explosive compound comprises one or more of a thacetone triperoxide, diacetone diperoxide, hexamethylene triperoxide diamine, a mononitrotoluene, a dinitrotoluene, a trinitrotoluene, ethylene glycol dinitrate, nitro methane, nitroglycerine, 1,3,5-trinitro-1,3,5-thazacyclooctane, 1,3,5,7-tetranitro-1,3,5,7-tetrazacyclooctane, pentaerythritol tetranitrate, 1,2,3-propanetriol trinitrate, aluminum metal + Fe$_2$O$_3$, aluminum metal + PTFE (e.g., nano-sized and stabilized), metal azides, e.g., XN$_3$, (where X = Na, Pb, Cu, Ag, for example, and mixtures thereof) ammonium nitrate (NH$_4$NO$_3$), polymorphic nitrogen, e.g., polymorphic nitrogen with cubic gauche structure (cg-N) and polynitrocubanes. Other known explosive compounds can be used in accordance with the present invention, the foregoing being examples only.

In one embodiment, the explosive compound is stabilized by its presence in the nanotube, as compared to the same compound outside the nanotube. In another embodiment, the explosive compound is rendered more reactive, that is, it is de-stabilized or activated by its presence in the nanotube, as
compared to the same compound outside the nanotube. Whether the compound is stabilized or de-stabilized depends upon which crystal morph is dictated by the confinement in the nanotube.

[0012] As used herein, an explosive compound is "stabilized" when its properties have been modified so as to render it one or more of less reactive, less friction sensitive, less shock sensitive or more controllably detonated. Thus, placement inside the nanotube may make the explosive compound both less reactive and less shock sensitive. Conversely, when an explosive compound is rendered more reactive by its placement in the nanotube, any one or more of these properties are increased. Thus, placement inside the nanotube may make the explosive compound both more reactive and more shock sensitive. In one embodiment, placement of the explosive compound in the nanotube may stabilize the compound with respect to a property while de-stabilizing the compound with respect to another property. Thus, in one embodiment, placement of the explosive compound in the nanotube renders the explosive compound less sensitive to shock and friction, while increasing its reactivity to a selected triggering mechanism. In another embodiment, placement of the explosive compound in the nanotube renders the explosive compound less sensitive to shock and friction, thus improving the ease and safety of handling, due to the decreased sensitivity obtained from confinement of the explosive compound in the nanotube.

[0013] In one embodiment, the present invention includes a process for forming an explosive nanotube, including providing a nanotube, in which the nanotube has an internal cavity; and exposing the nanotube to an explosive material, in which the explosive material enters the internal cavity, for example, by capillary action. The explosive material remains in the internal cavity following entry therein. The explosive material may be exposed to the nanotube as a vapor, a liquid, a solution or as a solid. In another embodiment, the explosive material may be provided in a solvent (e.g., at about room temperature), in a sublimation gas phase, or as a component of a super-critical material, such as carbon dioxide. The explosive material subsequently is retained in the nanotube, and subsequently can be detonated at a selected time.

[0014] In one embodiment, the process for forming a nanotube, when the nanotube is a multi-walled nanotube, further includes irradiating the filled nanotube
with electrons to shrink the nanotube diameter and change the crystal form of the material in the nanotube. This irradiation causes the multiple nanotube walls to shrink and thereby apply a high pressure to the material filling the multi-walled nanotube. The applied high pressure can cause the material in the nanotube to change its shape and in some embodiments to change its crystal form. This application of pressure can be used either to stabilize or de-stabilize the material in the nanotube.

[0015] In one embodiment, the process further includes detonating the explosive compound in the nanotube. In one embodiment, the detonating is by application of electron beam, electromagnetic radiation, heat or pressure, or heavy ion bombardment such as Ar or Hg ions or alpha, beta or gamma radiation from radioactive materials. In addition, other related disrupting mechanisms can be used to detonate the explosive compound, such as plasmons and/or phonons.

[0016] In one embodiment, the present invention includes a process of providing energy to a predetermined location, including providing a nanotube at a predetermined location on a substrate, in which the nanotube has an internal cavity; exposing the nanotube to an explosive material, wherein the explosive material enters the internal cavity; and detonating the explosive within the nanotube to release energy at the predetermined location. Thus, the present invention can be used to provide a very small, e.g., micro- or nano-scale, explosive force at a predetermined location, such as at a specific target site in a substrate, for any of a variety of desired purposes. Such purposes may include, for example, providing a predetermined quantity of energy at a selected site for causing a desired change, such as fusing a fusible link in a substrate such as a semiconductor device; or providing motive energy to cause a chemical reaction to take place on a micro- or nano-scale. In one embodiment, the substrate is a mass of conventional explosive material, and the explosive nanotube is distributed throughout the mass. Other uses will become apparent to those of skill in the art based on the disclosure herein, and such uses are contemplated within the scope of the present invention.

[0017] Thus, in one embodiment, the present invention provides a solution to the need for new methods of stabilizing explosive materials. In addition, the present invention provides a solution to the need for explosive materials that can be used in a micro- or nano-environment, which can be mixed with and used to control the
detonation of conventional explosive materials and which can be used as well in
bulk, similar to a more conventional explosive material.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] Fig. 1 is a schematic perspective view of an open-ended single-walled
nanotube.

[0019] Fig. 2 is a schematic perspective view of three single-walled nanotubes
depicting three different configurations or structures of exemplary nanotubes.

[0020] Fig. 3 is a schematic perspective view of a C\textsubscript{60} fullerene.

[0021] Fig. 4 is a schematic perspective view of a C\textsubscript{60} fullerene with a molecule
such as an explosive compound enclosed within the fullerene molecule, in
accordance with an embodiment of the invention.

[0022] Fig. 5 is a schematic cross-sectional depiction of a single-walled
nanotube containing an explosive compound within the cavity, in accordance with
an embodiment of the invention.

