

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
6 December 2007 (06.12.2007)

PCT

(10) International Publication Number
WO 2007/139271 A1

(51) International Patent Classification:
H01J 1/30 (2006.01) *H01J 1/304* (2006.01)

(74) Agent: LEE, Cheo Young; 11th, Won Bldg., 648-26, Yeoksam-dong, Gangnam-gu, Seoul 135-080 (KR).

(21) International Application Number:
PCT/KR2007/000368

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KZ, LA, LC, LK, LR, LS, LT, LU, LV, LY, MA, MD, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VC, VN, ZA, ZM, ZW.

(22) International Filing Date: 22 January 2007 (22.01.2007)

(25) Filing Language: Korean

(26) Publication Language: English

(30) Priority Data:
10-2006-0047655 26 May 2006 (26.05.2006) KR
10-2006-0074791 8 August 2006 (08.08.2006) KR

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

(71) Applicant: KOREA ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY [KR/KR]; 373-1, Guseong-dong, Yuseong-gu, Daejeon 305-701 (KR).

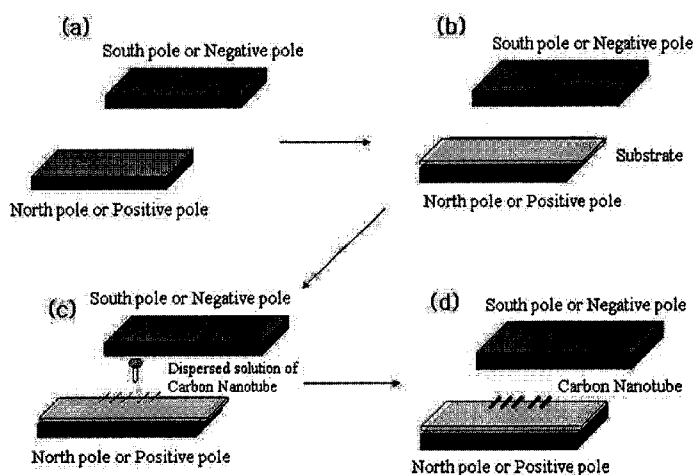
(72) Inventors: JUNG, Hee-Tae; 3-403, KAIST Kyosoo Apt., 383-2, Doryoung-dong, Yuseong-gu, Daejeon 305-340 (KR). YOUN, Sang Cheon; 6-202 Kyeongmin Apt., Dongho-dong, Donghae-si, Gangwon-do 240-043 (KR). KO, Young Koan; 108-601, e-Pyeonhansang Apt., Yeoksam 2-dong, Gangnam-gu, Seoul 135-082 (KR).

Published:

— with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: METHOD FOR MANUFACTURING A FIELD EMITTER ELECTRODE USING THE ARRAY OF CARBON NANOTUBES



(57) Abstract: The present invention relates to a method for fabricating a field emitter electrode, in which carbon nanotubes (CNTs) are aligned in the direction of a generated magnetic field. Specifically, the method comprises the steps of dispersing a solution of carbon nanotubes (CNTs) diluted in a solvent, on a substrate fixed to the upper part of an electromagnetic field generator, and fixing the carbon nanotubes aligned in the direction of an electromagnetic field generated from the electromagnetic field generator. According to the disclosed method, high-density and high-capacity carbon nanotubes aligned in the direction of a generated electromagnetic field can be fabricated in a simple process and can be applied as positive electrode materials for field emission displays (FEDs), sensors, electrodes, backlights and the like.

METHOD FOR MANUFACTURING A FIELD EMITTER ELECTRODE USING THE ARRAY OF CARBON NANOTUBES

5

TECHNICAL FIELD

The present invention relates to a method for fabricating a field emitter electrode, in which carbon nanotubes (CNTs) are aligned in the direction of a generated
10 electromagnetic field. More particularly, the present invention relates to a method for fabricating a field emitter electrode including carbon nanotubes (CNTs) aligned in the direction of a generated electromagnetic field, the method comprising the steps of dispersing a solution of carbon nanotubes (CNTs) diluted in a solvent, on a substrate fixed to the upper part of an electromagnetic field generator, and fixing the
15 carbon nanotubes aligned in the direction of an electromagnetic field generated from the electromagnetic field generator.

BACKGROUND ART

20

Generally, a field emission device is a light source based on electron emission in vacuum and refers to an element that emits light according to the principle by which electrons emitted from microparticles are accelerated by a strong electric field to impinge upon fluorescent materials. The above-mentioned field emission device
25 has advantages such as excellent light emitting efficiency and capability of realizing light-weight and compactness as compared to conventional illumination light sources such as an incandescent bulb, as well as environmental friendliness due to no use of heavy metals unlike fluorescent lamps. Thus, it has received a great deal of attention as a next generation light source for use in a variety of illumination
30 fields and display devices.

The performance of field emission devices significantly depends on the emitter electrode's capability to emit an electric field. Recently, carbon nanotubes (CNTs) have been actively used as the electron emitting material for an emitter electrode having excellent electron emission characteristics.

5

Carbon nanotube is an allotrope of carbon, which consists of carbons existing abundantly on the earth. They are tubular materials where a carbon atom is bound to other carbons in the form of a hexagonal honeycomb structure. Their diameter is about the size of a nanometer ($1/10^9$ meter), and their length is from several
10 hundred nanometer to several micrometer. Carbon nanotube has a large aspect ratio compared to other materials. Carbon nanotubes are known to have excellent mechanical properties and electrical selectivity, and in particular have an excellent electromagnetic field generation due to a large aspect ratio.

