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(72) Inventor: **LEE, Jung-Yul**

Gyeonggi-do 13924 (KR)

(74) Representative: **Vande Gucht, Anne et al
Solvay S.A.**

**Département de la Propriété Industrielle
Rue de Ransbeek, 310
1120 Bruxelles (BE)**

(71) Applicant: **Solvay SA**

1120 Brussels (BE)

(54) **ELECTRODE ASSEMBLY**

(57) The present invention concerns an electrode assembly comprising at least: a substrate, a conductive layer formed on the substrate comprising at least a metal nanowires, and a polysiloxane-based layer formed on the conductive layer; and a process for the production of said electrode assembly.

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Description

[0001] The present invention concerns an electrode assembly comprising at least: a substrate, a conductive layer formed on the substrate comprising at least a metal nanowires, and a polysiloxane-based layer formed on the conductive layer; and a process for the production of said electrode assembly.

BACKGROUND OF THE INVENTION

[0002] The following discussion of the prior art is provided to place the invention in an appropriate technical context and enable the advantages of it to be more fully understood. It should be appreciated, however, that any discussion of the prior art throughout the specification should not be considered as an express or implied admission that such prior art is widely known or forms part of common general knowledge in the field.

[0003] Transparent conductors are optically transparent, thin conductive materials. Such materials have a wide variety of applications, such as transparent electrodes in displays such as liquid crystal displays (LCD), light emitting diode (LED) displays, plasma displays, and organic light-emitting diode (OLED) displays, electroluminescent display displays (ELD), electrophoretic display (EPD), LED lighting, OLED lighting, touch panels, photovoltaic cells, electrochromic devices, smart windows, as anti-static layers and as electromagnetic interference shielding layers, and as resistive heaters.

[0004] Conventional transparent conductors include metal oxide films, in particular indium tin oxide (ITO) film due to its relatively high transparency at high conductivity. However, ITO has several shortcomings, such as high cost during its fabrication because it needs to be deposited using sputtering technique which involves the use of high temperatures and vacuum chambers. Metal oxide films are also fragile and prone to damage even when subjected to minor physical stresses such as bending, and as such, often does not applicable when a flexible substrate on which the metal oxide film is to be deposited is used.

[0005] Conductive polymers have a good flexibility and are often considered to be inexpensive because they can be formed by simple processing. Having these characteristics, it is believed that conductive polymer compositions are among the potential candidates to replace ITO film in forming the transparent conductor for various electronic device applications.

[0006] Metal nanowires are considered as another promising candidate to replace the commonly-used ITO due to its high dc conductivity and optical transmittance, and good mechanical flexibility, etc.

[0007] In US patent application publication No. US 2008/0259262 A1, disclosed are composite transparent conductors which comprise conductive medium based on metal nanowires and a secondary conductive medium based on a continuous conductive film. Development of conductive composition which can be suitably used for forming high quality transparent conductors, in particular those having not only satisfactory conductivity, transparency, and/or haze, but also an excellent reliability of at least one or all of them, is desired in the art.

DESCRIPTION OF THE INVENTION

[0008] The purpose of the present invention is therefore to provide an electrode assembly comprising at least:

- a substrate;
- a conductive layer formed on the substrate comprising at least a metal nanowires; and
- a polysiloxane-based layer formed on the conductive layer.

[0009] The electrode assembly according to the present invention exhibits a desirable sheet resistance as well as excellent reliability of the sheet resistance for an extended time period. The electrode assembly can also display good conductivity, transparency, and/or low haze. In addition, the conductor assembly of the present invention surprisingly exhibits an outstanding reliability of said properties over an extended time period, notably at a temperature comprised between 0 and 60°C. Said electrode assembly can be suitably used for touch panel and display applications.

[0010] It also appears that polysiloxane layer provides a higher contact angle and lower haze in comparison with a classical UV coating and the use of such a polysiloxane layer notably permit to increase the transmittance of the film in comparison with the conductive layer alone, while the use of a classical UV coating is substantially decreasing said transmittance in comparison with the use of the conductive layer alone.

[0011] The invention also concerns a method for the production of an electrode assembly comprising at least the steps of:

- forming a conductive layer formed on all or a part of a substrate; said conductive layer comprising at least a metal nanowires; and
- forming a polysiloxane-based layer on all or a part of the conductive layer.

[0012] Further, the present invention provides an electronic device, in particular touch panel and display, comprising the electrode assembly according to the present invention.

[0013] Other characteristics, details and advantages of the invention will emerge even more fully upon reading the description which follows.

DEFINITIONS

[0014] For convenience, before further description of the present disclosure, certain terms employed in the specification, and examples are collected here. These definitions should be read in the light of the remainder of the disclosure and understood as by a person of skill in the art. The terms used herein have the meanings recognized and known to those of skill in the art, however, for convenience and completeness, particular terms and their meanings are set forth below.

[0015] The articles "a", "an" and "the" are used to refer to one or to more than one (i.e., to at least one) of the grammatical object of the article.

[0016] The term "and/or" includes the meanings "and", "or" and also all the other possible combinations of the elements connected to this term.