[0023] Fig. 6 is a schematic illustration of a nanotube containing two nanotubes,
labeled A and B, in accordance with an embodiment of the invention.

[0024] Fig. 7 is a schematic illustration of a nanotube containing fullerenes or
buckyballs, in which the fullerenes each contain one of compounds A, B and C, in
accordance with an embodiment of the invention.

[0025] Fig. 8 is a schematic illustration of a nanotube containing two fullerenes,
in which the fullerenes act as isolating agents providing separation between
compounds A and B, in accordance with an embodiment of the invention.

[0026] Fig. 9 is a schematic illustration of a method of filling nanotubes with an
explosive compound, in accordance with an embodiment of the invention.

[0027] Fig. 10 is a schematic illustration of a method such as that of Fig. 4,
showing more details of the nanotube and the method, in accordance with an
embodiment of the invention.

[0028] Fig. 11 is a schematic illustration of another method of filling nanotubes
with fullerenes or short nanotubes, each containing an explosive compound, in
accordance with an embodiment of the invention.

[0029] Fig. 12 is a schematic illustration of another method of filling nanotubes
with either nanotubes or fullerenes (buckyballs), through a defect in the wall of the
nanotube to be filled, in accordance with an embodiment of the invention.
[0030] Fig. 13 is a schematic illustration showing an effect of electron radiation in, e.g., a SEM, on a nanotube subjected to such electron radiation.

[0031] Fig. 14 is a schematic illustration of another embodiment of the present invention, in which a plurality of nanotubes containing an explosive compound within the cavity are contained within a macroscopic mass of conventional explosive material.

[0032] Fig. 15 is a graph of binding energy (BE) versus the distance between molecular components of an explosive compound.

[0033] It should be appreciated that for simplicity and clarity of illustration, elements shown in the Figures have not necessarily been drawn to scale. For example, the dimensions of some of the elements may be exaggerated relative to each other for clarity. Further, where considered appropriate, reference numerals may be repeated among the Figures to indicate corresponding elements.

DETAILED DESCRIPTION

[0034] In one embodiment, the present invention relates to nanotubes in which the cavity of the nanotube contains an explosive compound. The nanotube may be single-walled nanotube (SWNT) or a multi-walled nanotube (MWNT). The nanotube, in one embodiment, is a carbon nanotube ("CNT"). In one embodiment, the present invention relates to single-walled carbon nanotubes ("SWCNT"), and in another to multi-walled carbon nanotubes ("MWCNT"), containing an explosive compound in the cavity of the nanotube or, in one embodiment, between the walls of a MWCNT. Although the present invention relates primarily to carbon nanotubes, the teachings herein are considered broadly applicable to other known types of nanotubes, such as silicon or metals such as titanium.

[0035] In defining the size and conformation of single-wall carbon nanotubes, the system of nomenclature described by Dresselhaus et al., Science of Fullerenes and Carbon Nanotubes, 1996, San Diego: Academic Press, Ch. 19, will be used herein. Single-walled carbon nanotubes are distinguished from each other by a double index (n, m), where n and m are integers that describe how to cut a single strip of hexagonal graphite such that the side edges of the strip join seamlessly when the strip is wrapped onto the surface (into the shape) of a cylinder. When n=m, the resultant tube is said to be of the "arm-chair" or (n, n) type, since when the tube is cut perpendicularly to the tube axis, only the sides of the hexagons are exposed.
and their pattern around the periphery of the tube edge resembles the arm and seat of an arm chair repeated n times. When \( m=0 \), the resultant tube is said to be of the "zig zag" or \((n, 0)\) type, since when the tube is cut perpendicular to the tube axis, the edge is a zig zag pattern. Where \( n=m \) and \( m≠0 \), the resulting tube has chirality.

The electronic properties are dependent on the conformation, for example, arm-chair tubes are metallic and have extremely high electrical conductivity. Other tube types are metals, metallics, semi-metals, semi-conductors, or electrical insulators, depending on their conformation. Regardless of tube type, all single-wall nanotubes have extremely high thermal conductivity and tensile strength.

[0036] The nanotubes of the present invention may be prepared by any known method, and some are commercially available. A wide variety of methods have been devised for producing CNT since the early disclosures by Iijima et al., including "Helical microtubules of graphitic carbon", NATURE, 354, 56 (1991) and "Single-shell carbon nanotubes of 1-nm diameter", NATURE, 363, 605-606 (1993).

For example, a number of methods are mentioned in U.S. Patent No. 7,052,668, the disclosure of which relating to preparation of SWCNTs is incorporated herein by reference. SWCNT are commercially available presently in small commercial quantities. Various methods are known for synthesis of carbon nanotubes, and presently there are three main approaches. These include the laser ablation of carbon (Thess, A. et al., SCIENCE 273, 483 (1996)), the electric arc discharge of graphite rod (Journet, C. et al., NATURE 388,756 (1997)), and the chemical vapor deposition of hydrocarbons (Ivanov, V. et al., CHEM. PHYS. LETT. 223, 329 (1994); Li A. et al., SCIENCE 274, 1701 (1996)). The production of multi-walled carbon nanotubes by catalytic hydrocarbon cracking is conducted on a commercial scale (U.S. Pat. No. 5,578,543), while the production of single-walled carbon nanotubes was still in a gram scale (as of 1998) by laser (Rinzler, A. G. et al., APPL. PHYS. A. 67, 29 (1998)) and arc (Haffner, J. H. et al., CHEM. PHYS. LETT. 296, 195 (1998)) techniques. The nanotubes of the present invention may be prepared by any of the variety of techniques known in the art, assuming the proper purity and defect requirements can be met. Such defects include known nanotube defects, such as holes or openings in the nanotube wall or walls caused by one or more missing atoms. Such defects may be desirable, however, for use in inserting or inducing the entry of molecules, such as the explosive compounds of the present invention, into
the nanotube interior space. As known in the art, such defects can often be
removed by irradiation of the nanotubes and, in one embodiment, after the defect
has been used to insert or induce the entry of an explosive compound into the
nanotube, the defect is then closed or removed by irradiation of the thus-filled
nanotube.