15 It has been reported that carbon nanotubes can be used as a positive electrode material for field emission displays due to their excellent field emission characteristics. In a prior paper (Kim, J.M. *et al.*, *Applied Physics Letters*, 75(20):3129, 1999), carbon nanotubes were aligned in a specific direction with a polymer complex by a mechanical rubbing, and the field emission characteristics of
20 the resulting carbon nanotubes were measured. However, in this case, there is a serious disadvantage in that the mixed polymer substance must be burned during the fabrication process, as well as a problem in that it is difficult to align carbon nanotubes over a large area in the direction of a generated electromagnetic field.

25 Also, a method for directly growing carbon nanotubes at high temperature to align the carbon nanotubes in a specific direction was proposed (Wong C.P., *et al.*, *Carbon*, 44:253, 2006). However, this method cannot be used in practice, because it has a serious disadvantage in that indium tin oxide (ITO) glass used as a positive electrode plate for a display device cannot resist high temperatures.

30

In an attempt to solve the above-described problems, a method for fabricating a field emitter electrode was proposed, which comprises attaching carbon nanotubes to a substrate, applying a conductive polymer to the substrate and aligning the carbon nanotubes in a specific direction (Korean Patent Publication No. 2006-
5 0024725). However, this method also fails to align carbon nanotubes in the direction of a generated electromagnetic field at high density over a large area, and does not overcome a disadvantage in that the polymer must be burned during the fabrication process.

10 Thus, there is an urgent need to develop a method for fabricating a field emitter electrode, which employs a simple process and in which carbon nanotubes are aligned in a specific direction along the direction of a generated electromagnetic field at high density over a large area.

15 Accordingly, the present inventors have made extensive efforts to solve the problems occurring in the prior methods for aligning carbon nanotubes in a specific direction. As a result, the present inventors have found that, when carbon nanotubes are aligned on a substrate fixed to the upper part of an electromagnetic field generator and are then fixed using a metal, it is possible to fabricate a field
20 emitter electrode including carbon nanotubes aligned at high density over a large area, thereby completing the present invention.

SUMMARY OF THE INVENTION

25

Therefore, it is an object of the present invention to provide a field emitter electrode having excellent field emission characteristics, in which carbon nanotubes aligned at high density over a large area are fixed on a substrate with a metal, as well as a fabrication method thereof.

30

To achieve the above object, in one aspect, the present invention provides a method for fabricating a field emitter electrode including carbon nanotubes aligned in the direction of a magnetic field, the method comprising the steps of: (a) dispersing a solution of carbon nanotubes or magnetic particle-bound carbon nanotubes diluted
5 in an organic solvent, on a substrate fixed to the upper part of a magnetic field generator; (b) aligning the carbon nanotubes in a magnetic field generated from the magnetic field generator, in the direction of the magnetic field by evaporating the organic solvent from the solution dispersed on the substrate; and (c) depositing a metal on the substrate, in order for the carbon nanotubes aligned in the direction of
10 the generated magnetic field to be fixed in the aligned direction even in magnetic field-free conditions.

In the present invention, the direction of the generated magnetic field is preferably perpendicular, horizontal or any angle between perpendicular and horizontal to the
15 substrate, and the magnetic particle-bound carbon nanotubes are preferably obtained by binding the magnetic particles to the carbon nanotubes using a physical-chemical method. Also, the physical-chemical method is preferably selected from the group consisting of a method of treating the carbon nanotubes with acid, a method of subjecting the magnetic particles to a reduction reaction, and a method of plating
20 the magnetic particles on the carbon nanotubes.

In the present invention, the magnetic field generator in the step (a) is preferably a magnet, and the magnetic field generated from the magnetic field generator preferably has a magnitude of 0.005-10 Tesla (T).

25

In the present invention, the magnetic particles are preferably iron (Fe)-containing particles. The iron (Fe)-containing particles are preferably selected from the group consisting of iron chloride (FeCl_3), ferrous oxide (FeO), ferric oxide (Fe_2O_3) and triiron tetroxide (Fe_3O_4).

30

In another aspect, the present invention provides a field emitter electrode fabricated according to said method, in which magnetic particle-bound carbon nanotubes are aligned on a substrate having a metal deposited thereon, in the direction of a magnetic field.

5

In still another aspect, the present invention provides a method for fabricating a field emitter electrode including carbon nanotubes aligned in the direction of a generated electric field, the method comprising the steps of: (a) dispersing a solution of carbon nanotubes diluted in an organic solvent, on a substrate fixed to
10 the upper part of an electric field generator; (b) aligning the carbon nanotubes on the substrate in an electric field generated from the electric field generator, in the direction of the generated electric field by evaporating the organic solvent from the solution dispersed on the substrate; and (c) depositing a metal on the substrate, in order for the carbon nanotubes aligned in the direction of the generated electric field
15 to be fixed in the aligned direction even in electric field-free conditions.

In the present invention, the direction of the generated electric field is preferably perpendicular, horizontal or any angle between perpendicular and horizontal to the substrate, and the electric field generator in the step (a) is an electric field. Also,
20 the electric field preferably has a magnitude of 1-500 V/ μ m.

In the present invention, the step (a) preferably additionally comprises adding a dispersion aid. The dispersion aid is selected from the group consisting of organic solvent TOAB (tetraoctylammonium bromide), and surfactants Triton X-100, SDS
25 (sodium dodecylsulfate), NADDBS (sodium dodecyl benzenesulfonate), and PAPPV (poly[2-(2'-ethylhexyloxy)-5-(phenylethynyl)-1,4-phenylenevinylene]).

