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(71) Applicants:
- **Tsing Hua University**
Haidian District
Beijing City (CN)
- **Hon Hai Precision Industry Co., Ltd.**
Tu-cheng City, Taipei Hsien (TW)

(72) Inventors:
- **Jiang, Kai-Li,**
Tsing Hua University
Beijing City (CN)
- **Liu, Liang,**
Tsing Hua University
Beijing City (CN)
- **Liu, Kai,**
Tsing Hua University
Beijing City (CN)
- **Zhao, Qing-Yu,**
Tsing Hua University
Beijing City (CN)
- **Zhai, Yong-Chao,**
Tsing Hua University
Beijing City (CN)
- **Fan, Shou-Shan,**
Tsing Hua University
Beijing City (CN)

(74) Representative: **Stuttard, Garry Philip**
Urquhart-Dykes & Lord LLP
Tower North Central
Merrion Way
Leeds LS2 8PA (GB)

(54) **Coaxial cable and method for making the same**

(57) A coaxial cable includes a core, an insulating layer, a shielding layer, a sheathing layer. The core includes an amount of carbon nanotubes having at least one conductive coating disposed about the carbon nanotubes. The carbon nanotubes are orderly arranged. The insulating layer is about the core. The shielding layer is about the insulating layer. The sheathing layer is about the shielding layer.

A method for making a coaxial cable, the method comprises the steps of: (a) providing a carbon nanotube structure; (b) forming at least one conductive coating on a plurality of carbon nanotubes of the carbon nanotube structure; (c) forming a carbon nanotube wire-like structure from the carbon nanotubes with at least one conductive coating; (d) enwrapping at least one layer of insulating material on the carbon nanotube wire-like structure; (e) enwrapping at least one layer of shielding material on the at least one layer of insulating material and (f) coating one layer of sheathing material on the at least one layer of shielding material.

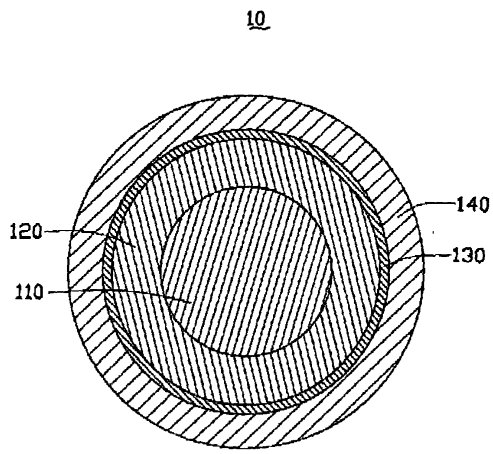

FIG. 1

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Description

[0001] The present disclosure relates to coaxial cables and method for making the same, more particularly, to a carbon nanotube based coaxial cable and the method for making the same.

[0002] Coaxial cables are used as carriers to transfer electrical power and signals. A conventional coaxial cable includes a core, an insulating layer outside the core, and a shielding layer outside the insulating layer, usually surrounded by a sheathing layer. The core includes at least one conducting wire. The conducting wire can be a solid or braided wire, and the shielding layer can, for example, be a wound foil, a woven tape, or a braid. However, as the conducting wire made of a metal, a skin effect will occur in the conducting wire, thus the effective resistance of the cable becomes larger, which causes signal decay during transmission. Further, the conducting wire and the shielding layer made of metal have less strength because of them large size. Therefore, the coaxial cables must have comparatively greater in weight and diameter in use.

[0003] A related method for making coaxial cable included the following steps of: coating a polymer on an outer surface of the at least one conducting wire to form an insulating layer; applying a plurality of metal wire or braided metal wire to the insulating layer to form a shielding layer; and covering a sheathing layer on the outside of the shielding layer.

[0004] Carbon nanotubes (CNTs) are a novel carbonaceous material and received a great deal of interest since the early 1990s. Carbon nanotubes have interesting and potentially useful heat conducting, electrical conducting, and mechanical properties. A conducting wire made by a mixture of carbon nanotubes and metal has been developed. However, the carbon nanotubes in the conducting wire of the prior art are arranged disorderly. Thus, the above-mentioned skin effect has still not been eliminated in coaxial cables employing carbon nanotubes.

[0005] What is needed, therefore, is a coaxial cable having good conductivity, high mechanical performance, lightweight and with small diameter to overcome the aforementioned shortcomings, and a method for making the same.

[0006] A coaxial cable comprises a core, an insulating layer, a shielding layer, a sheathing layer. The core comprises an amount of carbon nanotubes having at least one conductive coating disposed about the carbon nanotubes. The carbon nanotubes are orderly arranged. The insulating layer wraps the core. The shielding layer wraps the insulating layer. The sheathing layer wraps the shielding layer.

[0007] A method for making a coaxial cable, the method comprises (a) providing a carbon nanotube structure having a plurality of carbon nanotubes; and (b) forming at least one conductive coating on the plurality of carbon nanotubes of the carbon nanotube structure; (c) forming a carbon nanotube composite wire from the carbon nanotubes with at least one conductive coating; (d) enwrapping at least one layer of insulating material on the carbon nanotube composite wire; (e) enwrapping at least one layer of shielding material on the at least one layer of insulating material; and (f) coating one layer of sheathing material on the at least one layer of shielding material.

[0008] Other novel features and advantages of the present carbon nanotube-based coaxial cable and method for fabricating the same will become more apparent from the following detailed description of exemplary embodiments when taken in conjunction with the accompanying drawings.

[0009] Many aspects of the present coaxial cable and method for making the same can be better understood with references to the accompanying drawings. The components in the drawings are not necessarily drawn to scale, the emphasis instead being placed upon clearly illustrating the principles of the present coaxial cable and method for making the same.

[0010] FIG 1 is a schematic, cross-sectional view of a coaxial cable having a plurality of carbon nanotubes, in accordance with a first embodiment.

[0011] FIG 2 is a schematic, cross-sectional view of an individual carbon nanotube of the coaxial cable of FIG. 1, coated with conductive coating.

[0012] FIG. 3 is a flow chart of a method for making the coaxial cable of FIG. 1.

[0013] FIG. 4 is a system for making the coaxial cable of FIG. 1.

[0014] FIG 5 shows a Scanning Electron Microscope (SEM) image of a carbon nanotube film used in the method for making the coaxial cable of FIG 1.

[0015] FIG. 6 shows a SEM image of the carbon nanotube film with at least one layer of conductive coating respectively coated on each carbon nanotube therein used in the method of FIG 3.

[0016] FIG 7 shows a Transmission Electron Microscope (TEM) image of a carbon nanotube in the carbon nanotube film with at least one layer of conductive coating individually coated thereon of the carbon nanotube of FIG. 6.

[0017] FIG. 8 shows a SEM image of an individually coated twisted carbon nanotube wire-like structure, in accordance with the first embodiment.

[0018] FIG. 9 shows a SEM image of the carbon nanotubes with at least one layer of conductive coating individually coated thereon in the twisted carbon nanotube wire-like structure of FIG. 8.

[0019] FIG. 10 shows a schematic, cross-sectional view of a coaxial cable, in accordance with a second embodiment.

[0020] FIG. 11 shows a schematic, cross-sectional of a coaxial cable, in accordance with a third embodiment.

[0021] FIG. 12 shows a schematic, cross-sectional view of a coaxial cable employed with a single core having carbon nanotube wire-like structure, in accordance with a forth embodiment.

[0022] FIG. 13 shows a schematic view of the single core of the coaxial cable of FIG. 12.

[0023] FIG. 14 shows a schematic, cross-sectional view of the carbon nanotube wire-like structure of FIG. 12, wherein the carbon nanotube wire-like structure comprises a plurality of carbon nanotube wires.

[0024] FIG. 15 shows a Scanning Electron Microscope (SEM) image of an untwisted carbon nanotube wire when being employed by the carbon nanotube wire-like structure of FIG 12.

[0025] FIG. 16 shows a Scanning Electron Microscope (SEM) image of an untwisted carbon nanotube wire when being employed by the carbon nanotube wire-like structure of FIG. 12.

[0026] Corresponding reference characters indicate corresponding parts throughout the several views. The exemplifications set out herein illustrate at least one embodiment of the present coaxial cable and method for making the same, in at least one form, and such exemplifications are not to be construed as limiting the scope of the invention in any manner.

[0027] References will now be made to the drawings to describe, in detail, embodiments of the present coaxial cable and method for making the same.

[0028] Referring to FIG. 1, a coaxial cable 10 according to a first embodiment includes a core 110, an insulating layer 120, a shielding layer 130, and a sheathing layer 140. The insulating layer 130 wraps the core 110. The shielding layer 130 wraps the insulating layer 120. The sheathing layer 140 wraps the shielding layer 130. The core 110, the insulating layer 120, the shielding layer 130, and the sheathing layer 140 are coaxial.

[0029] The core 110 may be at least one carbon nanotube composite wire. Specifically, the core 110 may include a single carbon nanotube composite wire or a plurality of carbon nanotube composite wires. Here, the core 110 includes one carbon nanotube composite wire. A diameter of the carbon nanotube composite wire ranges from about 4.5 nanometers to about I millimeter. Here, the diameter of the carbon nanotube composite wire ranges from about 1 micrometers to about 30 micrometers.

[0030] The carbon nanotube composite wire includes a plurality of carbon nanotubes 111(shown in FIG. 2) and at least one conductive coating covered on the outer surfaces of the carbon nanotubes. Each conductive coating comprises of at lease one conductive layer 114. The carbon nanotubes 100 are joined end-to-end by and combined by van der Waals attractive force between them. Further, the carbon nanotube composite wire can be a twisted carbon nanotube composite wire with a plurality of carbon nanotubes 111 aligned around the axis of the twisted carbon nanotube composite wire like a helix. The carbon nanotube composite wire can also be an non-twisted carbon nanotube composite wire, and the carbon nanotubes 111 of the non-twisted carbon nanotube composite wire are arranged along an axis of the carbon nanotube composite wire (e.g., the carbon nanotubes are relatively straight and the axis of the carbon nanotubes 111 are parallel to the axis of the non-twisted carbon nanotube composite wire). A diameter of the carbon nanotube composite wire ranges from about 4,5 nanometers to about 100 micrometers. Here, the diameter of the carbon nanotube composite wire ranges from about 10 nanometers to about 30 micrometers.