[0037] In one embodiment, the nanotubes may be formed in a controlled pattern
of aligned SWCNTs on a solid substrate. In one embodiment, such a controlled
pattern of aligned or ordered array of SWCNTs may be formed on a solid substrate
by a method such as that disclosed by McLean, Robert S., et al., "Controlled Two-
Dimensional Pattern of Spontaneously Aligned Carbon Nanotubes", NANO

[0038] In one embodiment, the nanotubes may be formed in aligned or ordered
arrays with controlled density on a crystalline sapphire substrate. In one
embodiment, such aligned or ordered array of nanotubes may be formed by a
method such as that disclosed by Liu, Xiaolei, et al., "Novel Nanotube-on-Insulator
(NOI) Approach toward Single-Walled Carbon Nanotube Devices", NANO
LETTERS, Vol. 6, No. 1, pp. 34-39 (2006). This and the preceding publication
provide examples of processes for producing an ordered array of nanotubes.

[0039] In one embodiment, the nanotubes are formed directly on the target
substrate, i.e., in situ, by one of the foregoing or another known method. Thus, for
e.g., example, where a semiconductor device is to have the explosive nanotube of the
present invention deployed therein, at a selected location, a suitable site is selected,
the site may be activated and/or isolated for selection, and a suitable nanotube
production process applied, thereby to form one or more nanotube in the selected
location on the device. Thereafter, if the device is exposed to an explosive
compound by any of the methods disclosed herein, the explosive compound will
migrate into and be retained in the cavity of the nanotube, thus forming the
explosive compound-containing nanotube.

[0040] With reference to producing single-walled carbon nanotubes, it is noted
that in this disclosure and appended claims, "ex situ" production refers to production
of single-walled carbon nanotubes as a separate process from the formation of a
device or substrate with which the single-walled carbon nanotubes is subsequently
used, and "in situ" production refers to the production of single-walled carbon
nanotubes during the process of forming the device or substrate. The present invention is broadly applicable to both ex situ and in situ production of the nanotubes and provision of explosive compounds thereto for making the explosive compound-containing nanotubes.

[0041] In another embodiment, the nanotube(s) may be produced ex situ and subsequently transferred to a desired location in a device, or used for other purposes, such as in preparation of larger scale explosive devices. Examples of such larger scale devices include warheads on missiles and explosives for use in, e.g., mining, demolition and construction operations. In other embodiments, the explosive-containing nanotubes may be used in micro metal forming and other manufacturing such as in building MEMS (microelectromechanical system) devices.

[0042] In one embodiment, the nanotubes of the present invention are not derivatized or modified with pendant organic groups, oligomeric chains or polymeric chains. That is, the nanotubes in such embodiment are unmodified.

[0043] In another embodiment, the nanotubes of the present invention may be derivatized or modified by the presence of pendant organic groups, oligomeric chains or polymeric chains. As is known in the art, in some cases a defect in the nanotube outer wall may be in the form of a carboxylate group (-COO\(^-\)), which provides an anchor site for such pendant groups. For example, such pendant group may include a polyimine chain. Such groups may be added to modify the properties of the nanotubes, including properties such as solubility.

[0044] Once the nanotubes are formed, they may be optionally purified or similarly treated. For example, the nanotubes may be acid-washed and/or may be annealed. Annealing may be used to correct defects in the nanotube's structure.

[0045] The explosive compound may be provided to the nanotube by any appropriate method that results in the explosive compound entering the cavity of the nanotube. For example, the explosive compound may be provided or exposed to the nanotube cavity in the form of a vapor, a liquid, a solution, a solid or in a supercritical fluid. Ammonium nitrate may be easily placed in a nanotube cavity as a neat molten liquid because of its low melting point (169°C). Of course, any such exposure method must be carried out with extreme caution, due to the obviously dangerous explosive materials. Ammonium nitrate has several crystal morphs and which ones may form is limited by the diameter of the nanotube.
confinement in the proper crystal form can eliminate the known instability problems when ammonium nitrate is frozen and thawed repeatedly. In one embodiment, the proper crystal form, for ammonium nitrate, is the orthorhombic. The orthorhombic crystal form is the preferred crystal form for ammonium nitrate, absent water, which is easily absorbed by ammonium nitrate crystals. When ammonium nitrate is crystallized in the nanotube, the compound is protected from contamination. In one embodiment, when the ammonium nitrate is in the nanotube, there is one carbon atom for every two molecules of ammonium nitrate.

[0046] In exposing the explosive compound to the nanotube cavity, in one embodiment the compound is provided neat, that is, without solvent or other diluent. If there is no solvent or other diluent, then there is nothing present to compete with the explosive compound for the cavity of the nanotube. In another embodiment, a solvent may be used and the solvent may be removed from the nanotubes and/or nanotube cavities, leaving behind the explosive compound in the cavity, where the cavity was shared by both the solvent molecule and the explosive compound. This removal of the solvent may be accomplished, e.g., by simply evaporating the solvent (assuming the solvent is more volatile than the explosive compound) with for example, application of any needed heat or other energy sufficient to assist in the evaporation but not sufficient to result in the detonation of the explosive compound. In an embodiment in which the explosive compound is provided or exposed to the nanotube cavity as a component of a supercritical material, the same considerations apply as for a solvent, that the supercritical material can be removed from the nanotube cavity subsequent to entry of the explosive compound into the nanotube cavity. An example of providing or exposing the explosive compound to the nanotube cavity is provided below with the description of Figs. 9 and 10. In such case, the explosive compound may be vaporized, e.g., by sublimation or by sufficiently reducing the pressure in a closed chamber that the explosive compound vaporizes and can then be exposed to and enter the cavity of the nanotube. In the case of a solid, the explosive compound may be combined and mixed with the nanotubes to a degree sufficient to allow molecules of the explosive compound to migrate by capillary action, osmosis or diffusion into the cavity of the nanotube. In one embodiment, the explosive compound enters the internal cavity of the nanotube by capillary action. That is, for example, an individual molecule of an explosive
compound may be drawn into the internal cavity by capillary action. In another embodiment, an explosive compound together with another molecule, such as a solvent molecule, may be partially or fully drawn into the nanotube by capillary action, after which the solvent molecule is removed or escapes on its own. When capillary action is involved in moving the explosive compound into the nanotube, it is based on the same forces and interactions as in larger-scale capillary action, as when a liquid moves into a glass capillary.