[0017] The terms "comprise" and "comprising" are used in the inclusive, open sense, meaning that additional elements may be included. Throughout this specification, unless the context requires otherwise the word "comprise", and variations, such as "comprises" and "comprising", will be understood to imply the inclusion of a stated element or step or group of element or steps but not the exclusion of any other element or step or group of element or steps.

[0018] The term "including" is used to mean "including but not limited to". "Including" and "including but not limited to" are used interchangeably.

[0019] Ratios, concentrations, amounts, and other numerical data may be presented herein in a range format. It is to be understood that such range format is used merely for convenience and brevity and should be interpreted flexibly to include not only the numerical values explicitly recited as the limits of the range, but also to include all the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. For example, a temperature range of about 120°C to about 150°C should be interpreted to include not only the explicitly recited limits of about 120°C to about 150°C, but also to include sub-ranges, such as 125°C to 145°C, 130°C to 150°C, and so forth, as well as individual amounts, including fractional amounts, within the specified ranges, such as 122.2°C, 140.6°C, and 141.3°C, for example.

[0020] The term "between" should be understood as being inclusive of the limits.

[0021] As used herein, the term "hydrocarbon group" refers to a group mainly consisting of carbon atoms and hydrogen atoms, which group may be saturated or unsaturated, linear, branched or cyclic, aliphatic or aromatic. Hydrocarbon groups of the present invention may be alkyl groups, alkenyl groups, alkynyl groups, aryl groups, alkylaryl groups, aryalkyl groups, heterocyclic groups, and/or alkylheterocyclic groups.

[0022] As used herein, the terminology "(C_n-C_m)" in reference to an organic group, wherein n and m are each integers, indicates that the group may contain from n carbon atoms to m carbon atoms per group.

[0023] As used herein, "alkyl" groups include saturated hydrocarbons having one or more carbon atoms, including straight-chain alkyl groups, such as methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, cyclic alkyl groups (or "cycloalkyl" or "alicyclic" or "carbocyclic" groups), such as cyclopropyl, cyclopentyl, cyclohexyl, cycloheptyl, and cyclooctyl, branched-chain alkyl groups, such as isopropyl, tert-butyl, sec-butyl, and isobutyl, and alkyl-substituted alkyl groups, such as alkyl-substituted cycloalkyl groups and cycloalkyl-substituted alkyl groups. The term "aliphatic group" includes organic moieties characterized by straight or branched-chains, typically having between 1 and 22 carbon atoms. In complex structures, the chains may be branched, bridged, or cross-linked. Aliphatic groups include alkyl groups, alkenyl groups, and alkynyl groups.

[0024] As used herein, "alkenyl" or "alkenyl group" refers to an aliphatic hydrocarbon radical which can be straight or branched, containing at least one carbon-carbon double bond. Examples of alkenyl groups include, but are not limited to, ethenyl, propenyl, n-butenyl, i-butenyl, 3-methylbut-2-enyl, n-pentenyl, heptenyl, octenyl, decenyl, and the like. The term "alkynyl" refers to straight or branched chain hydrocarbon groups having at least one triple carbon to carbon bond, such as ethynyl.

[0025] The term "aryl group" includes unsaturated and aromatic cyclic hydrocarbons as well as unsaturated and aromatic heterocycles containing one or more rings. Aryl groups may also be fused or bridged with alicyclic or heterocyclic rings that are not aromatic so as to form a polycycle, such as tetralin. An "arylene" group is a divalent analog of an aryl group.

[0026] The term "heterocyclic group" includes closed ring structures analogous to carbocyclic groups in which one or more of the carbon atoms in the ring is an element other than carbon, for example, nitrogen, sulfur, or oxygen. Heterocyclic groups may be saturated or unsaturated. Additionally, heterocyclic groups, such as pyrrolyl, pyridyl, isoquinolyl, quinolyl, purinyl, and furyl, may have aromatic character, in which case they may be referred to as "heteroaryl" or "heteroaromatic" groups.

[0027] As used herein, the following terms refer to the corresponding substituent groups:

"amido" is $-R^1-C(O)N(R^4)R^4$

"amidosulfonate" is $-R^1-C(O)N(R^4)R^2-SO_3Z$

"benzyl" is $-CH_2-C_6H_5$

"carboxylate" is $-R^1-C(O)O-Z$ or $-R^1-O-C(O)-Z$

"ether" is $-R^1-(O-R^3)_p-O-R^3$

"ether carboxylate" is $-R^1-O-R^2-C(O)O-Z$ or $-R^1-O-R^2-O-C(O)-Z$

"ether sulfonate" is $-R^1-O-R^2-SO_3Z$

"ester sulfonate" is $-R^1-O-C(O)R^2-SO_3Z$,

"urethane" is $-R^1-O-C(O)-N(R^4)_2$,

wherein:

- each R^1 is absent or alkylene,
- each R^2 is alkylene,
- each R^3 is alkyl,
- each R^4 is H or an alkyl,
- p is 0 or an integer from 1 to 20, and
- each Z is H, alkali metal, alkaline earth metal, $N(R^3)_4$ or R^3 ,

wherein any of the above groups may be non-substituted or substituted, and any group may have fluorine substituted for one or more hydrogens, including perfluorinated groups.