[0031] Referring to FIG. 2, each of the carbon nanotubes 111 in the carbon nanotube composite wire (not shown) is covered by the at least one conductive coating on the outer surface thereof. A conductive coating is in direct contact with the outer surface of the individual carbon nanotube 111. More specifically, the at least one layer of conductive coating further may include a wetting layer 112, a transition layer 113 and an anti-oxidation layer 115. As mentioned above, the conductive coating has at least one conductive layer 114. In the present embodiment, the at least one conductive coating includes one wetting layer 112, that is applied to the outer circumferential surface of the carbon nanotube 111, one transition layer 113 covering the outer circumferential surface of the wetting layer 112, at least one conductive layer 114 wrapping the outer circumferential surface of the transition layer 113, and one anti-oxidation layer 115 covering the outer circumferential surface of the conductive layer 114.

[0032] Wettability between carbon nanotubes and most kinds of metal is poor. Therefore, if used, the wetting layer 112 is configured for providing a good transition between the carbon nanotube 111 and the conductive layer 114. The material of the wetting layer 112 can be selected from the group consisting of iron (Fe), cobalt (Co), nickel (Ni), palladium (Pd), titanium (Ti), and any combination alloy thereof. A thickness of the wetting layer 112 ranges from about 1 nanometer to about 10 nanometers. Here, the material of the wetting layer 112 is Ni and the thickness of the wetting layer 112 is about 2 nanometers. It can be understood that the wetting layer 112 is optional.

[0033] The transition layer 113 is arranged for combining the wetting layer 112 with the conductive layer 114. The material of the transition layer 113 should be one that works well both with the material of the wetting layer 112 and the material of the conductive layer 114. Materials such as copper (Cu), silver (Ag), or alloys thereof can be used. A thickness of the transition layer 113 ranges from about I nanometer to about 10 nanometers. Here, the material of the transition layer 113 is Cu and the thickness is about 2 nanometers. It also can be understood that the transition layer 113 is optional.

[0034] The conductive layer 114 is arranged for enhancing the conductivity of the carbon nanotube twisted wire. The material of the conductive layer 114 can be selected from any suitable conductive material including Cu, Ag, gold (Au) and any combination alloys thereof. A thickness of the conductive layer 114 ranges from about I nanometer to about 20 nanometers. Here, the material of the conductive layer 114 is Ag and has a thickness of about 10 nanometers.

[0035] The anti-oxidation layer 115 is configured for preventing the conductive layer 114 from being oxidized when the conductive layer 114 is exposed to the air and preventing reduction of the conductivity of the core 110. The material of the anti-oxidation layer 115 can be any suitable material including gold (Au), platinum (Pt), and any other anti-oxidation metallic materials or combination alloys thereof. A thickness of the anti-oxidation layer 115 ranges from about 1 nanometer to about 10 nanometers. In the present embodiment, the material of the anti-oxidation layer 115 is Pt and the thickness is about 2 nanometers. It can be understood that the anti-oxidation layer 115 is optional in practice.

[0036] Furthermore, a strengthening layer 116 can be applied to the outer surface of the conductive coating to enhance the strength of the coated carbon nanotubes. The material of the strengthening layer 116 can be any suitable material including a polymer with high strength, such as polyvinyl acetate (PVA), polyvinyl chloride (PVC), polyethylene (PE), or paraphenylene benzobisoxazole (PBO). A thickness of the strengthening layer 116 approximately ranges from about 0.1 to about 1 micron. In the present embodiment, the strengthening layer 116 covers the anti-oxidation layer 115, the material of the strengthening layer 116 is PVA, and the thickness of the strengthening layer 116 is about 0.5 microns. It can be understood that the strengthening layer 116 is optional in use when.

[0037] The insulating layer 120 is used to insulate the core 110 from the shielding layer 140. A material of the insulating layer 120 can be any suitable insulated material such as polytetrafluoroethylene, polyethylene, polypropylene, polystyrene, polyethylene foam and nano-clay-polymer composite material. In the present embodiment, the material of the insulating layer 120 is polyethylene foam.

[0038] The shielding layer 130 is made of electrically conductive material. The shielding layer 130 is used to shield electromagnetic signals or external electromagnetic signals. Specifically, the shielding layer 130 can be formed by woven wires or by winding films around the insulating layer 120. The wires can be metal wires, carbon nanotube wires or composite wires having carbon nanotubes. The films can be metal films, carbon nanotube films or a composite film having carbon nanotubes. The carbon nanotubes in the carbon nanotube film are arranged in an orderly manner or in a disorderly manner.

[0039] A material of the metal wires or metal films can be any suitable material including copper, gold or silver, and other metals or their alloys having good electrical conductivity. The carbon nanotube wires and carbon nanotube films include a plurality of carbon nanotubes oriented along a preferred direction, joined end to end, and combined by van der Waals attractive force. The composite film can be composed of metals and carbon nanotubes, polymer and carbon nanotubes, or polymer and metals. The material of the polymer can be polyethylene terephtalate (PET), polycarbonate (PC), acrylonitrile-Butadiene Styrene Terpolymer (ABS), polycarbonate/acrylonitrile-butadiene -styrene (PC/ABS) polymer materials, or other suitable polymer. When the shielding layer 130 is a composite film having carbon nanotubes, the shielding layer 130 can be formed by dispersing carbon nanotubes in a solution of the composite to form a mixture, and coating the mixture on the insulating layer 120. Specifically, the shielding layer 130 includes two or more layers formed by the wires or films or combination thereof.

[0040] The sheathing layer 140 is made of insulating material. In the first embodiment, the sheathing layer 140 can be made of nano-clay-polymer composite materials. The nano-clay can be nano-kaolin clay or nano-montmorillonite. The polymer can be silicon resin, polyamide, and polyolefin, such as polyethylene or polypropylene. In the present embodiment, the sheathing layer 140 is made of nano-clay-polymer composite materials. The nano-clay-polymer composite material has good mechanical property, fire-resistant property, and can provide protection against damage from machinery, chemical exposure, etc.

[0041] Referring to FIG. 3 and FIG. 4, a method for making the coaxial cable 10 includes the following steps: (a) providing a carbon nanotube structure 214 having a plurality of carbon nanotubes therein; (b) forming at least one conductive coating on each of the carbon nanotubes of carbon nanotube structure 214; (c) forming an individually coated carbon nanotube composite wire 222; (d) enwrapping at least one layer of insulating material on the carbon nanotube composite wire 222; (e) enwrapping at least one layer of shielding material on the at least one layer of insulating material; and (f) coatinging one layer of sheathing material on the at least one layer of shielding material.

[0042] In step (a), the carbon nanotube structure 214 can be a carbon nanotube film. The carbon nanotube film includes a plurality of carbon nanotubes, and there are interspaces between adjacent two carbon nanotubes. Carbon nanotubes in the carbon nanotube film can parallel to a surface of the carbon nanotube film. A distance between adjacent two carbon nanotubes can be larger than a diameter of the carbon nanotubes. The carbon nanotube film can have a free-standing structure. The "free-standing" means that the carbon nanotube film does not have to be formed on a surface of a substrate to be supported by the substrate, but sustain the film-shape by itself due to the great van der Waals attractive force between the adjacent carbon nanotubes in the carbon nanotube film.

[0043] The carbon nanotube film can be fabricated by the following substeps of: (a1) providing a carbon nanotube array 216 (e.g., a super-aligned carbon nanotube array 216); (a2) pulling out a carbon nanotube film from the carbon nanotube array 216 by using a tool (e.g., adhesive tape, pliers, tweezers, or another tool allowing multiple carbon nanotubes to be gripped and pulled simultaneously).

[0044] In step (a1), a super-aligned carbon nanotube array 216 can be formed by a chemical vapor deposition method and in detail includes (a11) providing a substantially flat and smooth substrate; (a12) forming a catalyst layer on the substrate; (a13) annealing the substrate with the catalyst layer in air at a temperature approximately ranging from about 700°C to about 900°C for about 30 to about 90 minutes; (a14) heating the substrate with the catalyst layer to a temperature approximately ranging from about 500°C to about 740°C in a furnace with a protective gas therein; and (a15) supplying a carbon source gas to the furnace for about 5 to 30 minutes to grow the super-aligned carbon nanotube array 216 on the substrate.

[0045] In step (a11), the substrate can be a P-type silicon wafer, an N-type silicon wafer, or a silicon wafer with a film of silicon dioxide thereon. Here, a 4-inch P-type silicon wafer function as the substrate.

[0046] In step (a12), the catalyst can be made of iron (Fe), cobalt (Co), nickel (Ni), or any alloy thereof.

[0047] In step (a14), the protective gas can be made up of at least one of nitrogen (N_2), ammonia (NH_3), and a noble gas. In step (a15), the carbon source gas can be a hydrocarbon gas, such as ethylene (C_2H_4), methane (CH_4), acetylene (C_2H_2), ethane (C_2H_6), or any combination thereof.

[0048] The super-aligned carbon nanotube array 216 can be approximately 200 to 400 microns in height and includes a plurality of carbon nanotubes parallel to each other and approximately perpendicular to the substrate. The carbon nanotubes in the carbon nanotube array 216 can be single-walled carbon nanotubes, double-walled carbon nanotubes, or multi-walled carbon nanotubes. Diameters of the single-walled carbon nanotubes approximately range from about 0.5 nanometers to about 10 nanometers. Diameters of the double-walled carbon nanotubes approximately range from about 1 nanometer to about 50 nanometers. Diameters of the multi-walled carbon nanotubes approximately range from about 1.5 nanometers to about 50 nanometers.