[0047] Determination of how many nanotubes in an array have been filled, and the degree to which the nanotubes have been filled may be made, for example, by transmission electron microscopy (TEM) or atomic force microscopy (AFM) of the array of nanotubes or of individual nanotubes in other locations or on other substrates.

[0048] Fig. 1 is a schematic perspective view of a single-walled nanotube 100. In the nanotube 100 shown in Fig. 1, both ends 100a and 100b are open. Such a nanotube may have both ends open as shown, both ends closed, or one end open and one end closed. When closed, the ends of a single-walled carbon nanotube form, essentially, a hemisphere of a buckyball. That is, the closed end of a SWCNT appears the same as or similar to half of a buckyball, in which the second half is converted into the cylindrical tube of the nanotube.

[0049] Fig. 2 is a schematic perspective view of three single-walled nanotubes 200, 202 and 204 depicting three different conformations of the nanotube. The nanotube 200 is shown with one end closed and a second end 200a separated or cut from the remainder of the nanotube 202. The nanotube 200 is a (m,n) = (5,5) nanotube, and thus is an "arm-chair" type nanotube. The nanotube 202 is shown with one end closed and a second end 202a separated or cut from the remainder of the nanotube 202. The nanotube 202 is a (m,n) = (9,0) nanotube, and thus is a "zig-zag" type nanotube. The nanotube 204 is shown with one end closed and a second end 204a separated or cut from the remainder of the nanotube 204. The nanotube 204 is a (m,n) = (10,5) nanotube, and thus is a "chiral" type nanotube.

[0050] Fig. 3 is a schematic perspective view of a C_{60} fullerene. As is known, fullerenes are substantially spherical structures including a number of carbon atoms, generally ranging upward from C_{60} arranged in a series of pentagonal and hexagonal forms. As is known and will be recognized, a nanotube is simply an
extended form of a fullerene, with additional carbon atoms arranged between the hemispherical end caps, in which the end caps can be viewed as hemispheres of a fullerene "sphere".

[0051] Fig. 4 is a schematic perspective view of a C_{60} fullerene with a molecule, such as an explosive compound, enclosed within the fullerene molecule, in accordance with an embodiment of the invention.

[0052] Fig. 5 is a highly schematic cross-sectional depiction of an exemplary explosive compound-containing single-walled nanotube or fullerene 300. The explosive compound-containing single-walled nanotube 300 includes a SWNT 302 having a cavity 304 in which an explosive compound 306 is contained, in accordance with an embodiment of the invention. The cavity 304 is defined by a wall 308 of the nanotube. As shown in Fig. 5, in one exemplary embodiment, the cavity 304 of the SWNT 302 may have an internal diameter, defined by the wall 308, in the range from about 1 to about 20 nanometers (nm). The wall thickness of the SWNT 302 is about 0.4 nm, as is known in the art. Thus, the outside diameter of the SWNT 302 would be at least about 1.8 nm. In one embodiment, the outside diameter of the SWNT 302 may vary depending on whether an explosive compound is present in the cavity 304 and on the exact identity of the explosive compound 306. The explosive compound 306 is depicted highly schematically such that each "ball" or circle shown represents one or more atoms of the explosive compound 306. The explosive compound 306 may be any of the explosive compounds disclosed herein, or any other suitable explosive compound known in the art. It is noted that the exemplary internal diameter shown in Fig. 5 and disclosed in this example is merely exemplary, and that the internal diameter of the nanotubes in accordance with the present invention is not so limited and can be suitably selected based on the nature of the explosive molecule. The nature of the explosive molecule includes both physical and chemical properties of the explosive compound.

[0053] Fig. 6 is a schematic illustration of a nanotube containing two nanotubes, labeled A and B, in accordance with an embodiment of the invention. The embodiment illustrated in Fig. 6 includes closed-end nanotubes, but the nanotubes may also have open ends on one or both ends. The embodiment illustrated in Fig. 6 includes two nanotubes inside a larger nanotube, in which the enclosed
nanotubes contain compounds A and B, within the enclosed nanotubes. Compounds A and B may be the same or different, and may include, for example, two different explosive compounds, two compounds which can react together to form an explosive compound, two compounds, the first of which is an explosive compound and the second of which is a compound providing some other, non-explosive effect, such as a chemical agent to be dispersed by the explosive compound in the first enclosed nanotube. As will be recognized, a great variety of combinations are possible, including not only two different compounds having similar or different properties, but also higher numbers of compounds, each of which may have similar or different properties, which may act to modulate the properties of each other. The foregoing is applicable not only to the embodiment illustrated in Fig. 6, but to all of the embodiments of the present invention in which more than one explosive or combination of an explosive compound and another compound can be provided within one or more nanotubes (that is, including single- and multi-walled fullerenes and single- and multi-walled nanotubes) used in one or more of the disclosed combinations.

[0054] Fig. 7 is a schematic illustration of a nanotube containing fullerenes (or buckyballs), in which the fullerenes each contain one of compounds A, B and C, in accordance with an embodiment of the invention. In this embodiment, as will be recognized, each compound A, B, C, is enclosed within a single fullerene molecule, and a combination of such filled fullerenes have been placed within a nanotube. As with the other embodiments described, the compounds A, B, C may be the same as or different from each other, and may have a variety of properties, as long as at least one has explosive properties.