[0028] As herein used, the term "boiling point" generally denotes the normal boiling point (also called the atmospheric boiling point or the atmospheric pressure boiling point) of a liquid; it corresponds to the case in which the vapor pressure of the liquid equals the defined atmospheric pressure at sea level, 1 atmosphere. It can be measured using a regular scale distillation procedure.

DETAILED DESCRIPTION OF THE INVENTION

[0029] Those skilled in the art will be aware that the present disclosure is subject to variations and modifications other than those specifically described. It is to be understood that the present disclosure includes all such variations and modifications. The disclosure also includes all such steps, features, compositions and compounds referred to or indicated in this specification, individually or collectively and any and all combinations of any or more of such steps or features.

Substrate

[0030] Substrate of the present invention may be a variety of base materials that can be used depending on the purpose as long as the base material can bear the conductive layer. Generally, a plate-like base material or a sheet-like base material is used.

[0031] The substrate may be transparent or opaque. Examples of a material that forms the substrate include transparent glass such as white plate glass, blue plate glass and silica-coated blue plate glass; synthesis resins such as polycarbonates, polyethersulfones, polyesters, acrylic resins, vinyl chloride resins, aromatic polyamide resins, polyamideimides and polyimides; metal such as aluminum, copper, nickel and stainless steel; additionally, ceramics, silicon wafers used for semiconductor substrates, and the like. A surface of the base material on which the conductive layer is formed can be subjected to a pretreatment such as a chemical treatment using a silane coupling agent or the like, a plasma treatment, ion plating, sputtering, a gas-phase reaction or vacuum deposition as desired.

[0032] A substrate with a thickness in a desired range depending on the use may be used. The thickness is generally selected from a range of from 1 μm to 500 μm , more preferably from 3 μm to 400 and still more preferably from 5 μm to 300 μm .

[0033] The substrate may be transparent and having a total visible light transmittance from 60% to 100%, preferably from 85% to 100%, and still more preferably from 90% to 100%, in the visible light region (400 nm to 700 nm). Meanwhile, the total light transmittance of the substrate may be measured based on JIS K 7361-1:1997.

[0034] Examples of such substrates include a glass substrate, and transparent solid polymers, for example polycarbonates (PC), polyesters, such as polyethyleneterephthalate (PET), acryl resins, polyvinyl resins, such as polyvinyl chloride, polyvinylidene chloride, and polyvinyl acetals, aromatic polyamide resins, polyamideimides, polyethylene naphthalene dicarboxylate, polysulphones, such as polyethersulfone (PES), polyimides (PI), cyclic olefin copolymers (COC), styrene copolymers, polyethylene, polypropylene, cellulose ester bases, such as cellulose triacetate, and cellulose

acetate, and any combination thereof. Preferably, the substrate is in the form of a sheet. In the present invention, the substrate may be rigid or flexible. Examples of the flexible substrate include, but are not limited to, those transparent solid polymers, including polycarbonates, polyesters, polyolefins, polyvinyls, cellulose ester bases, polysulphones, polyimides, and other conventional polymeric films, or adhesive layers embedded in specific display structures.

[0035] The substrate may notably comprise an adhesive layer formed on the substrate. In some cases an adhesive layer might be called as a hard coat layer, or a hardcoat.

[0036] An adhesive layer may refer to any optically clear material that bonds two adjacent layers (e.g. conductive layer and substrate) together with no or with very limited effect on the physical, electrical or optical properties of either layer. It is known that some types of adhesives can have a positive effect on the mechanical and optical properties of substrates. Adhesive material are well known in the art, including without limitation: acrylic resins, chlorinated olefin resins, resins of vinyl chloride-vinyl acetate copolymer, maleic acid resins, chlorinated rubber resins, cyclorubber resins, polyamide resins, cumarone indene resins, resins of ethylene-vinyl acetate copolymer, polyester resins, urethane resins, styrene resins, polysiloxanes and the like. The adhesion promoting monomers may be polymerized by conventional means such as radiation, thermal or redox curing with other vinyl monomers and prepolymers to form coatings, films or adhesives.

[0037] The adhesive composition also may comprise various additives as needed to alter or enhance certain properties such as, for example, to improve weatherability, components to improve abrasion resistance, additives to enhance appearance, and materials to improve toughness and mechanical properties. Examples of additives that may be used in the coating composition of the present invention include, but are not limited to, photoinitiators; slip agents; leveling agents; wetting agents; adhesion promoters; anti-absorption agents; anti-foaming agents, such as, for example, mixtures of foam destroying polymers and polysiloxanes; accelerators; pigment dispersion aids; anti-blocking agents; anti-caking agents; anti-slip agents; anti-skinning agents; anti-static agents; anti-stripping agents; binders; curing agents; deaerators; diluents; dispersants; dryers; emulsifiers; fillers; flattening agents; flow control agents; gloss agents; hardeners; lubricants; mar resistance aids; whiteners; plasticizers; solvents; stabilizers; surfactants; viscosity modifiers; UV stabilizers; UV absorbers; and water repellants. For example, the coating composition may further comprise finely divided SiO_2 , Al_2O_3 , ZrO_2 , or TiO_2 dispersed therein. These materials can modify the viscosity of the coating such that it may be applied easily and can enhance the abrasion resistance of the cured coating.

