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(54) **FABRICATION OF LIGHT EMITTING FILM COATED FULLERENES AND THEIR APPLICATION FOR IN-VIVO LIGHT EMISSION**

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(52) **U.S. Cl.** ..... **252/506; 252/500; 252/502; 252/510; 252/507; 252/509; 977/700; 977/734; 977/737; 977/742**

(58) **Field of Classification Search** ..... **252/500; 252/502; 506; 507; 509; 510; 977/700; 734; 977/737; 742**

See application file for complete search history.

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(57) **ABSTRACT**

A nanoparticle coated with a semiconducting material and a method for making the same. In one embodiment, the method comprises making a semiconductor coated nanoparticle comprising a layer of at least one semiconducting material covering at least a portion of at least one surface of a nanoparticle, comprising: (A) dispersing the nanoparticle under suitable conditions to provide a dispersed nanoparticle; and (B) depositing at least one semiconducting material under suitable conditions onto at least one surface of the dispersed nanoparticle to produce the semiconductor coated nanoparticle. In other embodiments, the nanoparticle comprises a fullerene. Further embodiments include the semiconducting material comprising CdS or CdSe.

**19 Claims, No Drawings**

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**FABRICATION OF LIGHT EMITTING FILM  
COATED FULLERENES AND THEIR  
APPLICATION FOR IN-VIVO LIGHT  
EMISSION**

**CROSS-REFERENCE TO RELATED  
APPLICATIONS**

This is a Continuation Application of U.S. patent applica-  
tion Ser. No. 10/534,452, filed Nov. 1, 2005, now U.S. Pat.  
No. 7,253,014, entitled "Fabrication of Light Emitting Film  
Coated Fullerenes and Their Application for In-Vivo Light  
Emission," which was a filing under 35 U.S.C. 371 of Inter-  
national Application No. PCT/US2003/037188 filed Nov. 19,  
2003, claiming priority of the benefit of U.S. Provisional  
Application Ser. No. 60/427,533 filed Nov. 19, 2002, all of  
which applications having the same title are hereby incorpo-  
rated by reference herein in their entirety.

**STATEMENT REGARDING FEDERALLY  
SPONSORED RESEARCH OR DEVELOPMENT**

Not applicable.

**BACKGROUND OF THE INVENTION**

**1. Field of the Invention**

This invention relates to the field of fullerenes and more  
specifically to the field of coating fullerenes with coatings  
capable of emitting and/or absorbing light.

**2. Background of the Invention**

Nanoparticles have been increasingly studied due to their  
physical and chemical properties. One such property is the  
ability of some nanoparticles to emit light. For instance, CdS  
nanoparticles have been used on photoconducting materials  
to increase photoconductivity and also to produce light emit-  
ters. Typically, photoluminescence of quantum dots of nano-  
particles is accomplished by irradiating the quantum dot with  
light of a frequency that results in emission of light at a  
different, lower frequency. The nanoparticle quantum dots  
are typically incorporated into structures such as diodes to  
enhance the photoluminescence of the structures. Such struc-  
tures are typically much larger than nanoparticle size. The  
nanoparticles are usually coated on the structures by a sol-gel  
type reaction.

A drawback to photoluminescence of semiconductor dots  
is that the emitted light is typically not polarized. For  
instance, the aspect ratio of light emitted from the quantum  
dot is typically too low for polarization. Further drawbacks  
include the size of the coated structures. For instance, the size  
of the coated structures may be too large for applications on  
the nano-scale such as the in-vivo environment. Other draw-  
backs include the long reaction times typically involved with  
the sol-gel type reactions

Consequently, there is a need for a more efficient process  
for coating light emitting and/or absorbing semiconductor  
materials on structures. Other needs include an improved  
process for illuminating the semiconductor materials. Addi-  
tional needs include a process for coating light emitting and/  
or absorbing semiconductor materials on structures that can  
be used for applications on the nano-scale.

**BRIEF SUMMARY OF SOME OF THE  
PREFERRED EMBODIMENTS**

These and other needs in the art are addressed in one  
embodiment by a method of making a semiconductor coated

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nanoparticle comprising a layer of at least one semiconduct-  
ing material covering at least a portion of at least one surface  
of a nanoparticle, comprising dispersing the nanoparticle  
under suitable conditions to provide a dispersed nanoparticle;  
and depositing at least one semiconducting material under  
suitable conditions onto at least one surface of the dispersed  
nanoparticle to produce the semiconductor coated nanopar-  
ticle.