[0055] Fig. 8 is a schematic illustration of a nanotube containing two fullerenes, in which the fullerenes act as isolating agents providing separation between compounds A and B, in accordance with an embodiment of the invention. In the embodiment illustrated in Fig. 8, the fullerenes are used as isolating agents to separate the compounds A and B from each other. In this embodiment, A and B may be the same as or different from each other, and may be, for example, two different compounds, potentially reactive with each other, or may be an explosive compound and another compound, as described with respect to other embodiments of the present invention. In the illustrated embodiment, the fullerenes
contained within the nanotube have an outside diameter approximately equal to the inside diameter of the nanotube in which they are contained. This is merely illustrative. The fullerenes may have any diameter, consistent with their desired function. For example, as long as the outer diameter provides a size of the fullerene sufficient to act as an isolation agent, the outer diameter can be less than the inside diameter of the nanotube with which it is used. In another embodiment, as described below, the fullerene may initially have an outside diameter less than the inner diameter of the nanotube in which it is placed, but the nanotube may be subsequently treated, e.g., by irradiation, to shrink the size of the nanotube so that its inside diameter becomes closer to or substantially the same as the outer diameter of the fullerene contained within the nanotube.

[0056] Fig. 9 is a schematic illustration of a system 400 and a method of filling nanotubes with an explosive compound, in accordance with an embodiment of the invention. As illustrated in Fig. 9, the system 400 includes an array 402 holding a plurality of nanotubes, a chamber 404 having therein an explosive compound 406, such as triacetone-triperoxide ("TATP", sometimes informally referred to simply as acetone peroxide), a valve 408 for controlling access of the explosive compound to the nanotubes, and a connection 410 to a vacuum pump. The valve 408 allows the chamber 404 to be isolated from the outside environment, and allows the user to provide the nanotubes 402 and subsequently to remove filled nanotubes when the process has been completed. The connection 410 to vacuum, e.g., to a vacuum pump, provides the capability of adjusting the pressure in the chamber 404, so as to induce the explosive compound 406 to form a vapor 406a of the explosive compound. The vapor 406a of the explosive compound can diffuse into the cavity of the nanotubes in the array 402. The array 402, in one embodiment, includes a plurality of aligned SWCNTs. In another embodiment, the array 402 includes one or more substrate upon which one or more SWCNTs have been placed in selected or predetermined locations.

[0057] Although not shown in Fig. 9, the system 400 may further include an energy source, such as a heat source, for applying energy to the container 404 to assist in vaporization of the explosive compound 406.

[0058] Fig. 10 is a schematic illustration of a method such as that of Fig. 4, showing more details of one of the plurality of nanotubes and of the method of filling
nanotubes with an explosive compound, in accordance with an embodiment of the invention. As shown in Fig. 10, the array 402 has a nanotube 302 (other nanotubes which also may be present are not shown) disposed thereon which will be exposed to vapors 406a of the explosive compound. As shown, the vapors 406a enter the cavity within the nanotube 302, and remain there, as shown, e.g., in Fig. 5.

[0059] Fig. 11 is a schematic illustration of another method of filling nanotubes with fullerenes or short nanotubes, each containing an explosive compound, in accordance with an embodiment of the invention. In this embodiment, a liquid is drawn into a larger diameter nanotube by capillary action. The liquid drawn into the larger nanotube may be a solution or suspension or other mixture of explosive compound in a solvent or carrier medium, or containing primarily a liquid explosive material, or being a suspension or other mixture of fullerenes and/or relatively short nanotubes, some or all of which fullerenes or short nanotubes contain explosive compounds. In the illustrated embodiment, each fullerene or short nanotube can contain compounds A and B (or in another embodiment, additional compounds, C, etc.), in which compounds A and B (and any additional) may have the properties described above, such as being the same or different, reactive, modulating, etc. In other embodiments, other combinations may be used.

[0060] Fig. 12 is a schematic illustration of another method of filling nanotubes with either nanotubes or fullerenes (buckyballs), through a defect in the wall of the nanotube to be filled, in accordance with an embodiment of the invention. In this embodiment, the larger nanotube may draw explosive compounds, fullerenes and/or relatively small nanotubes into its interior through defects in the wall or walls of the larger nanotube. The explosive compound, fullerenes or short nanotubes may contain the same mixtures or combinations as described above, e.g., with respect to the embodiment of Fig. 11, or other embodiments.

[0061] Fig. 13 is a schematic illustration showing an effect of electron radiation in, e.g., a SEM, on a nanotube subjected to such electron radiation. The electron beam is capable of annealing defects and causing shrinkage of the outer nanotube. This shrinkage can cause pressure to be applied to inner nanotubes, explosive-containing nanotube or fullerene within the cavity of the larger nanotube, and/or to explosive compounds contained within the larger nanotube. The applied pressure can result in substantial changes in the structure, e.g., crystal structure, of the
explosive compound contained within the nanotube. Such changes in structure may result in changes in the chemical properties of the contained compounds. Such irradiation can also be used to close or "heal" the defects in a nanotube such as that shown above in Fig. 12, following the filling of the nanotube with one or more of explosive compound, fullerene or relatively short nanotube.

[0062] In one embodiment, the process further includes detonating the explosive compound in the nanotube. The detonating may be, for example, by application of electron beam, electromagnetic radiation, heat or pressure, or heavy ion bombardment such as Ar or Hg ions or alpha, beta or gamma radiation from radioactive materials. In addition, other related disrupting mechanisms can be used to detonate the explosive compound, such as plasmons and/or phonons. Each of these detonating methods may be applied to the explosive nanotubes using methods and apparatus known in the art.