[0038] The adhesive materials can be applied to the substrate by the customary techniques, for example by spin coating, slit coating, spraying, dipping, spreading or electrodeposition. In some cases, a plurality of coats may be applied.

Conductive layer

[0039] Conductive layer forming composition may comprise at least one metal nanowires and at least one solvent. When deposited on the substrate, the nanowires are usually present so as to intersect each other to form a conductive metal nanowire network having plurality of intersections of metal nanowire.

[0040] In the present invention, an average diameter of the metal nanowires is from 10 nm to 50 nm, preferably 15 nm to 35 nm, more preferably 18 nm to 25 nm, notably 18 to 23 nm. In the present invention, the diameter of the metal nanowires can be measured by transmission electron microscope (TEM). An average length of the metal nanowires in the present invention is often in the range of 1 μm to 100 μm . The average length of the metal nanowires is preferably at least 10 μm , more preferably more than 10 μm , still more preferably at least 15 μm . The average length of the metal nanowires is preferably equal to or less than 50 μm , more preferably equal to or less than 30 μm . In the present invention, the length of the metal nanowires can be measured by optical microscope.

[0041] The aspect ratio of the metallic nanowires is preferably from 300 and 2000, preferably from 800 to 1200. The aspect ratio refers to a ratio of the average long axis length to the average short axis length. The aspect ratio can be computed using the average long axis length and the average short axis length computed using the above method.

[0042] In the present invention, the metal nanowires can be nanowires formed of metal, metal alloys, plated metals or metal oxides. Among the above, metallic nanowires formed of metal or a metallic compound are preferable, and metallic nanowires formed of metal are more preferable.

[0043] The metal is preferably at least one kind of metal chosen in the group constituted by Periods 4, 5 and 6 of the long-form periodic table (IUPAC 1991), more preferably at least one kind of metal selected from Groups 2 to 14, and still more preferably at least one kind of metal selected from Groups 2, 8, 9, 10, 11, 12, 13 and 14. The metal is particularly preferably included as a main component. Specific examples of the metal include copper, silver, gold, platinum, palladium, nickel, tin, cobalt, rhodium, iridium, iron, ruthenium, osmium, manganese, molybdenum, tungsten, niobium, tantalum, titanium, bismuth, antimony, lead, alloys thereof and the like. Among the above, copper, silver, gold, platinum, palladium, nickel, tin, cobalt, rhodium, iridium or an alloy thereof is preferable, and palladium, copper, silver, gold, platinum, tin or an alloy thereof is more preferable, and silver or an alloy containing silver is particularly preferable.

[0044] Examples of the metal nanowires include, but are not limited to, silver nanowires, gold nanowires, copper nanowires, nickel nanowires, gold-plated silver nanowires, platinum nanowires, and palladium nanowires. The metal nanowires in the composition preferably comprise silver nanowires. Silver nanowires are the most preferred metal

nanowires in the present invention because of its high electrical conductivity.

[0045] Excellent result can be obtained when silver nanowires having an average diameter of 10nm to 30 nm, preferably 18 nm to 25 nm, notably 18 nm to 23 nm and an average length of 10 to 30 μm , notably 10 to 25 μm are used in the composition according to the present invention.

[0046] Such silver nanowires may be prepared via the synthesis methods known in the art. For instance, so-called "polyol method" may be used for the synthesis of the silver nanowires to be used in the present invention. Reference can be made to Sun et al., "Crystalline silver nanowires by soft solution processing", *Nanoletters*, (2002), 2(2) 165-168.

[0047] In a particular embodiment of the present invention, the metal nanowires are used in the amount of 0.01 to 1.0 wt %, preferably 0.05 to 0.5wt%, notably 0.05 to 0.2 wt %, relative to the total weight of the composition. The composition comprising the metal nanowires in the amount of 0.01 to 1.0 wt % relative to the total weight of the composition, can exhibit particularly good conductivity, transparency and/or haze.

[0048] The conductive layer composition may notably be a dispersion.

[0049] At least one solvent to constitute the composition can be chosen among those chosen in the group constituted by water; aliphatic alcohols, such as methanol, ethanol, isopropanol, butanol, n-propylalcohol, ethylene glycol, propylene glycol, butanediol, neopentyl glycol, 1,3-pentanediol, 1,4-cyclohexanedimethanol, diethyleneglycol, polyethelene glycol, polybutylene glycol, dimethylolpropane, trimethylolpropane, sorbitol, esterification products of the afore-mentioned alcohols ; aliphatic ketones, such as cellosolve, propyleneglycol methylether, diacetone alcohol, ethylacetate, butylacetate, acetone and methylethylketone ; ethers such as tetrahydrofuran, dibutyl ether, mono- and polyalkylene glycol dialkyl ethers ; aliphatic carboxylic acid esters ; aliphatic carboxylic acid amides ; aromatic hydrocarbons ; aliphatic hydrocarbons ; acetonitrile ; aliphatic sulfoxides ; and any combination thereof. Water and/or alcohols can be preferably used.