In another embodiment, the present invention includes a  
semiconductor coated nanoparticle comprising a nanopar-  
ticle; and a semiconductor coating, wherein the semiconduc-  
tor coating coats at least a portion of the nanoparticle.

In other embodiments, the nanoparticle comprises a  
fullerene. Additional embodiments include the semiconduc-  
tor material comprising CdS or CdSe.

It will therefore be seen that a technical advantage of the  
present invention includes an improved method for coating  
nanoparticles capable of emitting light on structures that  
overcomes the problem of size of the structures as well as  
allowing non-spherical shapes to be coated by the use of  
non-spherical nanoparticle substrates. Further advantages  
include faster reaction times than the typical sol-gel process.

The foregoing has outlined rather broadly the features and  
technical advantages of the present invention in order that the  
detailed description of the invention that follows may be  
better understood. Additional features and advantages of the  
invention will be described hereinafter that form the subject  
of the claims of the invention. It should be appreciated by  
those skilled in the art that the conception and the specific  
embodiments disclosed may be readily utilized as a basis for  
modifying or designing other structures for carrying out the  
same purposes of the present invention. It should also be  
realized by those skilled in the art that such equivalent con-  
structions do not depart from the spirit and scope of the  
invention as set forth in the appended claims.

**DETAILED DESCRIPTION OF THE PREFERRED  
EMBODIMENTS**

It has been discovered that semiconducting material  
capable of emitting and/or absorbing light can be coated on  
nanoparticle substrates. The present invention provides a  
method of making a semiconductor coated nanoparticle com-  
prising a layer of at least one semiconducting material cover-  
ing at least a portion of at least one surface of a nanoparticle,  
comprising dispersing the nanoparticle under suitable condi-  
tions to provide a dispersed nanoparticle; and depositing at  
least one semiconducting material under suitable conditions  
onto at least one surface of the dispersed nanoparticle to  
produce the semiconductor coated nanoparticle. The present  
invention also provides for a nanoparticle substrate coated  
with a semiconducting material, with the semiconducting  
material preferably capable of emitting light. At least a por-  
tion of the surface of the nanoparticle substrate can be coated  
with the semiconducting material, preferably all of the sur-  
face.

Preferably, the nanoparticle substrate comprises  
fullerenes. Fullerenes comprise any carbonaceous material  
having a structure of a regular, three-dimensional network of  
fused carbon rings. Such a network of fused carbon rings can  
be arranged in any suitable structure. Without limiting the  
invention, examples of such structures include cylindrical,  
spherical, ovoid, oblate and oblong structures. Typical  
fullerenes include cylindrical carbon nanotubes and icosahed-  
ral C<sub>60</sub> carbon molecules. Preferably, the fullerenes com-  
prise at least one of C<sub>60</sub> molecules, C<sub>72</sub> molecules, C<sub>84</sub> mol-  
ecules, C<sub>96</sub> molecules, C<sub>108</sub> molecules, C<sub>120</sub> molecules, ovoid

molecules, single-walled carbon nanotubes (SWNTs), and multi-walled carbon nanotubes (MWNTs). More preferably, the fullerenes can be selected from C<sub>60</sub> molecules, ovoid molecules, and SWNTs. SWNTs comprise one tube about a given center, and MWNTs comprise more than one nested tube about a common center. In alternative embodiments, the fullerene comprises any surface modified fullerene.

Semiconducting materials are well known in the art, and the present invention includes any such semiconducting materials suitable for coating on a nanoparticle substrate. Preferably, the semiconducting materials are capable of emitting and/or absorbing light, more preferably capable of absorbing and emitting light. Without limiting the present invention, examples of suitable semiconducting materials include photonic bandgap engineered materials; III-V and II-VI binary, ternary, and quaternary compound semiconductors; metallic oxides; polymers; liquid crystals; and suitable organic compounds. Preferably, the semiconducting materials comprise at least one of ZnS, CdS, CdSe, GaAs, InP, GaS, TiO<sub>2</sub>, and Fe<sub>2</sub>S<sub>3</sub>. More preferably, semiconducting materials comprise at least one of CdS and CdSe. The coated nanoparticle substrate of the present invention comprises any suitable nanoparticle substrate coated with a desired amount of any suitable semiconducting material, preferably capable of emitting and/or absorbing light. A preferable embodiment of the present invention comprises a fullerene coated with CdS or CdSe. A more preferable embodiment of the present invention comprises a SWNT coated with CdS or CdSe.