[0049] The super-aligned carbon nanotube array 216 formed under the above conditions is essentially free of impurities such as carbonaceous or residual catalyst particles. The carbon nanotubes in the super-aligned carbon nanotube array 216 are closely packed together by van der Waals attractive force.

[0050] In step (a2), the carbon nanotube film can be formed by the following substeps: (a21) selecting a plurality of carbon nanotube segments having a predetermined width from a carbon nanotube array 216; and (a22) pulling the carbon nanotube segments at an even/uniform speed to achieve the carbon nanotube film.

[0051] In step (a21), the carbon nanotube segments having a predetermined width can be selected by using an adhesive tape such as the tool to contact the carbon nanotube array 216. Each carbon nanotube segment includes a plurality of carbon nanotubes parallel to each other. In step (a22), the pulling direction is arbitrary (e.g., substantially perpendicular to the growing direction of the carbon nanotube array 216).

[0052] More specifically, during the pulling process, as the initial carbon nanotube segments are drawn out, other carbon nanotube segments are also drawn out end-to-end due to the van der Waals attractive force between ends of adjacent segments. This process of drawing ensures that a continuous, uniform carbon nanotube film having a predetermined width can be formed. Referring to FIG 5, the carbon nanotube film includes a plurality of carbon nanotubes joined end-to-end. The carbon nanotubes in the carbon nanotube film are all substantially parallel to the pulling/drawing direction of the carbon nanotube film, and the carbon nanotube film produced in such manner can be selectively formed to have a predetermined width. The carbon nanotube film formed by the pulling/drawing method has superior uniformity of thickness and superior uniformity of conductivity over a typically disordered carbon nanotube film. Furthermore, the pulling/drawing method is simple, fast, and suitable for industrial applications.

[0053] The length and width of the carbon nanotube film depends on a size of the carbon nanotube array 216. When the substrate is a 4-inch P-type silicon wafer, as in the first embodiment, the width of the carbon nanotube film approximately ranges from about 0.01 centimeters to about 10 centimeters, the length of the carbon nanotube film can be above 100 meters, and the thickness of the carbon nanotube film approximately ranges from about 0.5 nanometers to about 100 microns.

[0054] In step (b), the at least one conductive coating can be formed on carbon nanotubes in the carbon nanotube structure 214 by a physical vapor deposition (PVD) method such as a vacuum evaporation or a sputtering. In the first embodiment, the at least one conductive coating is formed by a vacuum evaporation method.

[0055] The vacuum evaporation method for forming the at least one conductive coating of step (b) can further include the following substeps: (b1) providing a vacuum container 210 including at least one vaporizing source 212; and (b2) heating the at least one vaporizing source 212 to deposit the conductive coating on two opposite surfaces of the carbon nanotube structure 214.

[0056] In step (b1), the vacuum container 210 includes a depositing zone therein. In the present embodiment, three pairs of vaporizing sources 212 are respectively mounted on top and bottom portions of the depositing zone. Each pair of vaporizing sources 212 includes an upper vaporizing source 212 located on a top surface of the depositing zone, and a lower vaporizing source 212 located on a bottom surface of the depositing zone. The two vaporizing sources 212 are on opposite sides of the vacuum container 210. Each pair of vaporizing sources 212 is made of a type of metallic material. To vary the materials in different pairs of vaporizing sources 212, the wetting layer 112, the transition layer 113, the conductive layer 114, and the anti-oxidation layer 115 can be orderly formed on the carbon nanotubes in the carbon nanotube structure 214. The vaporizing sources 212 can be arranged along a pulling direction of the carbon nanotube structure 214 on the top and bottom portions of the depositing zone. The carbon nanotube structure 214 is located in the vacuum container 210 and between the upper vaporizing source 212 and the lower vaporizing source 212. There is a distance between the carbon nanotube structure 214 and the vaporizing sources 212. An upper surface of the carbon nanotube structure 214 directly faces the upper vaporizing sources 212. A lower surface of the carbon nanotube structure 214 directly faces the lower vaporizing sources 212. The vacuum container 210 can be vacuum-exhausted by using of a vacuum pump (not shown).

[0057] In step (b2), the vaporizing source 212 can be heated by a heating device (not shown). The material in the vaporizing source 212 is vaporized or sublimed to form a gas. The gas meets the cold carbon nanotubes in the carbon nanotube structure 214 and coagulates on the upper surface and the lower surface of carbon nanotubes in the carbon nanotube structure 214. Due to a plurality of interspaces existing between the carbon nanotubes in the carbon nanotube structure 214, in addition to the carbon nanotube structure 214 being relatively thin, the conductive material can be infiltrated in the interspaces between the carbon nanotubes in the carbon nanotube structure 214. As such, the conductive material can be deposited on the outer surface of most, if not all, of the carbon nanotubes. A microstructure of the carbon nanotube structure 214 with at least one conductive coating is shown in FIG 6 and FIG. 7.

[0058] Each vaporizing source 212 can have a corresponding depositing area by adjusting the distance between the carbon nanotube film and the vaporizing sources 212. The vaporizing sources 212 can be heated simultaneously, while the carbon nanotube structure 214 is pulled through the multiple depositing zones between the vaporizing sources 212 to form multiple layers of conductive material.

[0059] To increase density of the gas in the depositing zone, and prevent oxidation of the conductive material, the vacuum degree in the vacuum container 210 can be above 1 Pascal (Pa). In the first embodiment, the vacuum degree is about 4×10^{-4}Pa.

[0060] It is to be understood that the carbon nanotube array 216 formed in step (a1) can be directly placed in the vacuum container 210. The carbon nanotube film 214 can be pulled in the vacuum container 210 and successively passes each vaporizing source 212, with each conductive coating continuously depositing. Thus, the pulling step and the depositing step can be performed simultaneously.

[0061] In the first embodiment, the method for forming the at least one conductive coating includes the following steps: forming a wetting layer 112 on a surface of the carbon nanotube structure 214; forming a transition layer 113 on the wetting layer 112; forming a conductive layer 114 on the transition layer 113; and forming an anti-oxidation layer 115 on the conductive layer 114. In the above-described method, the steps of forming the wetting layer 112, the transition layer 113, and the anti-oxidation layer 115 are optional.

[0062] The step (b) further includes forming a strengthening layeroutside the at least one conductive coating. More specifically, the carbon nanotube structure 214 with the at least one conductive coating can be immersed in a container 220 with a liquid polymer. Thus, the entire surface and spaces between the plurality of carbon nanotubes of the carbon nanotube structure 214 can be soaked with the liquid polymer. After concentration (i.e., being cured), the strengthening layer can be formed on the outside of the coated carbon nanotubes.

[0063] In step (c), when the carbon nanotube structure 214 is the carbon nanotube film having a relatively small width (e.g., about 0.5 nanometers to 100 microns), the carbon nanotube structure 214 with at least one conductive coating thereon can be seen as a carbon nanotube composite wire 222 without additional mechanical or chemical treatment.

[0064] When the carbon nanotube structure 214 is the carbon nanotube film having a relatively large width (e.g., about 140 microns to above 10 centimeters). The carbon nanotube composite wire 222 can be made by a mechanical treatment (e.g., a conventional spinning or twisting process). The mechanical treatment to the carbon nanotube composite wire 222 can be executed by twisting or cutting the carbon nanotube structure 214 with the at least one conductive coating along an aligned direction of the carbon nanotubes in the carbon nanotube structure 214.

[0065] There are many ways to twist the carbon nanotube structure 214. One manner includes the following steps of: adhering one end of the carbon nanotube structure to a rotating motor; and twisting the carbon nanotube structure by the rotating motor to form the carbon nanotube composite wire 222. A second manner includes the following steps of: supplying a spinning axis; contacting the spinning axis to one end of the carbon nanotube structure 214; and twisting the carbon nanotube structure 214 by the spinning axis.

[0066] A plurality of carbon nanotube composite wires 222 can be stacked or twisted to form one carbon nanotube composite wire with a larger diameter. A plurality of coated carbon nanotube structures 214 can be arranged parallel to each other and then twisted to form the carbon nanotube composite wire 222 with the large diameter. Also two or more coated carbon nanotube structures 214 can be stacked and then twisted to form the carbon nanotube composite wire 222 with the large diameter.

[0067] The conductivity of the carbon nanotube composite wire 222 is better than the conductivity of the carbon manotube structure 214 without conductive coating on each carbon nanotube. The resistivity of the carbon nanotube composite wire 222 can be ranged from about $10\times10^{-8}\Omega\cdot$m to about $500\times10^{-8}\Omega\cdot$m. In the present embodiment, the carbon nanotube composite wire 222 has a diameter of about 120 microns, and a resistivity of about $360\times10^{-8}\Omega\cdot m$. The resistivity of the carbon nanotube structure 214 without conductive coating is about $1\times10^{-5}\Omega\cdot m$ ~$2\times10^{-5}\Omega\cdot m$.

[0068] An SEM image of a carbon nanotube composite wire 222 can be seen in FIGs. 8 and 9. The carbon nanotube composite wire 222 includes a plurality of carbon nanotubes with at least one conductive coating and aligned around the axis of carbon nanotube composite wire 222 like a helix.

[0069] Optionally, the steps of forming the carbon nanotube structure 214, the at least one conductive coating, and the strengthening layer can be processed in the vacuum container 210 to achieve a continuous production of the carbon nanotube composite wire 222. The acquired carbon nanotube composite wire 222 can be further collected by a first roller 224. The carbon nanotube composite wire 222 is coiled onto the first roller 224.