In the present invention, the step (a) of dispersing the solution of carbon nanotubes diluted in the organic solvent, on the substrate fixed to the upper part of the electric
30 field generator, is preferably carried out using a method selected from the group

consisting of a spin coating method, a spray method, a dip coating method, and an inkjet method. Also, the steps (a) and (b) are preferably repeated 1-1000 times to increase the density of the carbon nanotubes. Furthermore, the carbon nanotubes are preferably single-wall, double-wall or multi-wall carbon nanotubes.

5

In the present invention, the solvent in the step (a) is preferably selected from the group consisting of water (H₂O), dimethylformamide (DMF), N-methyl-2-pyrrolidone (NMP), dimethylacetamide (DMAc), cyclohexanone, ethyl alcohol, chloroform, dichloromethane, 1,2-dichlorobenzene and ethyl ether. The substrate
10 in the step (a) is preferably selected from the group consisting of indium tin oxide (ITO) glass, glass, quartz, glass wafers, silicon wafers, applied silica, plastics, and transparent polymers. The solvent in the step (b) is preferably removed by heating the solution to a temperature of 20-300°C. Furthermore, among the above-described organic solvents, chloroform, dichloromethane, diethyl ether and the like
15 have good volatility, and thus can be removed even at room temperature.

In the present invention, the concentration of the carbon nanotubes in the carbon nanotube dispersion in the step (a) is preferably 0.001-1.0 wt%, and the amount of the carbon nanotubes dispersed on the substrate in the step (a) is 1 pg/cm²-1 g/cm²
20 (amount of carbon nanotubes per unit area).

In the present invention, the metal in the step (c) is preferably deposited to a thickness of 1-5000 nm. Also, the metal in the step (c) is preferably selected from the group consisting of titanium (Ti), molybdenum (Mo), gold (Au), silver (Ag),
25 aluminum (Al), calcium (Ca), cadmium (Cd), iron (Fe), nickel (Ni), platinum (Pt), zinc (Zn) and copper (Cu).

In yet another aspect, the present invention provides a field emitter electrode fabricated according to said method, in which carbon nanotubes are aligned on a

substrate having a metal deposited thereon, in the direction of a generated electric field.

The above and other objects, features and embodiments of the present invention will
5 be more clearly understood from the following detailed description and accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

10

FIG. 1 is a schematic diagram showing that carbon nanotubes are aligned by the application of a magnetic field.

FIG. 2 shows transmission electron microscopy (TEM) photographs of carbon
15 nanotubes before and after purification (left: 50,000X magnification; and right: 100,000X magnification), in which FIG. 2(a) shows carbon nanotubes containing impurities before purification, and FIG. 2(b) shows pure carbon nanotubes after purification.

20 FIG. 3 is a transmission electron microscopy (TEM) photograph showing magnetic particles bound to carbon nanotubes (left: 50,000X magnification; and right: 100,000X magnification).

FIG. 4 shows the substrate after removing the magnet from FIG. 1(d) and is a
25 scanning electron microscopy (SEM) photograph showing that carbon nanotubes are aligned in the direction of a generated magnetic field (upper: 50,000X magnification; and lower: 25,000X magnification), in which FIG. 4(a) shows the substrate inclined at an angle of 80°, and FIG. 4(b) shows the substrate inclined at an angle of 45°.

30

FIG. 5 is a photograph of carbon nanotubes aligned in the direction of a generated magnetic field according to the present invention.

FIG. 6 is a graphic diagram showing the field emission characteristics of carbon nanotubes aligned in the direction of a generated electric field according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION, AND PREFERRED EMBODIMENTS

Carbon nanotubes have characteristic electromagnetic properties, and when carbon nanotubes bound to magnetic particles are fixed on a substrate having an electric or magnetic field flowing therethrough, it is possible to fabricate a field emitter electrode having more excellent field emission characteristics.

In one aspect, the present invention relates to a method for fabricating a field emitter electrode, in which carbon nanotubes (CNTs) are aligned in the direction of a generated magnetic or electric field.

In the present invention, a field emitter electrode, in which carbon nanotubes having magnetic particles bound thereto are aligned in the direction of a generated magnetic field or electric field, is fabricated according to the method shown in FIG. 1. Specifically, as shown in FIG. 1a, a circular magnet to be used in the present invention, having a magnitude of 1000 Gauss (G), is first prepared. Then, indium tin oxide (ITO) glass, on which carbon nanotubes are to be aligned, is attached to the magnet with a carbon adhesive (see FIG. 1b). Then, a dispersion of carbon nanotubes having magnetic particles bound thereto is dropped onto the indium tin oxide glass (see FIG. 1c). Then, a metal is deposited on the glass so as to fix the

carbon nanotubes aligned in the direction of a generated magnetic field or electric field (see FIG. 1d).

The method for fabricating the field emitter electrode will be described in further
5 detail in five divided steps.

Step 1: Preparation of carbon nanotubes

Carbon nanotubes for use in the present invention are not specifically limited, and
10 can be purchased from commercial sources or prepared according to any conventional method. For use in the present invention, carbon nanotubes should have a clean surface and contain no metal catalyst. Also, carbon nanotubes for use in the present invention are preferably single-wall, double-wall or multi-wall carbon nanotubes and can be prepared according to the Hipco (high-pressure CO
15 disproportionation) process.