[0063] In one embodiment, the explosive nanotube of the present invention can be used, for example, in an ordered array in the explosive portion of a shaped charge device. In one embodiment, a plurality of the nanotubes containing an explosive compound are arranged in an ordered array. Thus, the ordered array of nanotubes would be formed as described above, then would be filled as described herein, and the shaped charge device thus formed can be placed in, for example, a semiconductor or other device. The shaped charge can be detonated when desired, and upon detonation would form a hole or a cavity in the substrate against which the explosive force is applied. The size and shape of the shaped charge can be suitably determined based on the size and shape of the desired hole or cavity and on the nature of the substrate material. The substrate may be, for example, a portion of a semiconductor device, MEMS device, or any other nano- or micro-scale structure to which the explosive force may be desirably applied. The substrate may include, for example, additional system elements such as transistors, resistors, capacitors and various other electrical or electronic components, as part of the total device. The total device may be, for example, any electronic device such as a computer processor, a printed circuit board or any of a variety of specific devices utilizing such components. The device for detonating the ordered array of nanotubes may include, for example, command and control elements, which may include, for example, a detonator control, and internal command signal source, and
an internal situation monitor. The command and control elements may be arranged
to be activated by an external command signal, for example, as known in the art.

[0064] In one embodiment, a nano-explosive trigger system may be included,
such as the foregoing, which may be electrically actuated. In other embodiments,
the trigger mechanism may be activated by application of an external signal directly
to a trigger mechanism adapted to detonate the explosive directly, without use of a
switch and/or without an electrical power supply.

[0065] In another embodiment, a trigger mechanism may be provided in which
an alternate source of energy, such as electromagnetic energy of a selected
frequency (such as, for example, microwave radiation), an electron beam, thermal
energy, or other heavy ion or particle mechanisms, such as those mentioned
hereinabove, is used to detonate the explosive compound 306 in the explosive
compound-containing nanotube. In such an embodiment, the trigger mechanism
may include a component sensitive to such energy and capable of generating
and/or transmitting to the explosive compound an electrical charge sufficient to
detonate the explosive compound. In another such embodiment, the trigger
mechanism 606 may be replaced by a source of electromagnetic energy which is
itself sufficient to provide the energy needed to detonate the explosive compound.

[0066] In one embodiment, one of two relatively simple trigger mechanisms may
be used. The first of these is by resistive heating. The destruction of a CNT
through resistive heating may be carried out, e.g., in an electrical circuit in a device
such as a semiconductor device. The second of these is by application of an
electron beam. An electron beam, e.g., from a scanning electron microscope, may
be used to initiate a chemical reaction inside a CNT, for example, to detonate the
explosive. Some nanotubes are excellent electron field-emission devices and can
generate very hot nano-spots. These two relatively simple mechanisms should
supply enough energy to initiate a chemical reaction, i.e., to detonate the explosive
compound in the nanotube. Photo activation presents a further trigger method, e.g.,
by application of laser light to selected, target explosive-compound-containing
nanotubes. In one embodiment, an array of nanotubes may be detonated in a chain
reaction by triggering the explosion of one or more, which may generate sufficient
energy to detonate neighboring nanotubes, which in turn release sufficient energy to
detonate neighboring nanotubes, etc. In another embodiment, an array of
nanotubes may be detonated substantially simultaneously by triggering the explosion of many (but less than all) of the nanotubes by applying the triggering energy to the array as a whole in a single action.

[0067] In one embodiment, the explosive nanotubes of the present invention may be incorporated into the explosive portion of a nano-sized shaped charge device. Thus, the individual nanotubes, in an ordered array appropriately aligned and situated in the shaped charge device, can add an extra measure of control to the use of such a shaped charge device. Not only is the explosive force directed to a selected target by virtue of the shaped charge device itself, but by appropriate location and alignment of the explosive nanotubes of the present invention in the explosive portion of the shaped charge device, one can obtain an additional measure of control of accuracy and preciseness of the explosive force obtained from the shaped charge device.

[0068] Fig. 14. is a schematic illustration of another embodiment of the present invention, in which a plurality of nanotubes containing an explosive compound within the cavity are contained within a macroscopic mass of conventional explosive material. Thus, in one embodiment, the present invention includes a mass of conventional explosive containing a plurality of the explosive nanotubes. In one embodiment, a process in accordance with the present invention further includes combining a plurality of the explosive nanotubes with a mass of conventional explosive material. As suggested by Fig. 15, in one embodiment, the plurality of explosive nanotubes are substantially uniformly distributed in at least a portion, and preferably, throughout the entire mass, of the conventional explosive material. In another embodiment, the plurality of explosive nanotubes are distributed in at least a portion of the macroscopic mass of conventional explosive material. Thus, the explosive nanotubes may be distributed substantially uniformly throughout the mass, or may be distributed in a selected pattern in the mass. For example, if it is desired to control or adjust the direction of force generated by detonation of the mass of conventional explosive, the explosive nanotubes may be distributed in selected portions of the mass.

[0069] In one embodiment, microwave energy may be applied to the combined nanotubes and mass of conventional explosive, to initiate detonation of the explosive nanotubes and the explosive material. While other forms of
electromagnetic energy may also be used, microwaves are well absorbed by nanotubes and provide a relatively simple means for detonating the explosive nanotubes and thereby the mass of conventional explosive material. One of the benefits obtained by using such energy to detonate the explosive nanotubes is that the electromagnetic energy, e.g., microwave energy, initiates substantially simultaneous detonation of substantially all of the explosive nanotubes. As depicted in Fig. 15, the triggering signal, an electromagnetic wave, e.g., microwave radiation, travels through the material at or near the speed of light, rather than at the slower speed of a shock wave as in a conventional explosive. Thus, the entire mass can be caused to detonate substantially simultaneously.

[0070] Stabilization

[0071] In one embodiment, the nanotube is used to stabilize the explosive compound. Although not to be bound by theory, it is believed that the explosive molecule is held in the cavity of the nanotube by van der Waals forces between the atoms of the explosive compound and the atoms of the nanotube wall. This van der Waals interaction is believed to result in the stabilization of the explosive compound, relative to the same compound not in a nanotube cavity.