[0070] Step (d) can be executed by a first squeezing device 230. The melting polymer is coated on an outer surface of the carbon nanotube composite wire 222 by the first squeezing device 230. After concentration (e.g., being cured), the insulating layer 120 is formed. In the first embodiment, the polymer is polyethylene foam component. When the coaxial cable 10 includes two or more insulating layers 120, step (d) can be repeated.

[0071] In step (e), a layer of shielding material can be formed by woven wires or by winding films around the at least one layer of insulating material 120. The shielding films 232 can be provided by a second roller 234. The wires can be metal wires or carbon nanotube wires. The films can be metal films, carbon nanotube films or composite films having carbon nanotubes. The wires can be winded on the at least one layer of insulating material 120 by a rack 236. The carbon nanotubes in the carbon nanotube film can be orderly and/or disorderly.

[0072] Step (f) can be executed by a second squeezing device 240. The sheathing material is coated on an outer surface of the shielding layer 130 by the second squeezing device 240 to form the sheathing layer 140. After concentration (e.g., being cured), the sheathing layer 140 is formed. In the first embodiment, the sheathing material is nano-clay-polymer composite material. The acquired coaxial cable 10 can be further collected via a third roller 260 by coiling the coaxial cable 10 onto the third roller 260.

[0073] Referring to FIG. 10, a coaxial cable 30 according to a second embodiment includes a plurality of cores 310, a plurality of insulating layers 320, a shielding layer 330, and a sheathing layer 340. Each insulating layer 320 wrapsa corresponding core 310. The shielding layer 330 wraps the plurality of insulating layers 320. The sheathing layer 340 wraps the shielding layer 330. Between the shielding layer 330 and the insulating layer 320, insulating material is filled. The method for making the coaxial cable 30 of the second embodiment is similar to that of the coaxial cable 10 of the first embodiment.

[0074] Referring to FIG. 11, a coaxial cable 40 according to a third embodiment includes a plurality of cores 410, a plurality of insulating layer 420, a plurality of shielding layer 430, and a sheathing layer 440. Each insulating layer 430 wraps each a corresponding core 410. Each shielding layer 430 wraps a corresponding insulating layer 420. The sheathing layer 440 wraps all of the shielding layers 430. The method for making the coaxial cable 40 of the third embodiment is similar to that of the coaxial cable 10 of the first embodiment.

[0075] In this embodiment, each shielding layer 430 can shield each core 410 respectively. The coaxial cables 40 is configured for avoiding interference coming from outer factors, and avoid interference between the pluralities of cores 410.

[0076] Referring to FIG 12, a coaxial cable 50 according to a fourth embodiment includes a core 520, an insulating layer 530, a shielding layer 540, and a sheathing layer 550. The insulating layer 530 wraps the core 520. The shielding layer 540 wraps the insulating layer 530. The sheathing layer 550 wraps the shielding layer 540. The core 520, the insulating layer 530, the shielding layer 540, and the sheathing layer 550 are coaxial.

[0077] Referring to FIG. 13, the core 520 includes a carbon nanotube wire-like structure 500, a conductive coating 510, and a strengthening layer 516. The conductive coating 510 wraps the carbon nanotube wire-like structure 500 and includes at least one conductive layer 514. The strengthening layer 516 wraps the conductive coating 510. The carbon nanotube wire-like structure 500 includes one or a plurality of carbon nanotube wires 502. The diameter of the core 520 is about 10 microns to about 1 centimeter. Here, the carbon nanotube wire-like structure 500 includes a plurality of carbon nanotube wires 502 braided together and having a diameter of about 1 micron to about 1 centimeter.

[0078] The conductive coating 510 can further include a wetting layer 512, a transition layer 513, a conductive layer 514, and an anti-oxidation layer 515. As mentioned above, the conductive coating 510 has at least one conductive layer 514. Here, the conductive coating includes all of the aforementioned elements. The wetting layer 512 covers and wraps the carbon nanotube wire-like structure 500. The transition layer 513 covers and wraps the wetting layer 512. The conductive layer 514 covers and wraps the transition layer 513. The anti-oxidation layer 515 covers and wraps the conductive layer 514.

[0079] Referring to FIG. 14, the carbon nanotube wires 502 may be twisted carbon nanotube wires, untwisted carbon nanotube wires, or any combinations thereof. Here, the carbon nanotube wires 502 are combinations of the twisted carbon nanotube wires and the untwisted carbon nanotube wires.

[0080] Referring to FIG. 15, one untwisted carbon nanotube wire is shown. The untwisted carbon nanotube wire includes a plurality of carbon nanotubes segments having a plurality of carbon nanotubes substantially oriented along a same direction (i.e., a direction along the longitudinal axis of the untwisted carbon nanotube wire). The carbon nanotube segments can vary in width, thickness, uniformity and shape. The carbon nanotubes are parallel to the longitudinal axis of the untwisted carbon nanotube wire. The length of the untwisted carbon nanotube wire may be arbitrarily determined as desired. The diameter of the untwisted carbon nanotube wire can be from about 1 micron to about 1 centimeter.

[0081] Referring to FIG 16, one twisted carbon nanotube wire is shown. The twisted carbon nanotube wire includes a plurality of carbon nanotubes oriented around a longitudinal axial direction thereof. The carbon nanotubes are aligned around the axis of the carbon nanotube twisted wire like a helix. The length of the carbon nanotube wire can be arbitrarily determined as desired. The diameter of the twisted carbon nanotube wire can be from about 1 micron to about 1 centimeter. The twisted carbon nanotbue wire is formed by rotating the two ends of a carbon nanotube film in opposite directions using mechanical force or by other known means. Moreover, the twisted carbon nanotube wire can be treated with a volatile organic solvent. After being treated by the organic solvent, the adjacent and parallel carbon nanotubes of the twisted carbon nanotube wire may bundle up together, because of the surface tension of the organic solvent when the organic solvent volatilizing. The surface area of the twisted carbon nanotube wire may decrease, because the twisted carbon nanotubes in the carbon nanotube wire may bundle up together. The density and strength of the twisted carbon nanotube wire may be increased, because of bundling of the twisted carbon nanotube wire.

[0082] The coaxial cable 10, 30, 40, 50 provided in the embodiments has the following superior properties. Firstly, the coaxial cable 10, 30, 40, 50 includes a plurality of oriented carbon nanotubes joined end-to-end by van der Waals attractive force, whereby the coaxial cable has high strength and toughness. Secondly, the outer surface of each carbon nanotube is covered by at least one conductive coating, such that the core 110, 210, 410, 520 made of carbon nanotubes has high conductivity. Thirdly, the method for making the core 110, 210, 410, 520 of the coaxial cable 10, 30, 40, 50 can be performed by drawing a carbon nanotube structure from a carbon nanotube array and forming at least one conductive coating on the carbon nanotube structure. The method is simple and relatively inexpensive. Additionally, the coaxial cable 10, 30, 40, 50 can be formed continuously and, thus, a mass production thereof can be achieved. Fourthly, since the carbon nanotubes have a small diameter, and the cable includes a plurality of carbon nanotubes and at least one conductive coating thereon, thus the coaxial cable 10, 30, 40, 50 has a smaller width than a metal wire formed by a conventional wire-drawing method and can be used in ultra-fine cables. Finally, since the carbon nanotubes are hollow, and a thickness of the at least one layer of the conductive material is just several nanometers, thus a skin effect is less likely to occur in the coaxial cable 10, 30, 40, 50 and signals will not decay as much during transmission.

[0083] It is to be understood that the above-described embodiments are intended to illustrate rather than limit the invention. Variations may be made to the embodiments without departing from the spirit of the invention as claimed. The above-described embodiments illustrate the scope of the invention but do not restrict the scope of the invention.

[0084] It is also to be understood that the above description and the claims drawn to a method may include some indication in reference to certain steps. However, the indication used is only to be viewed for identification purposes and not as a suggestion as to an order for the steps.

Claims

1. A coaxial cable comprising:

a core comprising a plurality of carbon nanotubes having at least one conductive coating disposed about the carbon nanotubes, wherein the carbon nanotubes are orderly arranged;
an insulating layer wrapping the core;
a shielding layer wrapping the insulating layer; and
a sheathing layer wrapping the shielding layer.

2. A coaxial cable as claimed in claim 1, wherein the at least one conductive coating is in contact with the surface of the carbon nanotubes.

3. A coaxial cable as claimed in claim 1 or 2, wherein the carbon nanotubes and the conductive coating are organized in the form of at least one carbon nanotube composite wire and the carbon nanotubes are joined end-to-end by van der Waals attractive forces therebetween.

4. A coaxial cable as claimed in claim 3, wherein the resistivity of the carbon nanotube composite wire is in the range about $10\times10^{-8}\Omega\cdot m$ to about $500\times10^{-8}\Omega\cdot m$.

5. A coaxial cable as claimed in any of claims 1 to 4, wherein the carbon nanotubes in the carbon nanotube composite wire are aligned along the axial direction of the carbon nanotube composite wire.

6. A coaxial cable as claimed in any of claims 1 to 4, wherein the carbon nanotubes in the carbon nanotube composite wire are helically aligned around the axial direction of the carbon nanotube composite wire.

7. A coaxial cable as claimed in claim 4, wherein a diameter of the at least one carbon nanotube composite wire is in the range from about 4.5 nanometers to about 100 microns.

8. A coaxial cable as claimed in any of claims 1 to 7, wherein the at least one conductive coating comprises a conductive layer.

9. A coaxial cable as claimed in any of claims I to 8, wherein the at least onc conductive coating further comprises a wetting layer located between the carbon nanotube and the conductive layer, a transition layer between the wetting layer and the conductive layer and an anti-oxidation layer about the conductive layer.

10. A coaxial cable comprising:

a core comprising a carbon nanotube wire-like structure and at least one conductive coating wrapping the carbon nanotube wire-like structure, wherein the carbon nanotube wire-like structure comprises a plurality carbon nanotubes orderly arranged;
an insulating layer wrapping the core;
a shielding layer wrapping the insulating layer; and
a sheathing layer wrapping the shielding layer.