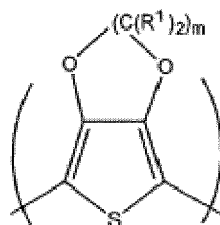
[0050] The composition may also comprise at least one π -conjugated conductive polymer.

[0051] In the present invention, a π -conjugated conductive polymer is understood to denote in particular any polymeric materials that conduct electricity. In the compositions the π -conjugated conductive polymers can be, for example, dissolved or dispersed in the solvent. Preferably, the conductive polymers are dispersed in water and/or alcohol.

[0052] An electrically conductive polymer usually means any polymer or polymer blend that is inherently or intrinsically, without the addition of electrically conductive fillers such as carbon black or conductive metal particles, capable of electrical conductivity, more typically to any polymer or oligomer that exhibits a bulk specific conductance of greater than or equal to 10^{-7} Siemens per centimeter (" S/cm ").

[0053] The π -conjugated conductive polymer may be chosen in the group constituted by polyaniline polymers, polypyrrole polymers, polythiophene polymers, and any combination thereof.

[0054] Preferably, the π -conjugated conductive polymer comprises a polydioxithiophene polymer that comprises monomeric units according to structure (I) per molecule of the polymer:



(I)

wherein:

- R^1 is independently H, alkyl, hydroxy, heteroalkyl, alkenyl, heteroalkenyl, hydroxalkyl, amidosulfonate, benzyl, carboxylate, ether, ether carboxylate, ether sulfonate, ester sulfonate, or urethane, and
- m is 2 or 3.

[0055] In one embodiment, all R^1 groups of the monomeric unit according to structure (I) are each H, alkyl, or alkenyl. In one embodiment, at least one R^1 groups of the monomeric unit according to structure (I) is not H. In one embodiment, each R^1 groups of the monomeric unit according to structure (I) is H.

[0056] In one embodiment, the electrically conductive polymer comprises an electrically conductive polythiophene homopolymer of monomeric units according to structure (I) wherein each R^1 is H and m is 2, known as poly(3,4-ethylenedioxythiophene), more typically referred to as "PEDOT".

[0057] The PEDOT polymer is preferably doped with at least one further compound. One example of such compound for doping includes polymeric acid dopant, in particular a water soluble polymeric dopant. Examples of doped PEDOT

polymers include PEDOT doped with lignosulfonic acid (LSA) (PEDOT/LSA), PEDOT doped with polyethyleneglycol (PEG) (PEDOT/PEG), PEDOT doped with polyoxometalate (POM) (PEDOT/POM), PEDOT doped with sulfonated polyimide (SPI) (PEDOT/SPI), PEDOT doped with carbon materials, such as activated carbon, graphene and carbon nanotube (CNT) (activated carbon/PEDOT composite, PEDOT/graphene composite, or PEDOT/CNT composite), PEDOT doped with DMSO and CNT (PEDOT/DMSO/CNT), PEDOT doped with tosylate, PEDOT doped with chloride anion, PEDOT doped with NO₃, PEDOT doped with PSS (PEDOT:PSS), PEDOT/PSS doped with pentacene, PEDOT doped with ammonium persulfate (APS) (PEDOT/APS), and PEDOT doped with dimethyl sulfoxide (DMSO) (PEDOT/DMSO), but the present invention is not limited thereto. More preferably, the PEDOT polymer is doped with a polymer having at least one sulfonic acid, such as polystyrene sulfonic acid (PSS).

[0058] In the preferred embodiment of the present invention, the π -conjugated conductive polymer comprises at least one polythiophene polymer, preferably poly(3,4-ethylenedioxythiophene)(PEDOT) polymer, doped with at least one water soluble polymeric dopant, preferably polystyrene sulfonic acid (PSS). The ratio of PEDOT and PSS is preferably from 5:95 to 50:50 by weight.

[0059] The π -conjugated conductive polymer may be used in the amount of 0.01 to 1.0 wt %, preferably 0.05 to 0.2 wt %, relative to the total weight of the composition. A composition comprising the π -conjugated conductive polymer in the amount of 0.01 to 1.0 wt % relative to the total weight of the composition, can exhibit particularly good conductivity and transparency.

[0060] The PEDOT:PSS co-doped with *para*-toluene sulfonic acid is especially preferred.

[0061] The weight ratio between the π -conjugated conductive polymer and the metal nanowires in the composition is preferably 1:0.5-1:5, more preferably 1:1-1:3. The composition comprising the π -conjugated conductive polymer and the metal nanowires in said range may attain well-balanced conductivity and optical properties.

[0062] Without wishing to be bound by any theory, incorporation of the π -conjugated conductive polymer into the composition comprising at least one metal nanowires may prevent oxidation and/or degradation of the metal nanowires and/or its conductive network. Also, such incorporation allows increased conductivity compared to the conductive system solely based on the metal nanowire network.