Without being limited by theory, it has not been demonstrated, but it is believed that providing a hollow quantum dot comprising a semiconducting material, preferably capable of emitting and/or absorbing light, such as CdS, coated on a nanoparticle substrate, such as a SWNT, can result in the emission of light and also can result in an aspect ratio suitable to produce a polarized light emission.

#### Method of Coating the Nanoparticle Substrate

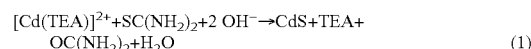
Dispersing the nanoparticle under suitable conditions to provide a dispersed nanoparticle is accomplished by dispersing the nanoparticle in a liquid. The nanoparticle can be any suitable nanoparticle, preferably a fullerene. Preferably, dispersing the nanoparticle activates at least a portion of at least one surface of the nanoparticle. Without limiting the present invention to any theory, it is believed that dispersing a fullerene activates the surface of the fullerene for deposition of a semiconducting material, preferably one capable of emitting and/or absorbing light. The fullerene is preferably dispersed by chemical functionalization.

Chemical functionalization of a fullerene is well known in the art, and the present invention can include any chemical functionalization technique suitable for dispersing a fullerene and activating its surface. Without being limited by theory, it is believed that chemical functionalization provides at least one specific reactive site for growth of the semiconducting material. Moreover, without limiting the invention, examples of suitable chemical functionalization techniques include hydroxylation. Hydroxylation comprises reacting the surface of the fullerene with a chemical reagent or reagents that result in the formation of a number of hydroxide groups chemically bound to the surface of the fullerene. The hydroxide group is a chemical species consisting of an oxygen and a hydrogen, i.e., OH.

In an alternative embodiment, the fullerene is dispersed by surfactant addition. Suitable surfactants include sodium dodecylsulfate (SDS), dodecyltrimethyl ammonium bromide (DTAB), N-hexadecyl-N(2-hydroxy-ethyl)-N,N'-dimethylammonium bromide, sodium dodecyl (benzenesulfonate),

and dodecyl(benzene)trimethylammonium halide. Preferably, the surfactants comprise sodium dodecylsulfate and/or dodecyltrimethyl ammonium bromide. Surfactant addition comprises dispersing the fullerene in a water solution of the surfactant. This can be accomplished by the addition of heat or through sonic waves.

Depositing at least one semiconducting material under suitable conditions onto at least one surface of the dispersed nanoparticle, preferably a fullerene, is accomplished by catalyzing growth of the semiconducting material on the activated surface of the nanoparticle. Catalyzing such growth comprises contacting the dispersed fullerene with a solution comprising chemical precursors to the semiconducting material. Preferably, the nanoparticle substrate is at least partially dissolved in the solution. It is also preferable to use a non sol-gel approach to allow seeded growth on the surface of the fullerene and have a faster reaction time than a typical sol-gel approach. The solution comprises chemical precursors that react to generate the desired semiconducting material. For instance, when the semiconducting material comprises CdS, the CdS solution can be prepared by the following Equation (1), where TEA is triethanolamine.



In another example, when the semiconducting material comprises CdSe, the CdSe solution can be prepared by the following Equation (2),



Preferably, capping agents are used to control the surface growth. Capping agents can include at least one of n-tetradecylphosphonic acid, ethanol, and organic thiols of the general formula RSH, where R is an organic group, which is preferably n-tetradecylphosphonic acid. Without being limited by theory, it is believed that the capping agents act as surfactants to the fullerene and also slow and control the growth of the semiconducting material by weakly binding to the surface of the growing material. Capping agents are preferably added to the solution in excess, preferably at least in a ratio of 4:1 with regard to the metal source, e.g., the Cd precursor compound in the synthesis of CdSe.