11. A method for making a coaxial cable comprising the steps of:

(a) providing a carbon nanotube structure comprising a plurality of carbon nanotubes;
(b) forming at least one conductive coating on a plurality of carbon nanotubes of the carbon nanotube structure;
(c) forming a carbon nanotube composite wire from the carbon nanotubes with at least one conductive coating;
(d) enwrapping at least one layer of insulating material on the carbon nanotube composite wire;
(e) enwrapping a layer of shielding material on the at least one layer of insulating material; and
(f) coating at least one layer of sheathing material on the at least one layer of shielding material.

12. A method as claimed in claim 11, wherein step (b) is executed by the steps of:

(b1) providing a vacuum container with at least one conductive material vaporizing source; and
(b2) heating the at least one conductive material vaporizing source to deposit a conductive coating on each of the carbon nanotubes in the carbon nanotube structure.

13. A method as claimed in claim 11, wherein step (c) further comprises the steps of:

(c1) adhering one end of the carbon nanotube structure to a rotating motor; and
(c2) twisting the carbon nanotube structure by the rotating motor.

14. A method as claimed in claim 11, wherein step (c) further comprises the following steps of:

(c1') supplying a spinning axis;
(c2') contacting the spinning axis to one end of the carbon nanotube structure; and
(c3') twisting the carbon nanotube structure by the spinning axis.

15. A method as claimed in claim 11, wherein in step (c), the carbon nanotube composite wire is acquired by cutting the carbon nanotube structure parallel to an alignment direction of the carbon nanotubes.

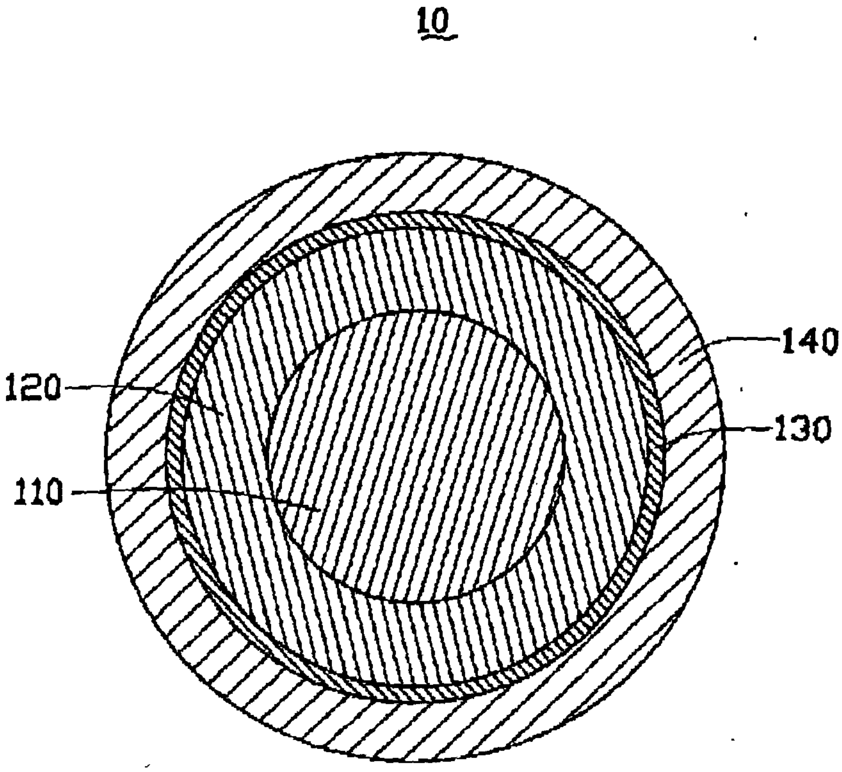

FIG. 1

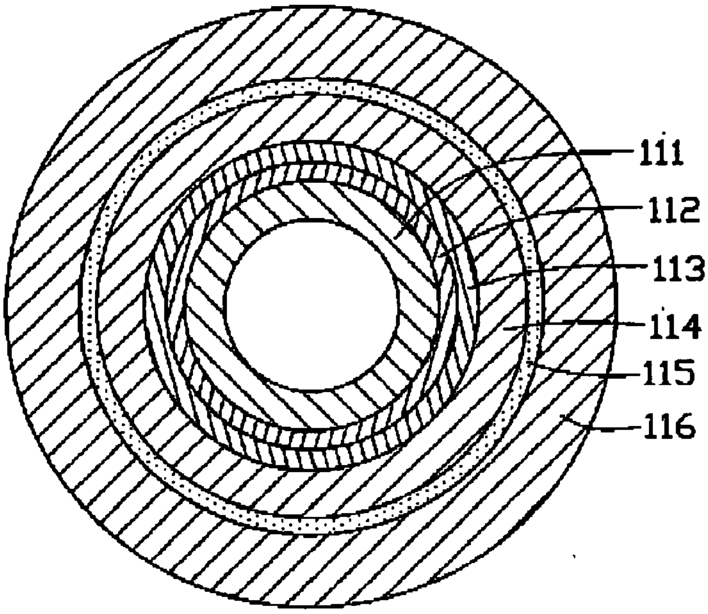

FIG. 2

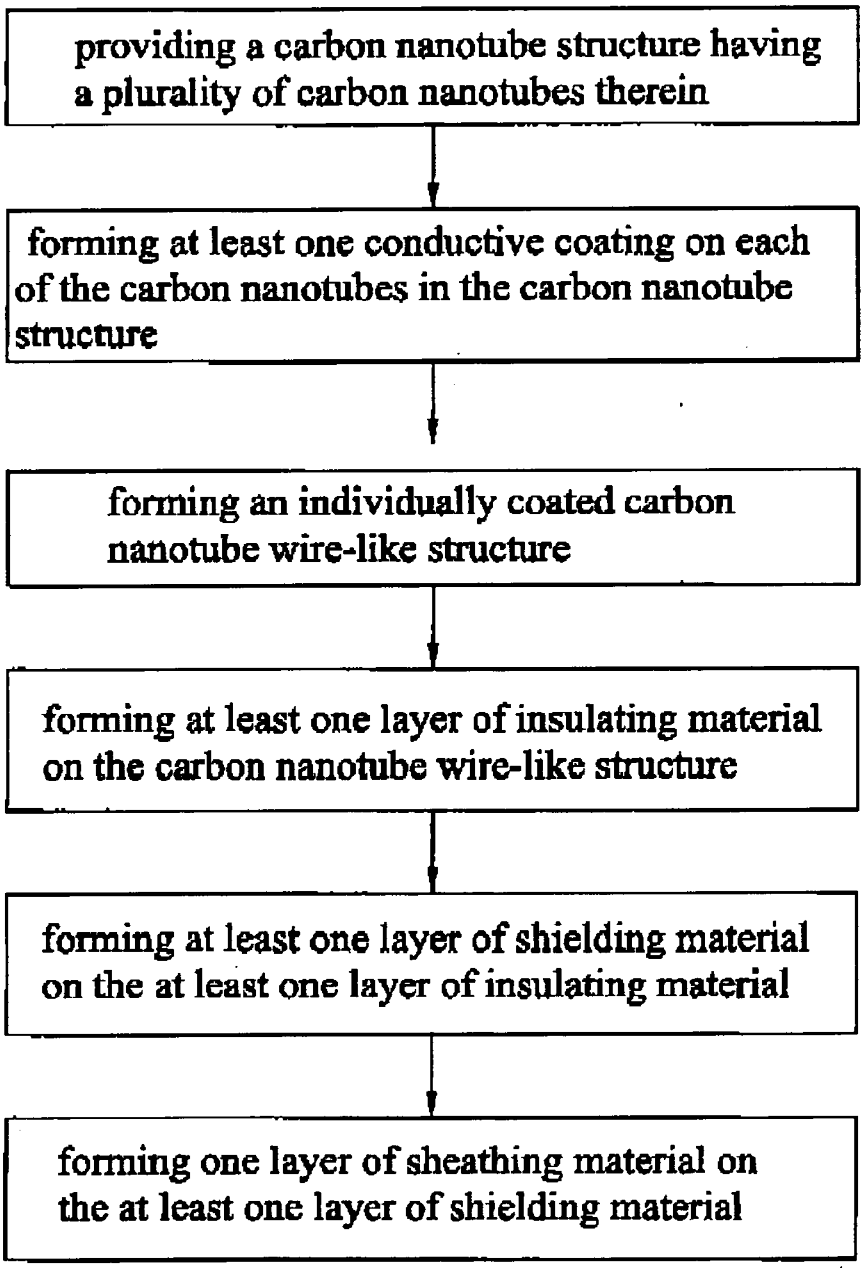
providing a carbon nanotube structure having a plurality of carbon nanotubes therein
forming at least one conductive coating on each of the carbon nanotubes in the carbon nanotube structure
forming an individually coated carbon nanotube wire-like structure
forming at least one layer of insulating material on the carbon nanotube wire-like structure
forming at least one layer of shielding material on the at least one layer of insulating material
forming one layer of sheathing material on the at least one layer of shielding material