[0063] The composition may also comprise at least one binder. The binder may be an organic compound, an inorganic compound, or a hybrid compound thereof. Examples of the organic binder include polyesters, such as polyethylene terephthalate, polybutylene terephthalate, and polyethylene naphthalate; polyimides, such as polyimide, and polyamideimide; polyamides, such as polyamide 6, polyamide 6,6, polyamide 12, and polyamide 11; fluororesins, such as polyvinylidene fluoride, polyvinyl fluoride, polytetrafluoroethylene, ethylenetetrafluoroethylene copolymer, and polychlorotrifluoroethylene; vinyl resins, such as polyvinyl alcohol, polyvinyl ether, polyvinyl butyral, polyvinyl acetate, and polyvinyl chloride; epoxy resin; oxetane resin; xylene resin; aramide resin; polyimide silicon; polyurethane; polyurea; melamine resin; phenol resin; polyether; organosilicons; poly(ethylene oxide)s (PEO); silicon(Si)-based binder, such as aminosilane-based binders, and tetraalkoxysilane-based binders; acrylic resin, and their copolymers.

[0064] The binder, when present, is typically used in an amount of 0.01 to 1.0 wt %, preferably 0.05 to 0.2 wt %, relative to the total weight of the composition.

[0065] The composition may also comprise an amine compound, preferably at least one amine compound having a boiling point from 180-300 °C. Without wishing to be bound by any theory, it is believed that by incorporating this particular amine compound functions as a pH control agent for π -conjugated conductive polymer which usually exists in an acidic status, oxidation and/or degradation of metal nanowires in the same composition when contacted with the π -conjugated conductive polymer often possessing highly acidic nature can be prevented or substantially reduced. The compositions which comprise said amine compound can attain a stable degree of dispersion as having good miscibility between π -conjugated conductive polymer and metal nanowires. In addition, the incorporation of said amine compound enables an extended shelf-life during delivery and storage.

[0066] The boiling point of the amine compound is preferably at least 190 °C, more preferably at least 195 °C. The maximum boiling point may be as high as about 300 °C (e.g. in case of glycol amine). The amine compounds which have a boiling point of at least 180 °C as well as exhibit an anti-corrosion effect are particularly preferred in the present invention. The amine compounds often having an excellent solubility in water are often preferred, for instance, in view of their good processability during the formulation preparation. In the present invention, the amine compound is preferably present in liquid state at room temperature. Said amine compound preferably comprises at least one group other than the amine group, the group which confers sufficient solubility in water. Particular example of such group includes alcohol group.

[0067] Suitable class of the amine compound includes alkanol amines, such as monoalkanol amines, dialkanol amines, and trialkanol amines. Alkanol amines may be defined as an amine compound comprising at least one amine function and at least one hydroxyl function. From the point of commercial availability, ethanol amines and propanol amines may be used as the amine compound in the present invention. Among the ethanol amines, N-substituted monoethanol amines, unsubstituted or N-substituted diethanol amines and unsubstituted or N-substituted triethanol amines are preferred. Particular examples of the ethanol amines include methyldiethanolamine, n-butylethanolamine, n-butyldiethanolamine,

dibutylethanolamine, cyclohexylethanolamine, cyclohexyldiethanolamine, 4-(2-hydroxyethyl)morpholine, hydroxyethyl-aniline, ethylhydroxyethylaniline, hydroxyethylpiperidine, dihydroxyethylaniline, and n-propylethanolamine, but the present invention is not limited thereto. Particular examples of the propanol amines include diisopropanolamine, triisopropanolamine, methyl-diisopropanolamine, dibutylisopropanolamine, cyclohexylisopropanolamine, cyclooctylisopropanolamine, cyclooctyldiisopropanolamine, 4-(2-hydroxypropyl)morpholine, 3-(2-ethylhexyloxy)-propylamine, aminoethyl-isopropanolamine, 3-(2-ethylhexyloxy)propylamine, and 3-amino-1-propanol, but the present invention is not limited thereto.

[0068] Preferably the amine compound is a compound comprising at least one secondary amine function or a tertiary amine function and at least one hydroxyl function. Said amine compound may comprise a hydrocarbon group and at least one secondary amine function or a tertiary amine function and at least one hydroxyl function, such as for instance N-alkylalkanolamine and N-dialkylalkanolamine.

[0069] More preferably the amine compound has a boiling point from 180 to 300 °C and comprises at least one secondary amine function and at least one hydroxyl function, such as for instance: N-Butylethanolamine; N-(2-Hydroxyethyl)ethylenediamine; 4-[(2-aminoethyl)amino]-3-hexanol; 5-amino-4-(methylamino)-pentanol; 2-[-2-methoxypropyl]amino]-ethanol; N,N-Bis(4-hydroxybutyl)amine; Bis(2-hydroxypropyl)amine; and 2,2'-dihydroxydiethylamine.