Step 2: Binding of magnetic particles to carbon nanotubes

In order to bind magnetic particles to the carbon nanotubes prepared in the step 1,
20 iron chloride (FeCl_3), ferrous oxide (FeO), ferric oxide (Fe_2O_3) and triiron tetroxide (Fe_3O_4) are added to a mixture of ethanol, distilled water and hexane and heated to prepare an iron-oleate complex. The prepared iron-oleate complex is mixed with oleic acid and dimethylformamide (DMF), and the carbon nanotubes prepared in the step 1 are added to the mixture. The mixture containing the carbon nanotubes
25 added thereto is completely dissolved in 1-octadecene and then heated to evaporate the solvents from the mixture. The remaining material is washed 3-4 times with ethanol, thus preparing carbon nanotubes having magnetic particles bound thereto.

Step 3: Dispersion of magnetic particle-bound carbon nanotubes on substrate

The magnetic particle-bound carbon nanotubes prepared in the step 2 are diluted in at least one solvent selected from the group consisting of dimethylformamide (DMF), N-methyl-2-pyrrolidone (NMP), dimethylacetamide (DMAc), cyclohexanone, ethyl alcohol, chlorobenzene, 1,2-dichlorobenzene and chloroform
5 at a concentration of 0.001-1.0 wt%. Then, the dispersion of the magnetic particle-bound carbon nanotubes is dropped on an indium tin oxide (ITO) glass substrate fixed to the upper part of a magnet having a magnetic field, and the solvent is allowed to evaporate.

10 Step 4: Increasing density of magnetic particle-bound carbon nanotubes on substrate

On the indium tin oxide (ITO) glass substrate prepared in the step 3, from which the solvent completely evaporated, 1-2 drops of the dispersion of the magnetic particle-bound carbon nanotubes diluted in the solvent are added, and then the solvent is
15 allowed to evaporate in high-temperature condition. To increase the density of the magnetic particle-bound carbon nanotubes, the above step can be repeated 5-20 times. By doing so, the magnetic particle-bound carbon nanotubes prepared according to the above method are aligned in the direction of the magnetic field generated from the magnet.

20

Step 5: Fixing magnetic particle-bound carbon nanotubes on substrate

In order for the carbon nanotubes aligned by the magnetic field in the step 4 to be aligned in the aligned direction even in magnetic field-free conditions, a metal
25 selected from the group consisting of titanium (Ti), molybdenum (Mo), gold (Au), aluminum (Al), calcium (Ca), cadmium (Cd), iron (Fe), nickel (Ni), platinum (Pt), zinc (Zn) and copper (Cu) is deposited on the substrate, thus fabricating a pure field emitter electrode.

In another aspect, the present invention relates to a method for fabricating a field emitter electrode, in which carbon nanotubes (CNTs) are aligned in the direction of a generated electric field.

5 In the above description, only the method comprising using the magnet as the electromagnetic field generator and aligning the carbon nanotubes by binding magnetic particles thereto has been described in detail. However, through the above description, it will be obvious to those skilled in the art that the electric field generator is an electric field, and the field emitter electrode can be fabricated either
10 by aligning the carbon nanotubes on the substrate by adding a surfactant to the solution of the carbon nanotubes, or by aligning pure carbon nanotubes on the substrate fixed to the upper part of the electromagnetic field generator. Specifically, the field emitter electrode aligned in the direction of the generated electric field can be fabricated through the following steps:

15 (a) dispersing a solution of carbon nanotubes diluted in an organic solvent, on a substrate fixed to the upper part of an electric field generator;

(b) aligning the carbon nanotubes on the substrate in an electric field generated from the electric field generator, in the direction of the generated electric field by evaporating the organic solvent from the solution dispersed on the
20 substrate; and

(c) depositing a metal on the substrate, in order for the carbon nanotubes aligned in the direction of the generated electric field to be fixed in the aligned direction even in electric field-free conditions.

25 According to the present invention, the field emitter electrode, in which carbon nanotubes (CNTs) are aligned in perpendicular, horizontal or any angle between perpendicular and horizontal to the substrate according to the direction of a generated electromagnetic field, can be fabricated. Also, the characteristic field emission properties of the carbon nanotubes aligned at high density over a large
30 area in the direction of a generated electromagnetic field can be used to fabricate a

field emitter electrode having a greatly improved field emission effect. The field emitter electrode fabricated according to the method of the present invention can be used as a field emitter electrode for displays, and can also be applied in scanning electron microscopes (SEM) and transmission electron microscopes (TEM), which
5 employ field emission phenomena.

Example

The present invention will hereinafter be described in further detail by examples. However, it is to be understood that these examples can be modified into other
10 various forms, and the scope of the present invention is not intended to be limited to such examples. Such examples are given to more fully describe the present invention for a person skilled in the art.

Example 1: Preparation of carbon nanotubes

15 500 mg of carbon nanotubes were placed in a furnace at 365°C, in which they were thermally treated for 90 minutes, while 0.1 SLM (standard liters per minute) of air was injected into the furnace. The thermally treated carbon nanotubes were added to 500 ml of hydrochloric acid, sonicated for 1 hour and filtered through a 1- μ m
20 filter. Then, the filtered carbon nanotubes were added to 500 ml of hydrochloric acid, sonicated for 1 hour and filtered through a 1- μ m filter. The hydrochloric acid treatment process was repeated 3-5 times to purify the carbon nanotubes. Also, the carbon nanotubes were observed with transmission electron microscopy (TEM) photographs before and after the purification process (see FIG. 2). As a result, as
25 shown in FIG. 2, the carbon nanotubes contained impurities before purification (see FIG. 2a), but they contained no impurities after purification (see FIG. 2b). The purified carbon nanotubes were immersed in a mixture of sulfuric acid and hydrogen peroxide (4:1 v/v) and stirred for 9 hours to cut them. Then, the

resulting carbon nanotubes were diluted in distilled water, filtered through a 500-nm filter and dried in an oven at 120°C for at least 12 hours.