FIG. 3

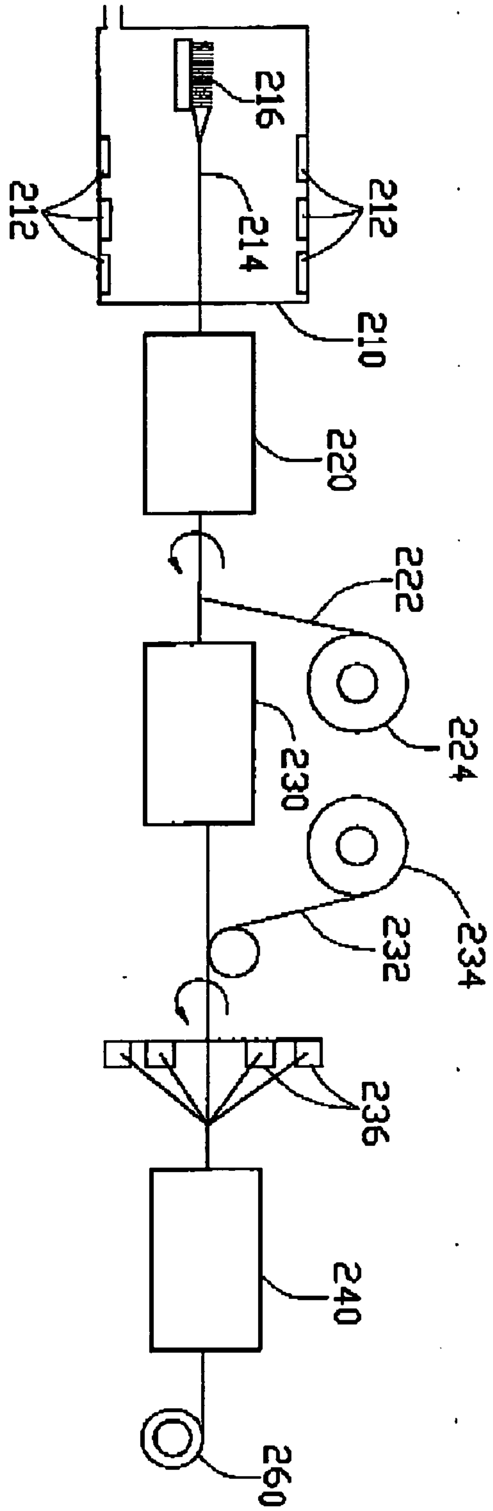

FIG. 4

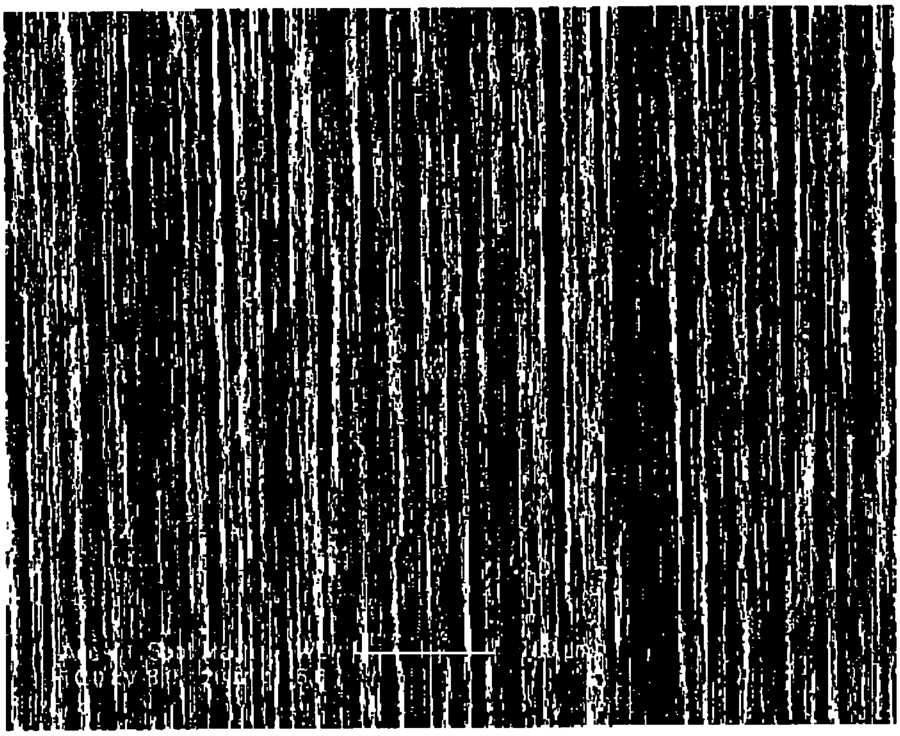

FIG. 5

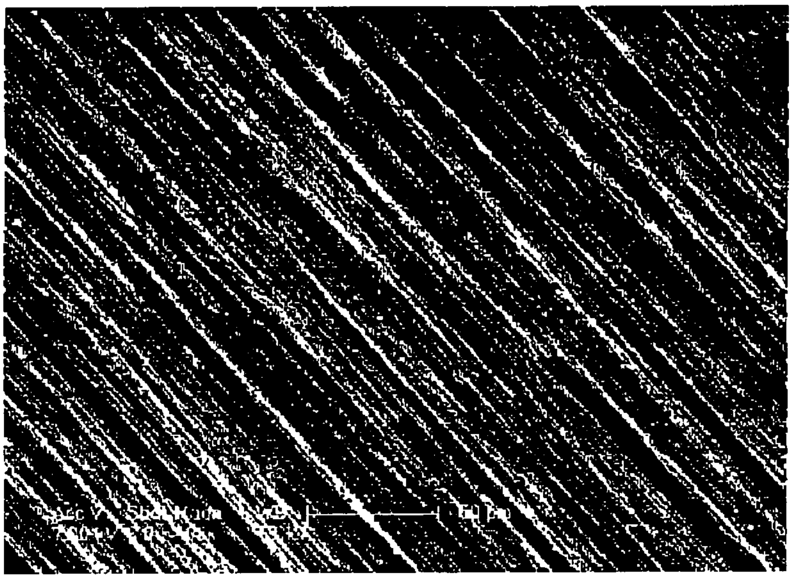

FIG. 6

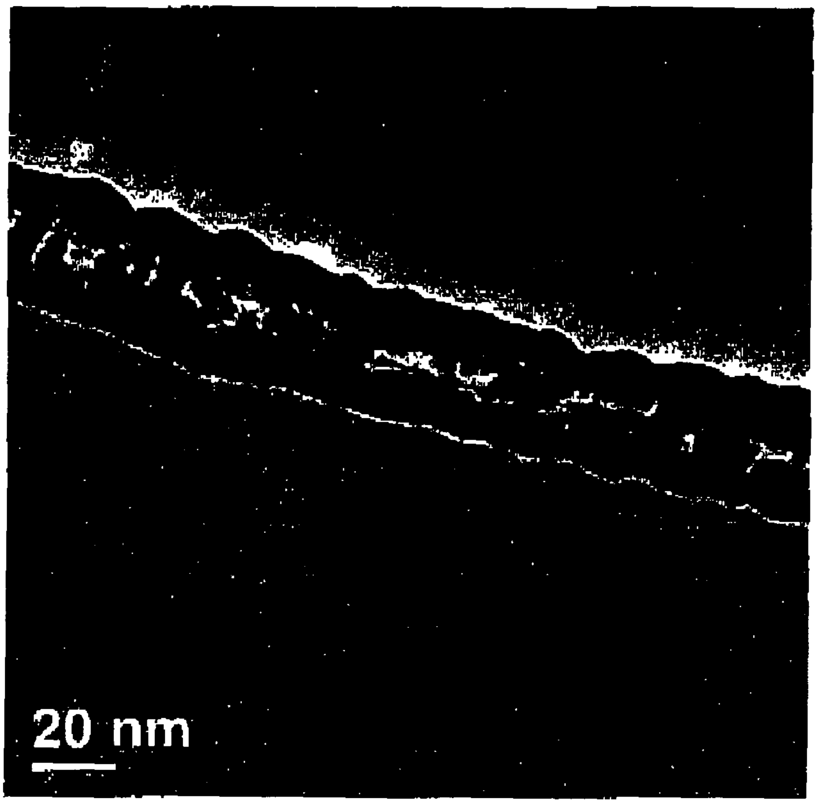

FIG. 7