[0070] Another class of the amine compound includes polyamines. Particular examples of the polyamines include diamines, such as hexamethylenediamine, triamines, such as diethylenetriamine, and tetramines, such as triethylene-tetramine, but the present invention is not limited thereto.

[0071] Further class of the amine compound includes alkoxyated alkylamines. Particular examples of the alkoxyated alkylamines include ethoxylated alkylamines, but the present invention is not limited thereto.

[0072] In general, said amine compound can be applied to an aqueous solution of π -conjugated conductive polymer. Particular preferred examples of the amine compound include the product line of trademark SYNERGEX®, such as SYNERGEX® T series for instance, the product commercially available from Taminco, particularly N-Butyldiethanolamine and N-Butylethanolamine.

[0073] The amine compound may be used in the amount of 0.01 to 1.0 wt %, preferably 0.1 to 0.5 wt %, relative to the total weight of the composition. A composition comprising the amine compound in said range can exhibit particularly good reliability of conductivity, and/or excellent shelf-life.

[0074] The amount of the amine compound can be selected so as to adjust the pH of π -conjugated conductive polymer solution to equal to or more than 7, more preferably to more than 9, preferably comprised between 9 and 11.

[0075] Compositions of the invention may also comprise at least one polysaccharide. Polysaccharides may be especially chosen in the group constituted by: glucans, starches, (such as those derived, for example, from cereals, for instance wheat, corn or rice, from vegetables, for instance yellow pea, and tubers, for instance potato or cassava), amylose, amylopectin, glycogen, dextrans, celluloses and derivatives thereof such as methylcelluloses, hydroxyalkyl-celluloses, and ethylhydroxyethylcelluloses, mannans, xylans, lignins, arabans, galactans, galacturonans, chitin, chitosans, glucuronoxylans, arabinoxylans, xyloglucans, glucomannans, pectic acids and pectins, arabinogalactans, carageenans, agars, gum arabics, gum tragacanth, ghatti gums, karaya gums, carob gums, galactomannans such as guar and derivatives thereof, such as hydroxypropyl guar or cationic guar, and mixtures thereof.

[0076] Polysaccharides are preferably chosen in the group constituted by: cellulose, hydroxyethyl celluloses, cetylhydroxyethyl celluloses, hydroxypropyl celluloses, hydroxypropylmethyl celluloses, hydroxyethylmethyl celluloses

[0077] The polysaccharide may be used in the amount of 0.1 to 1.5 wt %, preferably 0.3 to 0.7 wt %, relative to the total weight of the composition.

[0078] Optionally, the composition may contain one or more additives known in the art. Reference can be made to the disclosure of the United States Patent Application Publication No. US 2014/0203223 A.

[0079] Such additives may be for instance chosen in the group constituted by: a sensitizer, a chain transfer agent, a crosslinking agent, a dispersant, a solvent, a surfactant, an oxidation inhibitor, a sulfuration inhibitor, a metal corrosion inhibitor, a viscosity adjusting agent, and an antiseptic agent. A surfactant may notably be a leveling agent. Among surfactant having leveling agent properties, nonionic organic surfactants may be cited such as Dynol 607 from Air Products and Surfynol 104 grades from Air Products.

[0080] Preferably the present invention concerns a composition comprising at least:

(A) 0.01 to 1.0 wt %, preferably 0.05 to 0.5 wt%, notably 0.05 to 0.3 wt %, of at least one metal nanowires relative to the total weight of the composition;

(B) 0.01 to 1.0 wt %, preferably 0.05 to 0.5wt%, notably 0.05 to 0.2 wt %, of at least one π -conjugated conductive polymer, relative to the total weight of the composition;

(C) 0.01 to 1.0 wt %, preferably 0.1 to 0.5 wt %, of at least one amine compound, notably having a boiling point from 180 °C to 300 °C, relative to the total weight of the composition; and

(D) at least one solvent.

[0081] Several methods for preparing the composition may be used. Such method may comprise (a) preparing a first solution comprising at least one metal nanowires; preparing a second solution comprising at least one π -conjugated conductive polymer and optionally at least one amine compound; and (c) mixing the first solution and the second solution to obtain the composition. One or more of the above-explained solvents may be used to form the first solution and/or the second solution.

[0082] The method for preparing the composition preferably comprises adjusting the pH level of a solution of (B) at least one π -conjugated conductive polymer to over pH 9, preferably between 9 and 11. It has been surprisingly found that by controlling the pH of the conductive polymer to such degree, exceptionally advantageous reliability of the transparent conductor can be obtained.

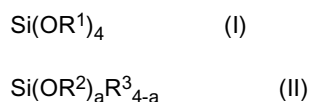
[0083] It may also be possible to dissolve at least a polysaccharide in a liquid medium, for instance comprising water and optionally a solvent, and then add at least one metal nanowires.

[0084] Usually the conductive layer of the present invention may be obtained by application of the composition comprises at least a metal nanowires and a solvent on the surface of a substrate and curing the composition applied on the surface.