The semiconducting material is grown on the fullerene until the desired thickness of the coating is achieved. Preferably, the nanoparticle coating is between 0.1-50 μm thick, more preferably less than 10 μm thick. After the desired thickness is achieved, the coating reaction is quenched, and the coated fullerenes can be removed from the solution. The coated fullerenes can be removed by any suitable technique, preferably by centrifuge. Preferably, the coated fullerene is then purified by re-dispersing the fullerene in a suitable solvent such as ethanol.

To further illustrate various illustrative embodiments of the present invention, the following examples are provided.

#### EXAMPLES

##### Examples 1-13 (CdS Fullerenols)

Examples 1-13 demonstrate the coating of fullerenols by CdS.

##### Experiment 1

A [Cd<sup>2+</sup>] bath concentration was set at 50 mM. Only triethanolamine (TEA) ratios were varied to avoid colloidal (precipitation) regime of CdS deposition from the bath. Relative molar ratios of Cd:TEA:NH<sub>4</sub>OH:thiourea were set at 1:3.75:14.4:1, respectively. A typical experiment involved

adding 10 mL of a 50 mg/L solution of fullerenols [ $C_{60}(OH)_n$ ] to a centrifuge tube.  $NH_4OH$ , TU, TEA, and cadmium acetate were added in the respective order to the fullereneol solution, which produces the aforementioned 1 ( $Cd^{2+}$ ):3.75 (TEA):14.4 ( $NH_4OH$ ):1 (thiourea) relative molar ratios with  $[Cd^{2+}]$  set at 50 mM. Therefore, in this example,  $[Cd^{2+}]$ =50 mM,  $[TEA]$ =187.5 mM,  $[NH_4OH]$ =720 mM, and  $[thiourea]$ =50 mM. Reagents were reacted without stirring in 50 mL centrifuge tubes with a water bath held at 60° C. for 8 hours. It was allowed to cool to room temperature. All bath final volumes were 30 mL. Results include a colloid size of 1.5  $\mu$ m and an orange deposit on the walls. In addition, a large amount of precipitate was produced and a clear liquid supernatant was observed.

#### Experiment 2

Bath conditions were identical to Experiment 1, except for changing the TEA relative ratio from 3.75 to 1.875 (93.75 mM). Results include a colloid size of 2-2.5  $\mu$ m. In addition, other colloid sizes were polydispersed as low as 400 nm.

#### Experiment 3

Bath conditions were similar to Experiment 1. All bath reagent concentrations diluted 10-fold (5 mM  $Cd^{2+}$ ; 1:3.75:14.4:1 relative molar ratios of  $Cd^{2+}$ : TEA:  $NH_4OH$ : thiourea). 5 mL of 50 mg/L fullereneol seed was used. Baths were reacted without stirring at room temperature for 12 hours. The bath final volumes were 30 mL. The resulting CdS appeared amorphous.

#### Experiment 4

Bath conditions were identical to Experiment 3, except for the omission of 5 mL of added fullereneol seed. This was an unseeded (control) bath. The resulting CdS appeared amorphous.

#### Experiment 5

Bath conditions were identical to Experiment 4 (unseeded), but the  $[Cd^{2+}]$  equaled 12.5 mM. The 1:3.75:14.4:1 relative molar ratios of  $Cd^{2+}$ : TEA :  $NH_4OH$  : TU were maintained. The resulting CdS appeared bulk and amorphous with no colloids.

#### Experiment 6

Bath conditions were identical to Experiment 5, but the  $[Cd^{2+}]$  equaled 25 mM. The resulting CdS appeared bulky and amorphous with no colloids.

#### Experiment 7

Bath conditions were identical to Experiment 5, but the  $[Cd^{2+}]$  equaled 37.5 mM. It appeared that the bulk texture changed to a colloidal nature.

#### Experiment 8

Bath conditions were identical to Experiment 5, but the  $[Cd^{2+}]$  equaled 50 mM. The experiment resulted in colloidal CdS colloids with more monodispersed colloids later seen.

#### Experiment 9

Bath conditions were identical to Experiment 8, but 10 mL of 50 mg/L fullereneol seed solution was added. Results included all colloids, with a colloid size of 1-1.6  $\mu$ m. Also, larger 2-2.6  $\mu$ m colloids were seen. The colloids were polydispersed.