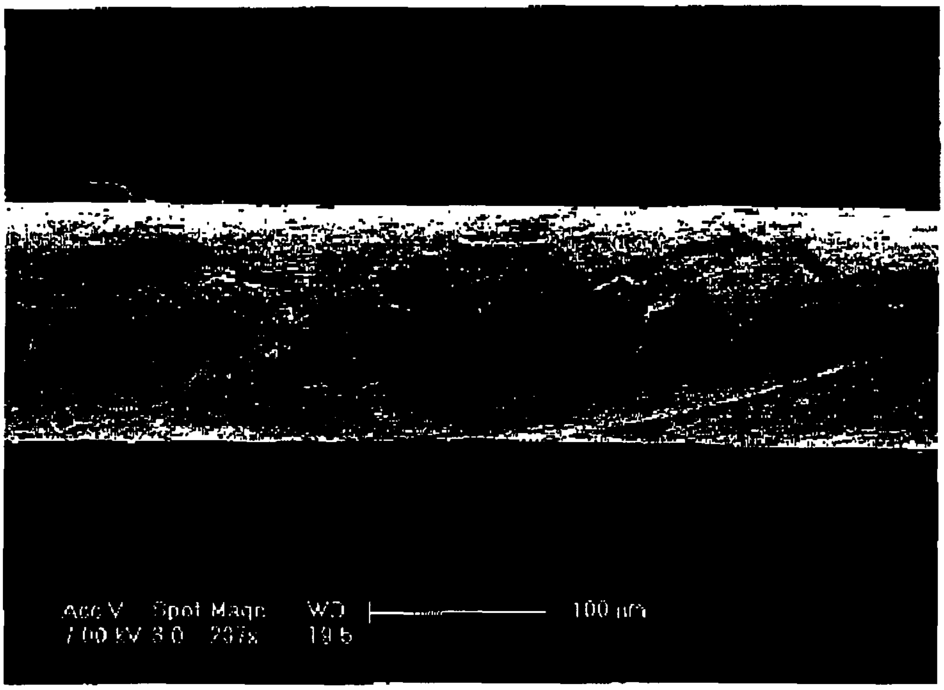

FIG. 8

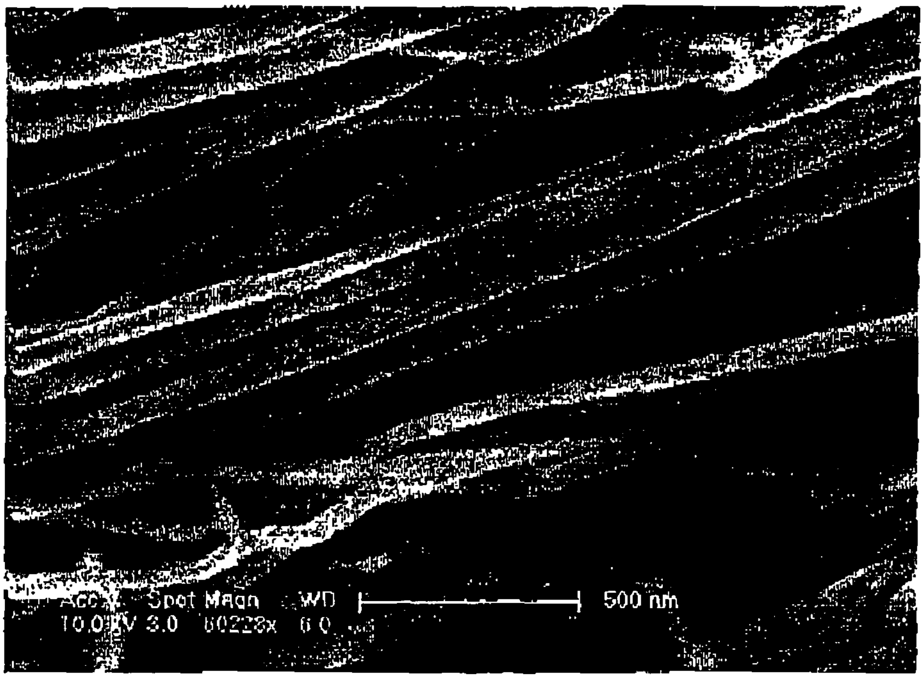

FIG. 9

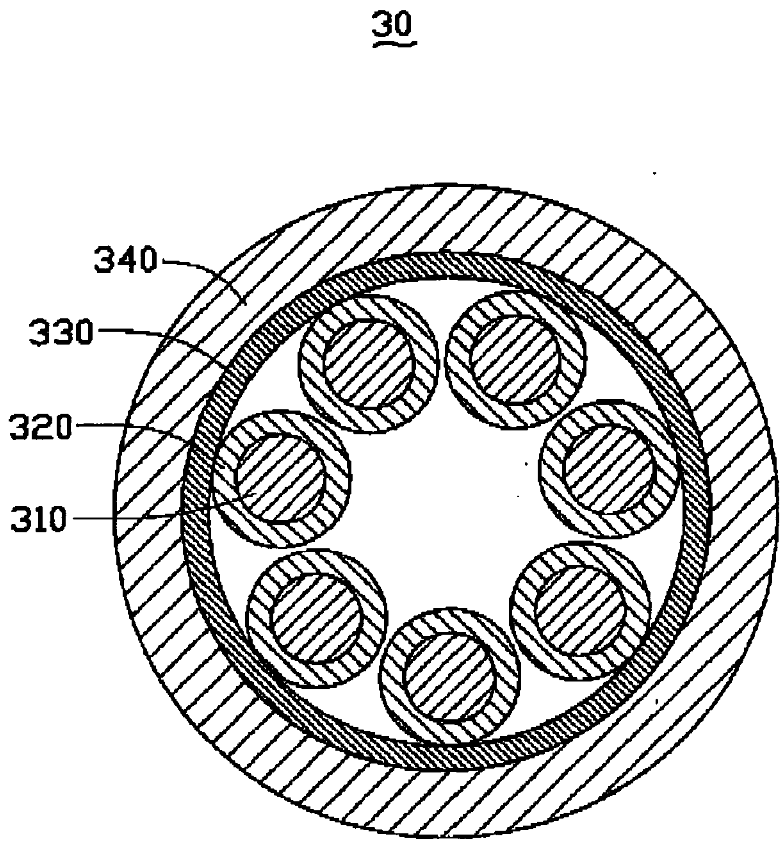

FIG. 10

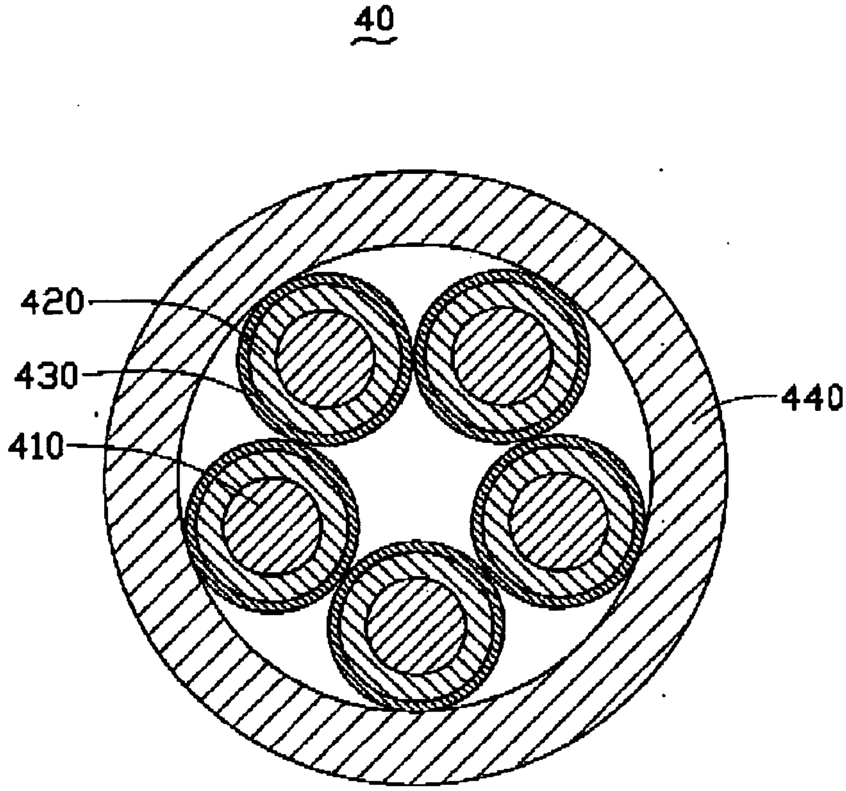

FIG. 11

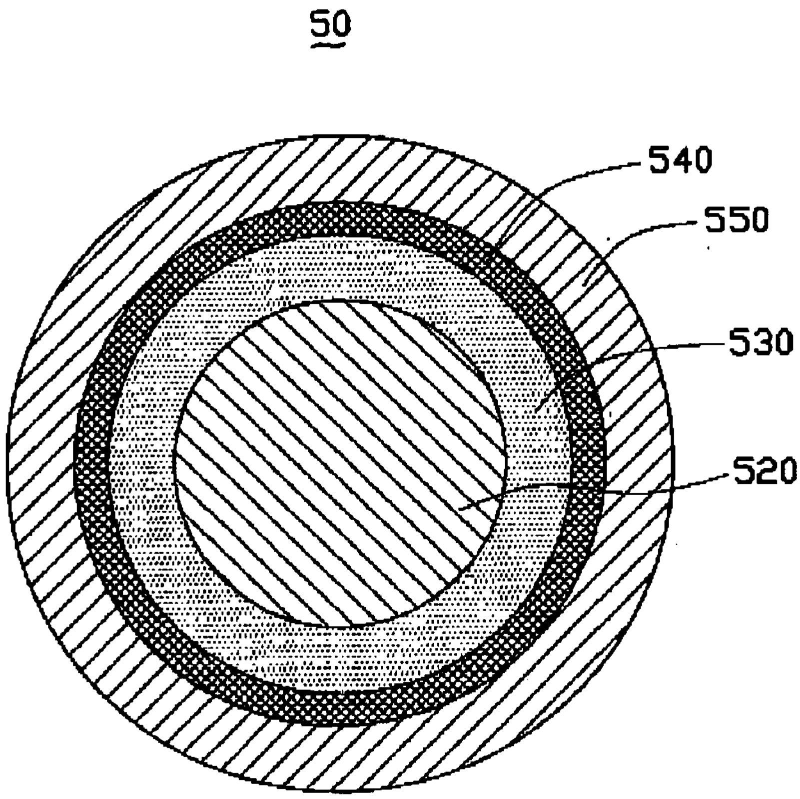