Example 2: Binding of magnetic particles to carbon nanotubes

5

10.8 g of iron chloride ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$) and 36.5 g of sodium oleate ($\text{C}_{18}\text{H}_{33}\text{NaO}_2$) were added to a mixture of 80 ml of ethanol, 60 ml of distilled water and 140 ml of hexane, and heated at 70°C for 4 hours, thus preparing an iron-oleate complex. 12 g of the prepared iron-oleate complex, 2.83 g of oleic acid and 3 ml of dimethylformamide (DMF) solvent were mixed with each other, and 150 mg of the carbon nanotubes prepared in Example 1 were dispersed in the mixture.

Then, the mixture was completely dissolved in 130 ml of 1-octadecene at room temperature, and the mixture was heated to a temperature of 320°C, allowed to react for 30 minutes at that temperature, and then cooled to room temperature. The reaction material was washed 3-4 times with ethanol, centrifuged to remove the supernatant, and then filtered through a 1- μm filter, thus affording carbon nanotubes having ferric oxide (Fe_2O_3) bound thereto. The prepared carbon nanotubes were observed with a transmission electron microscopy (TEM) photograph (see FIG. 3). As a result, as shown in FIG. 3, it could be seen that the carbon nanotubes had the magnetic particles bound thereto.

Example 3: Dispersion of magnetic particle-carbon nanotubes on substrate

25 5 mg of the magnetic particle-carbon nanotubes prepared in Example 2 were dispersed in 50 ml of dimethylformamide (DMF), and 10 ml of the dispersion was then diluted in 40 ml of pure dimethylformamide (DMF).

Meanwhile, indium tin oxide (ITO) glass was fixed on a magnet having a magnetic field of 1000 gauss, and then placed in an oven at 120°C. As the temperature of the indium tin oxide (ITO) glass was increased to 120°C, about 1 μl of said solution of the magnetic particle-bound carbon nanotubes diluted in dimethylformamide was dropped on the indium tin oxide (ITO) glass in the oven and maintained at 120°C for 10 minutes to evaporate the dimethylformamide (DMF).

Example 4: Increasing density of magnetic particle-bound carbon nanotubes on substrate

On the indium tin oxide (ITO) glass substrate, which was prepared in Example 3 and from which the dimethylformamide (DMF) was completely evaporated, about 1 μl of the solution of the magnetic particle-bound carbon nanotubes diluted in dimethylformamide was further dropped. Then, the temperature of the oven containing the glass substrate was 120°C for 10 minutes to evaporate the dimethylformamide (DMF). In order to increase the density of the magnetic particle-bound carbon nanotubes on the substrate, this step was repeated several tens of times.

The substrate prepared according to the above-described method was observed with a transmission electron microscopy (SEM) photograph and, as a result, it could be seen that the magnetic particle-bound carbon nanotubes were aligned in the direction of the magnetic field generated from the magnet (see FIG. 4).

Example 5: Fixation of magnetic particle-bound carbon nanotubes on substrate

In order for the magnetic particle-bound carbon nanotubes to be aligned in the direction of the generated magnetic field even in magnetic field-free conditions, titanium (Ti) was deposited on the substrate to total heights of 30 nm and 70 nm at a

rate of 0.5 nm/sec at room temperature using an e-beam deposition system (MooHan Co. Ltd., Korea). After completion of the deposition, the magnet was removed, thus fabricating a pure field emitter electrode (see FIG. 5). As shown in FIG. 5, it could be seen that the carbon nanotubes in the field emitter electrode were
5 aligned in the direction of the generated magnetic field.

Also, in order to examine the field emission characteristics of the carbon nanotube electrodes in the fabricated field emitter electrode, the current density of the carbon nanotubes according to an electric field was measured (see FIG. 6). As shown in
10 FIG. 6, it could be seen that the field emitter electrode according to the present invention had excellent field emission characteristics.

INDUSTRIAL APPLICABILITY

15

As described above, according to the present invention, a field emitter electrode, in which high-density and high-capacity carbon nanotubes (CNTs) are aligned in the direction of a generated electromagnetic field can be fabricated in a simple process. The field emitter electrode according to the present invention can be used as a field
20 emitter electrode for displays, and can also be applied in scanning electron microscopes (SEM) and transmission electron microscopes (TEM), which employ field emission phenomena.

While the present invention has been described with reference to the particular
25 illustrative embodiment, it is not to be restricted by the embodiment but only by the appended claims. It is to be appreciated that those skilled in the art can change or modify the embodiment without departing from the scope and spirit of the present invention.