[0072] There are three basic methods of stabilization inside the nanotube. One is isolation, such as where the molecule is prevented from interacting with an external molecule like oxygen. The second is a modification of molecular binding energy of the explosive molecule itself by interaction with the tube walls, such that the explosive molecule is less likely to change state. The third is a geometric confinement process where the molecule cannot rotate to the right angle to interact with an adjacent molecule or atom within the explosive molecule.

[0073] In one embodiment, the explosive compound is stabilized by the proximity of the walls of the nanotube and the fact that the explosive compound is separated from the general environment by the nanotube. Thus, in one embodiment, the explosive compounds under consideration can be controlled and the properties enhanced by the nano-confinement boundary mechanism of the nanotube. Aluminum (Al) metal and TATP provide examples. Nano-sized grains of Al have very useful explosive properties when mixed and reacted with oxygen on the nanoscale, while TATP is unstable at room temperature. Aluminum nano-sized particles can be explosive when oxygen is available. Placing the aluminum particles in a
nanotube should exclude the oxygen and thereby protect the aluminum nano-sized particles from detonating prematurely. When such aluminum-loaded nanotubes are to be detonated, an overpressure or concentrated form of oxygen can be provided, resulting in reaction between the aluminum particles and the oxygen and detonation. Powerful and inexpensively made from acetone and hydrogen peroxide, TATP’s lack of nitrogen renders it a possible stealth explosive candidate which, when placed in a carbon nanotube, would be difficult to detect. Several properties of TATP suggest it can be loaded into a nanotube by various methods, including the use of: a room temperature solvent, a sublimation gas phase, and super critical carbon dioxide. An example is provided below in which TATP is provided or exposed to nanotubes in a vapor or sublimed state. Based on the size of the TATP molecule and the 1-2 nm size of the cavity of a nanotube, the TATP will be stabilized by its presence in the nanotube.

Fig. 15 is a graph of binding energy (BE) versus the distance between molecular components of an explosive compound. Molecular dynamic codes (MDC) can be used to calculate the binding energy (BE) of molecules such as TATP. The BE is a basic parameter to use for a measure of the stability of a molecule. The BE of an explosive compound such as TATP in bulk form can be compared to the BE calculated for the same compound in the confining environments of various nanotubes. Different diameters and symmetries may be used to show the BE is increased for some configurations of explosive molecule and nanotube or fullerene and decreased for some configurations of explosive molecule and nanotube or fullerene. This is particularly expected for explosive reactions that involve materials such as TATP and metal azides that essentially just fall apart into simple gaseous components as they explode. Other explosive materials recombine in complex steps with self contained oxidizers, but it is expected that these explosive compounds will also be stabilized by being in the cavity of a nanotube. For example, in the cavity of a nanotube, due to the small size, essentially only one molecule may be present at a given location, and thus the oxidizer within the molecule may be isolated from a site at which it can react. In another view, the explosive compound may be stabilized simply due to its isolation from other molecules of its own kind as well as being isolated from the effects of shock and friction, again due to its isolation.
In the graph shown in Fig. 15, the middle curve is an exemplary explosive compound, when not confined within a nanotube - that is, the bulk explosive material. The upper curve is an explosive compound inside tube in an embodiment when the confinement renders the explosive compound less stable. The lower curve is for the explosive compound when confined within a nanotube in an embodiment in which the explosive compound is rendered more stable (stabilized) by being inside the nanotube. As noted above, in some embodiments, putting an explosive compound inside a nanotube can reduce its stability.

Thus, in one embodiment, the present invention further provides a process of stabilizing an explosive compound, including providing an explosive compound, wherein the explosive compound has a first sensitivity to shock and/or friction; providing a nanotube having an internal cavity defined by walls of the nanotube; exposing the nanotube to the explosive compound, wherein the explosive compound enters the internal cavity; wherein in the cavity the explosive compound has a second sensitivity to shock and/or friction, and the second sensitivity is reduced in relation to the first sensitivity.

As used throughout this disclosure and the appended claims, reference to a nanotube is deemed to include open-ended nanotubes, nanotubes in which one or both ends are closed, and fullerenes. Thus, unless and except where specifically directed to a particular one of these structures, reference to a nanotube includes all of these structures.

Although the invention has been shown and described with respect to certain embodiments, equivalent alterations and modifications will occur to others skilled in the art upon reading and understanding this specification and the annexed drawings. In particular regard to the various functions performed by the above described integers (components, assemblies, devices, compositions, steps, etc.), the terms (including a reference to a "means") used to describe such integers are intended to correspond, unless otherwise indicated, to any integer which performs the specified function of the described integer (i.e., that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein illustrated exemplary embodiment or embodiments of the invention. In addition, while a particular feature of the invention may have been described above with respect to only one of several illustrated embodiments, such
feature may be combined with one or more other features of the other embodiments, as maybe desired and advantageous for any given or particular application. Thus, the invention is considered to include all embodiments that would be obtained if all of the claims were in multiple dependent format and dependent upon every other claim, whether preceding or following. Therefore, it is to be understood that the invention disclosed herein is intended to cover such modifications as fall within the scope of the appended claims.
CLAIMS

What is claimed is:

1. A nanotube containing an explosive compound, comprising:
a nanotube having an internal cavity defined by a wall of the nanotube; and
an explosive compound contained within the internal cavity of the nanotube.

2. The nanotube of claim 1 wherein the nanotube is a single-walled nanotube.

3. The nanotube of claim 1 wherein the internal cavity comprises an inside diameter ranging from about 1 nanometer to about 20 nanometers.