#### Experiment 10

Bath conditions were identical to Experiment 8, but 5 mL of 50 mg/L fullereneol seed solution was added. Results included all polydispersed colloids. Also, larger 2.6  $\mu$ m colloids were present with small 300-800 nm colloids.

#### Experiment 11

Bath conditions were identical to Experiment 10, but the  $Cd^{2+}$  concentration was changed to 37.5 mM. Results included polydispersed colloids with sizes of 2.5-3  $\mu$ m.

#### Experiment 12

Bath conditions were identical to Experiment 10, but the  $Cd^{2+}$  concentration was changed to 25 mM. Results included very small monodispersed colloids with a size of 350-600 nm. Results also included the appearance of some non-colloidal deposits.

#### Experiment 13

Bath conditions were identical to Experiment 10, but the  $Cd^{2+}$  concentration was changed to 12.5 mM. Results included no colloids and also an amorphous film-like CdS deposit.

#### Examples 14-23 (CdS SWNTs)

Examples 14-23 demonstrate the coating of SWNTs with CdS.

#### Experiment 14

1 mL of an aqueous 1% (w/w) sodium dodecylsulfate (SDS) solution of SWNTs (25 mg SWNTs/L) was added to a centrifuge tube, followed by the addition of  $NH_4OH$  and TU. In a separate tube, a  $[Cd^{2+}(TEA)]$  solution was made by adding TEA to  $Cd(OAc)_2$  and shaking to allow the TEA to complex with the  $Cd^{2+}$  cations. This mixture was added dropwise to the SWNT/ $NH_4OH$ /TU solution to produce the aforementioned 1 ( $Cd^{2+}$ ):3.75 (TEA):14.4 ( $NH_4OH$ ):1 (TU) relative molar ratios, where  $[Cd^{2+}]$  was set at 5 mM. Therefore, in this example,  $[Cd^{2+}]$ =5 mM,  $[TEA]$ =18.75 mM,  $[NH_4OH]$ =72 mM, and  $[TU]$ =5 mM. Reagents were reacted overnight at room temperature. The CdS coated SWNTs were washed six times by repeated centrifugation/redispersion in absolute EtOH. All bath final volumes were 1.6 mL.

#### Experiment 15

Bath conditions were identical to Experiment 14, but the  $[Cd^{2+}]$  equaled 0.5 mM. The 1:3.75:14.4:1 relative molar ratios of  $Cd^{2+}$ :TEA: $NH_4OH$ :TU were maintained.

#### Experiment 16

Bath conditions were identical to Experiment 14, but the  $[Cd^{2+}]$  equaled 0.8 mM.

#### Experiment 17

Bath conditions were identical to Experiment 14, but the  $[Cd^{2+}]$  equaled 1 mM.

#### Experiment 18

Bath conditions were identical to Experiment 14, but the  $[Cd^{2+}]$  equaled 1.5 mM.

#### Experiment 19

Bath conditions were identical to Experiment 14, but the  $[Cd^{2+}]$  equaled 2.5 mM.

#### Experiment 20

Bath conditions were identical to Experiment 14, but the  $[Cd^{2+}]$  equaled 7.5 mM.

#### Experiment 21

Bath conditions were identical to Experiment 14, but the  $[Cd^{2+}]$  equaled 10 mM.

#### Experiment 22

Bath conditions were identical to Experiment 14, but the  $[Cd^{2+}]$  equaled 25 mM.

## Experiment 23

Bath conditions were identical to Experiment 14, but the  $[Cd^{2+}]$  equaled 28 mM.

## Examples 24-27 (CdSe SWNTs)

Examples 24-27 demonstrate the coating of SWNTs with CdSe.