THE CLAIMS

What is claimed is:

1. A method for fabricating a field emitter electrode including carbon nanotubes
5 aligned in the direction of a magnetic field, the method comprising the steps of:
 - (a) dispersing a solution of carbon nanotubes or magnetic particle-bound carbon nanotubes diluted in an organic solvent, on a substrate fixed to the upper part of a magnetic field generator;
 - (b) aligning the carbon nanotubes in a magnetic field generated from the
10 magnetic field generator, in the direction of the magnetic field by evaporating the organic solvent from the solution dispersed on the substrate; and
 - (c) depositing a metal on the substrate, in order for the carbon nanotubes aligned in the direction of the generated magnetic field to be fixed in the aligned direction even in magnetic field-free conditions.
- 15 2. The method for fabricating a field emitter electrode according to claim 1, wherein the direction of the generated magnetic field is perpendicular, horizontal or any angle between perpendicular and horizontal to the substrate.
- 20 3. The method for fabricating a field emitter electrode according to claim 1, wherein the magnetic particle-bound carbon nanotubes are obtained by binding the magnetic particles to the carbon nanotubes using a physical-chemical method.
4. The method for fabricating a field emitter electrode according to claim 3, wherein
25 the physical-chemical method is selected from the group consisting of a method of treating the carbon nanotubes with acid, a method of subjecting the magnetic particles to a reduction reaction, and a method of plating the magnetic particles on the carbon nanotubes.

5. The method for fabricating a field emitter electrode according to claim 1, wherein the magnetic particles are iron (Fe)-containing particles.

6. The method for fabricating a field emitter electrode according to claim 1, wherein
5 the magnetic field generated from the magnetic field generator has a magnitude of 0.005-10 Tesla (T).

7. A method for fabricating a field emitter electrode including carbon nanotubes aligned in the direction of a generated electric field, the method comprising the
10 steps of:

(a) dispersing a solution of carbon nanotubes diluted in an organic solvent, on a substrate fixed to the upper part of an electric field generator;

(b) aligning the carbon nanotubes on the substrate in an electric field generated from the electric field generator, in the direction of the generated electric
15 field by evaporating the organic solvent from the solution dispersed on the substrate; and

(c) depositing a metal on the substrate, in order for the carbon nanotubes aligned in the direction of the generated electric field to be fixed in the aligned direction even in electric field-free conditions.

20

8. The method for fabricating a field emitter electrode according to claim 7, wherein the direction of the generated electric field is perpendicular, horizontal or any angle between perpendicular and horizontal to the substrate.

25 9. The method for fabricating a field emitter electrode according to claim 7, wherein the electric field generator in the step (a) is an electric field.

10. The method for fabricating a field emitter electrode according to claim 9, wherein the electric field has a magnitude of $0.1\text{V}/\mu\text{m} \sim 500\text{V}/\mu\text{m}$.

30

11. The method for fabricating a field emitter electrode according to claim 7, wherein the step (a) additionally comprises adding a dispersion aid.
12. The method for fabricating a field emitter electrode according to claim 11,
5 wherein the dispersion aid is selected from the group consisting of organic solvent TOAB (tetraoctylammonium bromide), and surfactants Triton X-100, SDS (sodium dodecylsulfate), NADDBS (sodium dodecyl benzenesulfonate), and PAPPV (poly[2-(2'-ethylhexyloxy)-5-(phenylethynyl)-1,4-phenylenevinylene]).
- 10 13. The method for fabricating a field emitter electrode according to claims 1 or 7, wherein the step (a) of dispersing the solution of carbon nanotubes diluted in the organic solvent, on the substrate fixed to the upper part of the electric field generator, is carried out using a method selected from the group consisting of a spin coating method, a spray method, a dip coating method, and an inkjet method.
- 15 14. The method for fabricating a field emitter electrode according to claims 1 or 7, wherein the steps (a) and (b) are repeated 1-1000 times to increase the density of the carbon nanotubes.
- 20 15. The method for fabricating a field emitter electrode according to claims 1 or 7, wherein the solvent in the step (a) is selected from the group consisting of water (H₂O), dimethylformamide (DMF), N-methyl-2-pyrrolidone (NMP), dimethylacetamide (DMAc), cyclohexanone, ethyl alcohol, chloroform, dichloromethane, 1,2-dichlorobenzene and ethyl ether.
- 25 16. The method for fabricating a field emitter electrode according to claims 1 or 7, wherein the substrate in the step (a) is selected from the group consisting of indium tin oxide (ITO) glass, glass, quartz, glass wafers, silicon wafers, applied silica, plastics, and transparent polymers.

17. The method for fabricating a field emitter electrode according to claims 1 or 7, wherein the concentration of the carbon nanotubes in the carbon nanotube dispersion in the step (a) is 0.001-1.0 wt%.
- 5 18. The method for fabricating a field emitter electrode according to claims 1 or 7, wherein, the solvent in the step (b) is removed by heating the solution to a temperature of 20-300 °C.
19. The method for fabricating a field emitter electrode according to claims 1 or 7,
10 wherein the amount of the carbon nanotubes dispersed on the substrate in the step (a) is 1 pg/cm²-1 g/cm² (amount of carbon nanotubes per unit area).
20. The method for fabricating a field emitter electrode according to claims 1 or 7, wherein the metal in the step (c) is deposited to a thickness of 1-5000 nm.
- 15 21. The method for fabricating a field emitter electrode according to claims 1 or 7, wherein the metal in the step (c) is selected from the group consisting of titanium (Ti), molybdenum (Mo), gold (Au), silver (Ag), aluminum (Al), calcium (Ca), cadmium (Cd), iron (Fe), nickel (Ni), platinum (Pt), zinc (Zn) and copper (Cu).