4. The nanotube of claim 1 wherein the explosive compound comprises one or more of a thacetone triperoxide, diacetone diperoxide, hexamethylene triperoxide diamine, a mononitrotoluene, a dinitrotoluene, a trinitrotoluene, ethylene glycol dinitrate, nitro methane, nitroglycerine, 1,3,5-trinitro-1,3,5-triazacyclooctane, 1,3,5,7-tetranitro-1,3,5,7-tetraazacyclooctane, pentaerythhtol tetranitrate, ammonium nitrate, 1,2,3-propanetriat nitrate, metal azides, polymorphic nitrogen and polynitrocubanes.

5. The nanotube of claim 1 wherein the explosive compound is stabilized as a result of its containment in the internal cavity of the nanotube.

6. The nanotube of claim 1 wherein the nanotube containing an explosive compound is itself contained within a larger nanotube.

7. The nanotube of claim 1 wherein a plurality of the nanotubes containing an explosive compound are arranged in an ordered array.

8. A macroscopic mass of conventional explosive material comprising a plurality of the explosive nanotubes of claim 1 distributed in at least a portion of the macroscopic mass.
9. A process for forming an explosive nanotube, comprising providing a nanotube, said nanotube having an internal cavity defined by a wall of the nanotube; exposing said nanotube to an explosive compound, wherein the explosive compound enters the internal cavity.

10. The process of claim 9 wherein the explosive compound remains in the internal cavity following entry therein.

11. The process of claim 9 wherein the exposing comprises exposing the explosive compound to the nanotube as a vapor, a liquid, a solution, a solid or in a super-critical fluid.

12. The process of claim 9 further comprising irradiating the nanotube with electrons after filling.

13. The process of claim 12 wherein, when the nanotube is a multiwalled nanotube, the irradiation shrinks the nanotube diameter and changes the crystal form of the material in the nanotube.

14. The process of claim 9 further comprising placing the nanotube in a selected location on a substrate.

15. The process of claim 9 further comprising detonating the explosive compound within the nanotube.

16. The process of claim 15 wherein the detonating is by application of electric current, electron beam, electromagnetic radiation, heat, pressure, heavy ion beam, alpha, beta or gamma rays, plasmons and/or phonons.

17. The process of claim 9 further comprising placing the nanotube containing an explosive compound within a larger nanotube.
18. The process of claim 9 wherein the providing comprises arranging a plurality of the nanotubes in an ordered array.

19. The process of claim 9 further comprising combining a plurality of the explosive nanotubes with a mass of conventional explosive material.

20. The process of claim 19 wherein the plurality of explosive nanotubes are substantially uniformly distributed in at least a portion of the conventional explosive material.

21. The process of claim 19 further comprising applying microwave energy to the combined nanotubes and mass of conventional explosive, to initiate detonation of the explosive nanotubes and the explosive material.

22. The process of claim 21 wherein the microwave energy initiates substantially simultaneous detonation of substantially all of the explosive nanotubes.

23. A process of providing energy to a predetermined location, comprising:
   providing a nanotube at a predetermined location on a substrate, said nanotube having an internal cavity defined by a wall of the nanotube;
   exposing said nanotube to an explosive compound, wherein the explosive material enters the internal cavity; and
   detonating the explosive compound within the nanotube to release energy at the predetermined location.

24. The process of claim 23 wherein the nanotube is a single-walled nanotube.

25. The process of claim 23 wherein the explosive compound comprises one or more of a thacetone triperoxide, diacetone diperoxide, hexamethylene triperoxide diamine, a mononitrotoluene, a dinitrotoluene, a trinitrotoluene, ethylene glycol dinitrate, nitro methane, nitroglycerine, 1,3,5-trinitro-1,3,5-triazacyclooctane,
1,3,5,7-tetratnitro-1,3,5,7-tetraazacyclooctane, pentaerythritol tetranitrate, ammonium nitrate, 1,2,3-propanetrial trinitrate, metal azides, polymorphic nitrogen and polynitrocubanes.

26. The process of claim 23 wherein the explosive compound is stabilized as a result of its containment in the internal cavity of the nanotube.

27. The process of claim 23 further comprising placing the nanotube containing an explosive compound within a larger nanotube.

28. The process of claim 23 wherein the providing comprises arranging a plurality of the nanotubes in an ordered array.

29. The process of claim 28 wherein the ordered array is a component of a shaped charge explosive device.

30. The process of claim 23 wherein the substrate is a mass of conventional explosive material, and the step of exposing is carried out prior to the step of providing the nanotube on the substrate, and the step of providing comprises distributing the nanotubes throughout the mass.

31. A process of stabilizing an explosive compound, comprising:

  providing an explosive compound, wherein the explosive compound has a first sensitivity to shock and/or friction;
  providing a nanotube having an internal cavity defined by a wall of the nanotube;
  exposing the nanotube to the explosive compound, wherein the explosive compound enters the internal cavity;
  wherein in the cavity the explosive compound has a second sensitivity to shock and/or friction, and the second sensitivity is reduced in relation to the first sensitivity.
32. The process of claim 31 wherein the nanotube is a single-walled nanotube.

33. The process of claim 31 wherein the explosive compound comprises one or more of a thacetone triperoxide, diacetone diperoxide, hexamethylene triperoxide diamine, a mononitrotoluene, a dinitrotoluene, a trinitrotoluene, ethylene glycol dinitrate, nitro methane, nitroglycerine, 1,3,5-trinitro-1,3,5-triazacyclooctane, 1,3,5,7-tetranitro-1,3,5,7-tetraazacyclooctane, pentaerythrtol tetranitrate, ammonium nitrate, 1,2,3-propanetriol trinitrate, metal azides, polymorphic nitrogen and polynitrocubanes.

34. The process of claim 31 further comprising placing the nanotube containing an explosive compound within a larger nanotube.

35. The process of claim 31 wherein the providing comprises arranging a plurality of the nanotubes in an ordered array.

36. The process of claim 35 wherein the ordered array is a component of a shaped charge explosive device.
Defect in wall of NT

NT or Buckyball

NT

Liquid suspension or solution

Fig. 11

Fig. 12
Distance between molecular components of explosive compound such as TATP

Fig. 15