FIG. 12

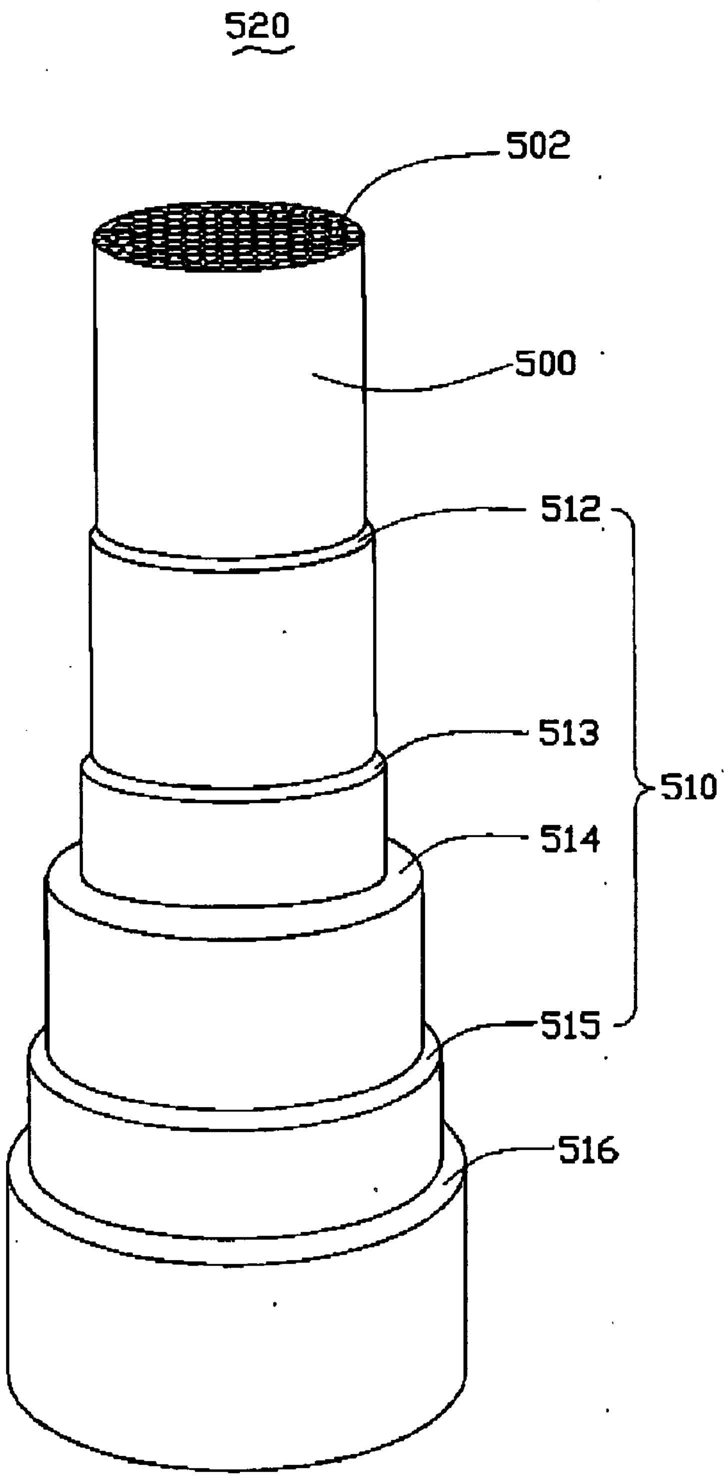

FIG. 13

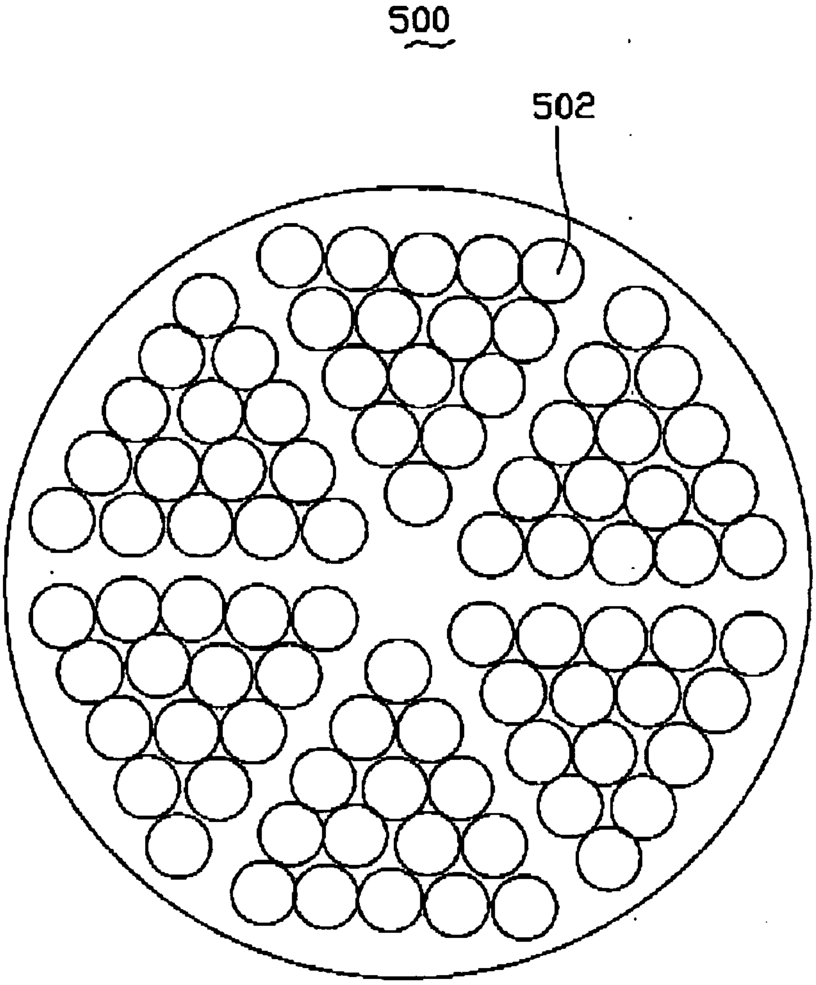

FIG. 14

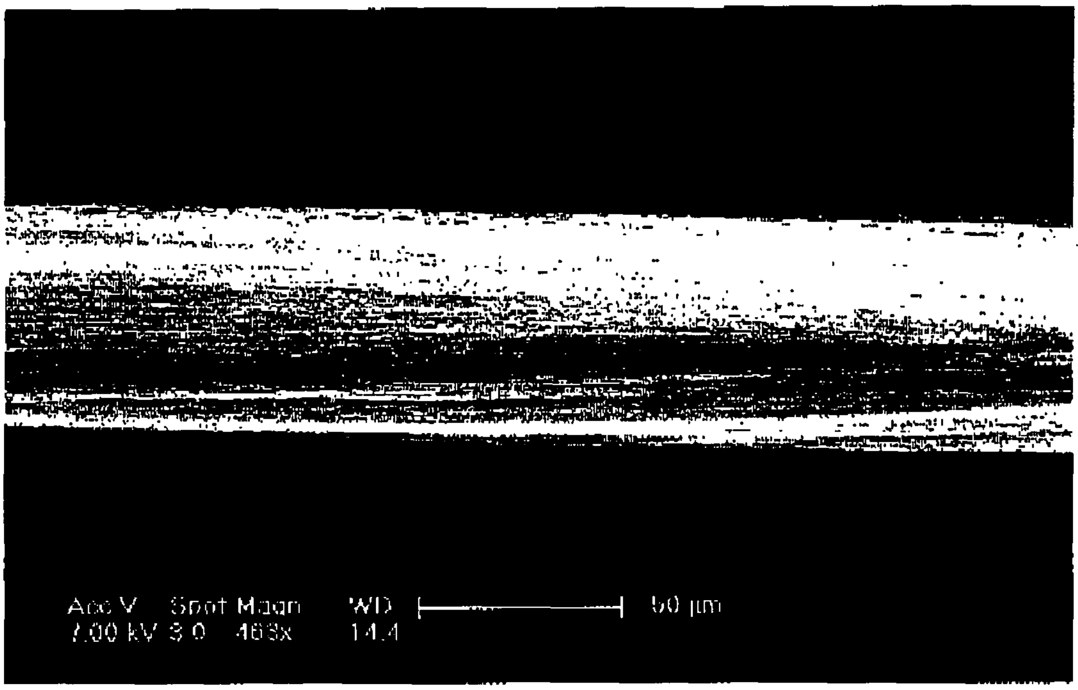

FIG. 15

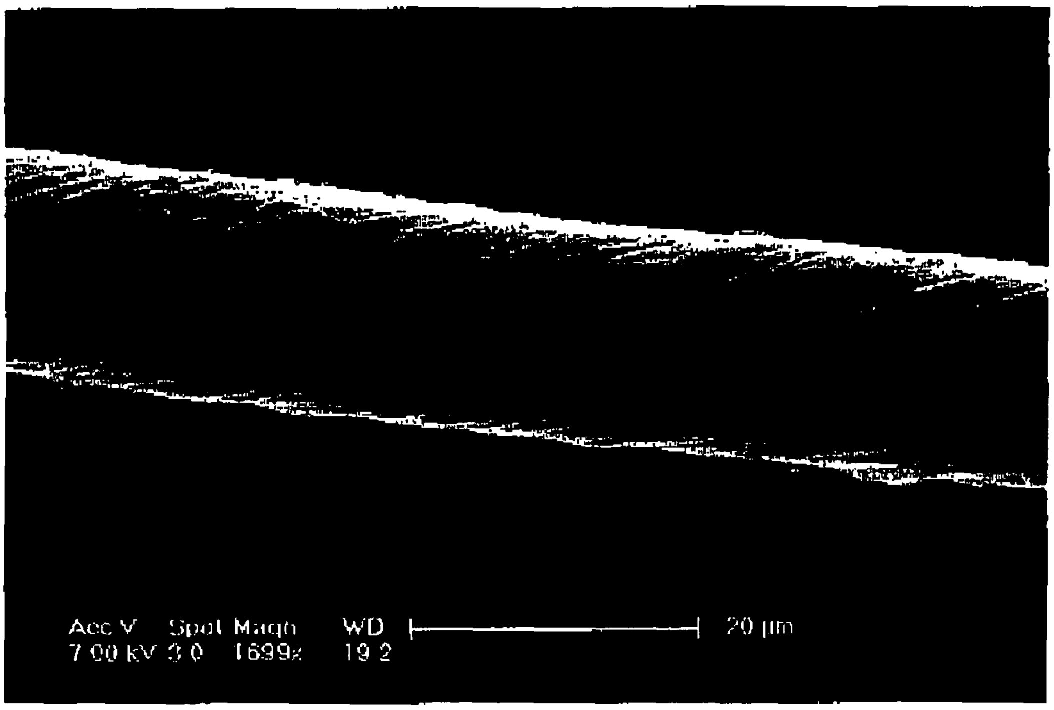

FIG. 16