1/3

FIG. 1

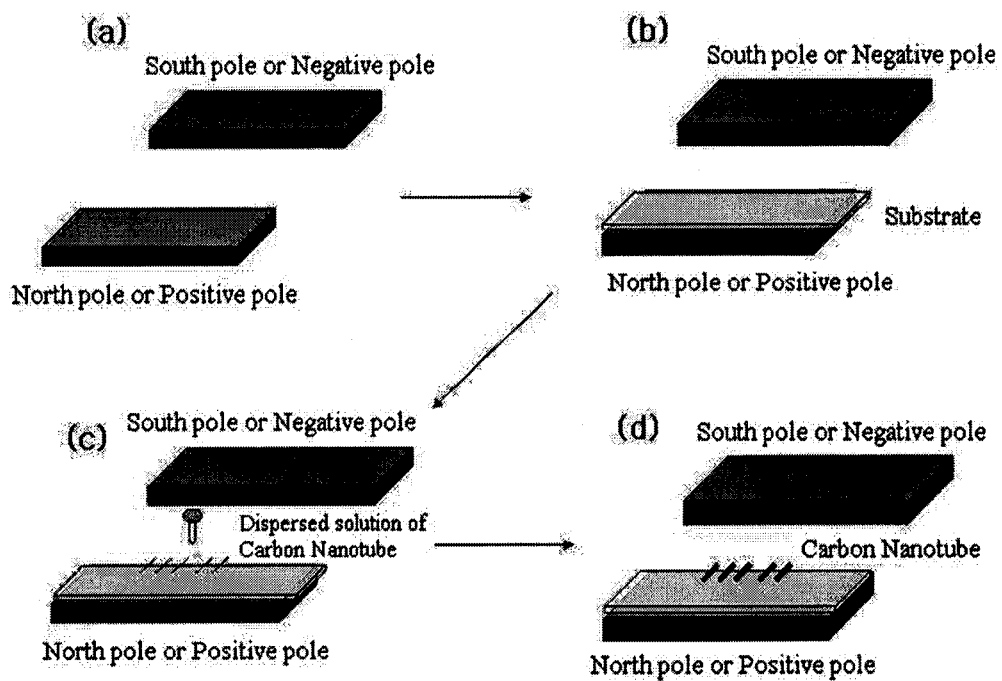
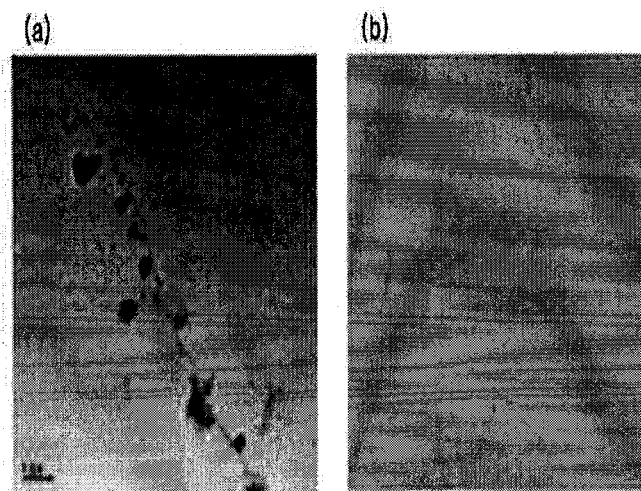


FIG. 2



2/3

FIG. 3

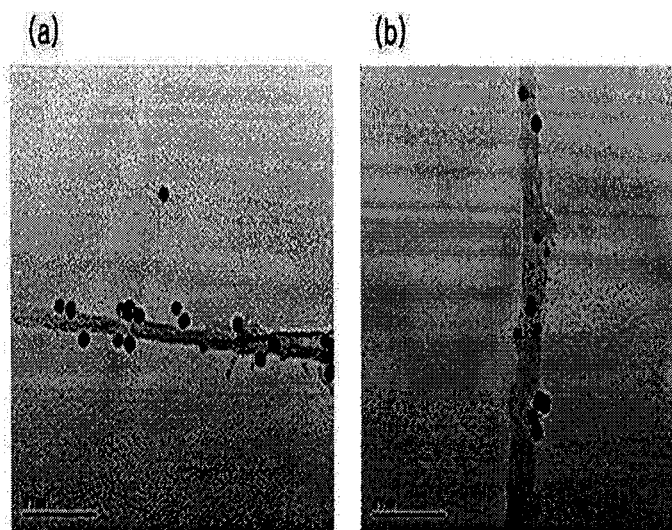
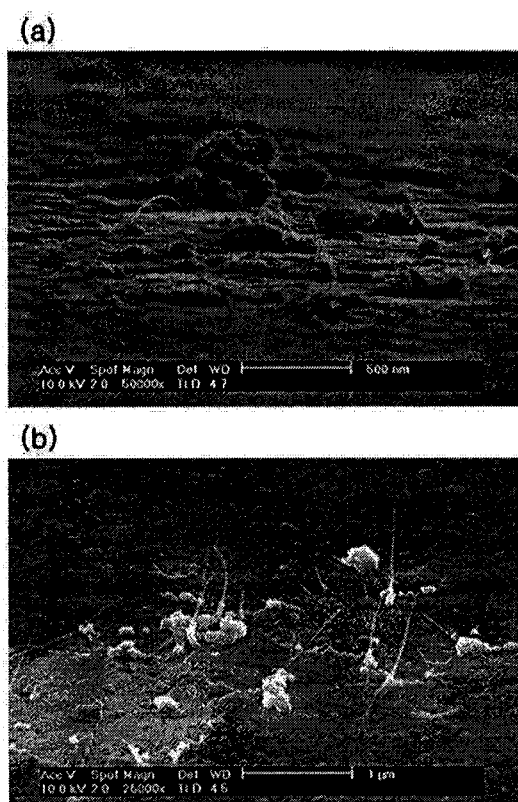