## Experiment 24

In a 50 mL centrifuge tube, 25 mg annealed HiPCO SWNTs was added. The tubes had been previously annealed under argon in a sealed tube furnace at 800° C., cooled, and gently ground. 30 mL of 1-octadecene (ODE) was added, and the tubes were vigorously sonicated for 20 seconds. After 30 seconds of settling, the tube was slightly swirled to suspend the SWNTs but not to disturb large settled chunks of undispersed SWNTs. The top 15 mL of the suspension was quickly transferred by pipet to a 50 mL Schlenk flask. 71.4 mg (256  $\mu$ mol) tetradecylphosphonic acid (TDPA) and 8.2 mg (64  $\mu$ mol) CdO was added to this suspension. This mixture was heated with stirring under argon to 300° C. to dissolve the CdO and then cooled to 250° C. At this point, 0.08 g of an SePBu<sub>3</sub> mixture (containing 2.53 mg (32  $\mu$ mol) Se, 9.5 mg tetrabutylphosphine (TBP), 72.4 mg trioctylphosphine (TOP), and 15 mg toluene) was injected into the flask, and the reaction was allowed to proceed at 250° C. until completion (ca. 30 min), at which point the heating mantle was removed. The room temperature SWNT suspension was then extracted with an equal portion of MeOH/CHCl<sub>3</sub> (1:1) several times to remove excess Cd-TDPA complex. Absolute EtOH was added to the ODE/SWNT portion (~30 mL) to precipitate the tubes. Finally, the tubes were washed six times by repeated centrifugation/redispersion in EtOH.

## Experiment 25

Experimental conditions were identical to those of Experiment 24, except that oleic acid (73 mg, 256  $\mu$ mol) was substituted for TDPA as the complexing agent for cadmium.

## Experiment 26

Experimental conditions were similar to those of Experiment 24, except that trioctylphosphine oxide (TOPO) was used as the solvent rather than ODE. The SWNTs were added to a hot (84° C.) melt of 5 g TOPO, and sonicated in a large test tube. After 10 seconds of settling, the top 80% of the suspension was quickly transferred by pipet to a 50 mL Schlenk flask and to this suspension was added 71.4 mg (256  $\mu$ mol) tetradecylphosphonic acid (TDPA) and 8.2 mg (64  $\mu$ mol) CdO. This mixture was heated with stirring under argon to 300° C. to dissolve the CdO and then cooled to 250° C. At this point, 0.08 g of an Se-TBP mixture (containing 2.53 mg (32  $\mu$ mol) Se, 9.5 mg tetrabutylphosphine (TBP), 72.4 mg trioctylphosphine (TOP), and 15 mg toluene) was injected into the flask, and the reaction was allowed to proceed at 250° C. until completion (ca. 30 min), at which point the heating mantle was removed. When the melt had cooled to ca. 60° C., a large excess of toluene was added (~40 mL). This mixture was centrifuged, the supernatant discarded, and the tubes were washed 6 times by repeated centrifugation/redispersion in EtOH.

## Experiment 27

Experimental conditions were identical to those of Experiment 26, except that oleic acid (73 mg, 256  $\mu$ mol) was substituted for TDPA as the complexing agent for cadmium.

It will be understood that the present invention is not limited to the nanoparticle substrate comprising fullerenes. In alternative embodiments, the present invention comprises

any inert nanoparticles. A preferable example of such an inert nanoparticle is an alumoxane. Additional examples include a fullerene coated with gold (or any other metal), an oxide, or a dielectric.

5 Even though it has not been demonstrated that the present invention produces light or polarized light from the nanoparticle substrate coated with the semiconducting materials, it is believed that such an invention could be functionalized for use with in vivo applications. Examples of such in vivo applications include disabling or destroying foreign bodies in the blood and lymph systems such as parasites, bacteria, viruses and pathogenic proteins; physical alteration or destruction of specific biomolecular structures such as cholesterol deposits on the interior of veins and arteries, as well as intracellular pathogens; cauterization of blood vessels without the need for invasive surgical techniques; photon-assisted wound healing; photon-assisted reconstruction of severed nerve tissue site specific molecular identification for diagnostic purposes; and the like. It is further believed but has not been demonstrated that the nanoparticle substrate coated with the semiconductor materials of the present invention can have the wavelength of emitted light selected for maximum effectiveness by the choice of nanoparticle and/or semiconductor materials and deposition parameters, and that it can be directly injected into targeted structures or can be fed intravenously.

Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations may be made herein without departing from the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. A composition, comprising, a fullerene; a functionalizing group disposed on at least a portion of a surface of the fullerene, wherein the functionalizing group comprises one or more hydroxide groups chemically bound to said surface portion of the fullerene; and a film of a semiconducting material disposed on at least the portion of the surface of the fullerene that includes the functionalizing group, wherein the semiconducting material disposed on at least said surface portion of the fullerene has a thickness in a range of about 100 nm to about 5000 nm and wherein the semiconductor material comprises at least one of ZnS, CdS, CdSe, GaAs, InP, GaS, TiO<sub>2</sub>, and Fe<sub>2</sub>S<sub>3</sub>.
2. The composition of claim 1, wherein the functionalizing group provides at least one reactive site for growth of the semiconducting material.
3. The composition of claim 1, wherein the functionalizing group is suitable for dispersing the fullerene in a liquid.
4. The composition of claim 1, wherein the fullerene has at least one of a cylindrical, spherical, ovoid, oblate and oblong structure.
5. The composition of claim 1, wherein the film of the semiconducting material coats all of the surface of the fullerene.
6. The composition of claim 5, wherein the fullerene has at least one of a cylindrical, spherical, ovoid, oblate and oblong structure.
7. The composition of claim 1, wherein the fullerene comprises at least one of a C<sub>60</sub> molecule, C<sub>72</sub> molecule, C<sub>84</sub> molecule, C<sub>96</sub> molecule, C<sub>108</sub> molecule, C<sub>120</sub> molecule, single-walled carbon nanotube, and multi-walled carbon nanotube.
8. The composition of claim 1, wherein the semiconducting material is capable of at least one of absorbing and emitting light.

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9. A composition, comprising:  
 a fullerene;  
 a functionalizing group disposed on at least a portion of a  
 surface of the fullerene, wherein the functionalizing  
 group comprises one or more hydroxide groups chemi- 5  
 cally bound to said surface portion of the fullerene; and  
 a semiconducting material coating at least the portion of  
 the surface of the fullerene that includes the functional-  
 izing group, wherein the semiconductor material com-  
 prises at least one of ZnS, CdS, CdSe, GaAs, InP, GaS, 10  
 TiO<sub>2</sub>, and Fe<sub>2</sub>S<sub>3</sub> and wherein the semiconducting mate-  
 rial coating on at least said surface portion of the  
 fullerene has a thickness in a range of about 100 nm to  
 about 5000 nm.
10. The composition of claim 9, wherein the fullerene has 15  
 at least one of a cylindrical, spherical, ovoid, oblate and  
 oblong structure.
11. The composition of claim 9, wherein the semiconduct-  
 ing material coats all of the surface of the fullerene.
12. The composition of claim 11, wherein the fullerene has 20  
 at least one of a cylindrical, spherical, ovoid, oblate and  
 oblong structure.
13. The composition of claim 9, wherein the functionaliz-  
 ing group provides at least one reactive site for growth of the  
 semiconducting material. 25
14. The composition of claim 9, wherein the functionaliz-  
 ing group is suitable for dispersing the fullerene in a liquid.

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15. The composition of claim 9, wherein the fullerene  
 comprises at least one of a C<sub>60</sub> molecule, C<sub>72</sub> molecule, C<sub>84</sub>  
 molecule, C<sub>96</sub> molecule, C<sub>108</sub> molecule, C<sub>120</sub> molecule,  
 single-walled carbon nanotube, and multi-walled carbon  
 nanotube.
16. The composition of claim 9, wherein the semiconduct-  
 ing material is capable of absorbing light.
17. The composition of claim 9, wherein the semiconduct-  
 ing material is capable of emitting light.
18. The composition of claim 1, wherein the film of the  
 semiconducting material is of uniform heterogeneity.
19. A composition, comprising,  
 a fullerene;  
 a functionalizing group disposed on at least a portion of a  
 surface of the fullerene, wherein the functionalizing  
 group comprises one or more hydroxide groups chemi-  
 cally bound to said surface portion of the fullerene; and  
 a semiconducting material disposed on the portion of the  
 surface of the fullerene that includes the functionalizing  
 group, wherein the semiconductor material comprises at  
 least one of ZnS, CdS, CdSe, GaAs, InP, GaS, TiO<sub>2</sub>, and  
 Fe<sub>2</sub>S<sub>3</sub> and wherein the semiconducting material coats all  
 of the surface of the fullerene and has a thickness in a  
 range of about 100 nm to about 5000 nm.

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