FIG. 4

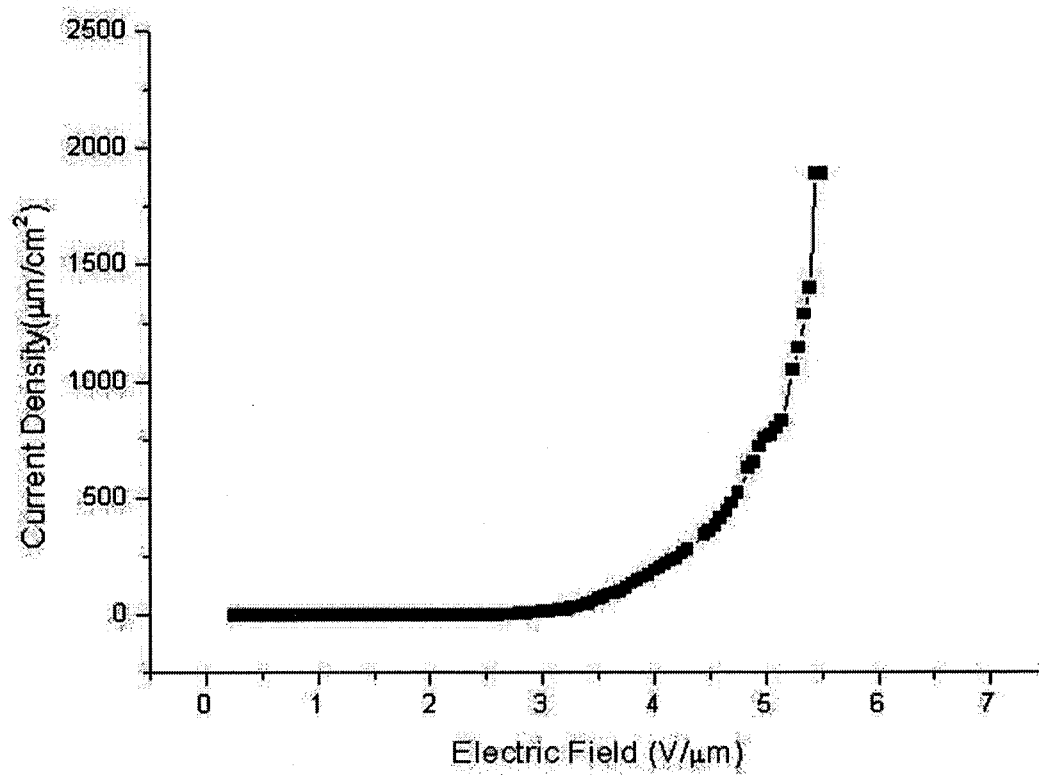


3/3

FIG. 5



FIG. 6



A. CLASSIFICATION OF SUBJECT MATTER*H01J 1/30(2006.01)i, H01J 1/304(2006.01)i*

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC8 : H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean Utility models and applications for Utility models since 1975

Japanese Utility models and applications for Utility models since 1975

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKIPASS (KIPO internal), "Keywords : field, emission, carbon nanotube, magnetic field, electric field, align, deposition"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6741019 B (ROBERT WILLIAM FILAS et al.) 25 MAY 2004 see abstract, column 5 lines 38-41, 66-67, column 6 lines 1-7, 39-44, column 9 lines 27-35, column 10 lines 22-42, column 11 lines 1-23, Fig. 1, 2	1 - 21
A	JP 2004-234865 A (SONY CORP.) 19 AUGUST 2004 see abstract, paragraph [0028], claims 1, 5, Fig. 1, 2	1 - 21
A	US 6538367 B (KYUNG MOON CHOI et al.) 25 MARCH 2003 see abstract, column 4 lines 48-66, column 5 lines 6-13, Fig. 3	1 - 21
A	US 6890230 B (JOHANN TRUJILLO et al.) 10 MAY 2005 see abstract, claims 1, 2, Fig. 1, 2	1 - 21
P, A	KR 10-2006-0062437 A (KOREA INSTITUTE OF SCIENCE TECHNOLOGY) 12 JUNE 2006 see abstract, claims 1-3, 6, Fig. 2	1 - 21



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

26 APRIL 2007 (26.04.2007)

Date of mailing of the international search report

26 APRIL 2007 (26.04.2007)

Name and mailing address of the ISA/KR

Korean Intellectual Property Office
920 Dunsan-dong, Seo-gu, Daejeon 302-701,
Republic of Korea

Facsimile No. 82-42-472-7140

Authorized officer

OH, Jun Cheol

Telephone No. 82-42-481-8506



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/KR2007/000368

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6741019 B	25.05.2004	AU200065430A1 CA2322254A1 EP1100106A2 JP13167692 KR1020010051096	26.04.2001 18.04.2001 16.05.2001 22.06.2001 25.06.2001
JP 2004-234865 A	19.08.2004	NONE	
US 6538367 B	25.03.2003	EP1069587A2 JP13057146	17.01.2001 27.02.2001
US 6890230 B	10.05.2005	AU2002329725A8 US2003042833A1 W02003021624A3	18.03.2003 06.03.2003 21.08.2003
KR 10-2006-0062437 A	12.06.2006	NONE	