[0085] Examples of such method of applying the composition on the substrate include wettings, such as dipping, coatings, such as spin coating, dip coating, slot-die coating, spray coating, flow coating, bar coating, meniscus coating, capillary coating, roll coating, and electro-deposition coating, and spreading, but the present invention is not limited thereto. The thickness of the conductive layer on the substrate is preferably from 10 nm to 1000 nm, more preferably 20 to 500 nm, particularly 30 to 150 nm, notably 40 to 100 nm. This thickness may be determined by a person skilled in the art considering the type of rod to apply the coating to determine the wet thickness and the solid content of the coating formulation. Drying may be performed under air or under inert atmosphere such as nitrogen or argon. Drying is typically conducted under atmospheric pressure or under reduced pressure, particularly under atmospheric pressure. Drying is usually conducted at a temperature sufficiently high to allow evaporation of the solvent. Drying may be performed at a temperature between 10 to 200 °C depending on selection of the solvent. Optional curing can be conducted by a subsequent treatment, such as a heat treatment and/or a treatment with radiation. Preferably, ultraviolet (UV) radiation in particular with a wavelength ranging from 100 nm to 450 nm, for example 172, 248 or 308 nm, can be suitably used. One or more optional treatment step, such as cleaning, drying, heating, plasma treatment, microwave treatment, and ozone treatment, may be conducted in any time during the process for the manufacture of transparent conductor.

Polysiloxane-based layer

[0086] Polysiloxane-based layer forming composition may comprise at least one compound of Formula (I) and optionally at least one compound of Formula (II) as follows:



wherein:

- a plurality of R^1 may be the same as or different from each other and each of R^1 independently represents a hydrogen atom or a hydrocarbon group
- a plurality of R^2 and a plurality of R^3 may be the same as or different from each other, and each of R^2 and each of R^3 independently represent a hydrogen atom or a hydrocarbon group, and
- a represents an integer of 1 to 3.

[0087] The polysiloxane-based layer of the invention preferably comprise a reaction product obtained by reacting at least one compound of Formula (I) and optionally at least one compound of Formula (II).

[0088] Preferable examples of the respective hydrocarbon groups for R^1 in the Formula (I) and for R^2 and R^3 in the Formula (II) include alkyl groups or aryl groups. In a case in which R^1 , R^2 and R^3 represent an alkyl group, the number of carbon atoms is preferably 1 to 18, more preferably 1 to 8, and still more preferably 1 to 4. In addition, in a case in which R^1 , R^2 and R^3 represent an aryl group, a phenyl group is preferable. The alkyl group or the aryl group may have a substituent, and examples of introducible substituents include halogen atoms, amino groups, mercapto groups and the like. Meanwhile, the compound is a low molecular compound, and the molecular weight is preferably comprised between 30 and 1000.

[0089] Hereinafter, specific examples of the compounds of Formula (I) will be described, but the invention is not limited thereto.

[0090] Preferable compounds of Formula (I) are chosen in the group constituted by: tetramethoxysilane, tetraethox-

ysilane, tetrapropoxysilane, tetrabutoxysilane, methoxytriethoxysilane, ethoxytrimethoxysilane, methoxytripropoxysilane, ethoxytripropoxysilane, propoxytrimethoxysilane, propoxytriethoxysilane, dimethoxydiethoxysilane, or the like. Among the above, particularly preferable examples include tetramethoxysilane, tetraethoxysilane, and the like.

[0091] Next, specific examples of the compound represented by the Formula (II) will be described, but the invention is not limited thereto.

[0092] In a case in which a is 2, the compound of Formula (II) is a difunctional alkoxy silane, and may be chosen in the group constituted by: dimethyl dimethoxysilane, diethyl dimethoxysilane, propyl methyl dimethoxysilane, dimethyl diethoxysilane, diethyl diethoxysilane, dipropyl diethoxysilane, γ -chloropropyl methyl diethoxysilane, γ -chloropropyl methyl dimethoxysilane, (p-chloromethyl)phenyl methyl dimethoxysilane, γ -bromopropyl methyl dimethoxysilane, acetoxymethyl methyl diethoxysilane, acetoxymethyl methyl dimethoxysilane, acetoxypentyl methyl dimethoxysilane, benzoyloxypropyl methyl dimethoxysilane, 2-(carbomethoxy) ethyl methyl dimethoxysilane, phenyl methyl dimethoxysilane, phenyl ethyl diethoxysilane, phenyl methyl di-propoxysilane, hydroxymethyl methyl diethoxysilane, N-(methyl-diethoxysilyl-propyl)-O-polyethylene oxide urethane, N-(3-methyl-diethoxysilylpropyl)-4-hydroxy-butylamide, N-(3-methyl-diethoxysilylpropyl) gluconamide, vinyl methyl dimethoxysilane, vinyl methyl diethoxysilane, vinyl methyl dibutoxysilane, isopropenyl methyl dimethoxysilane, isopropenyl methyl diethoxysilane, isopropenyl methyl dibutoxysilane, vinyl methyl bis(2-methoxyethoxy)silane, allyl methyl dimethoxysilane, vinyldecyl methyl dimethoxysilane, vinyloctyl methyl dimethoxysilane, vinylphenyl methyl dimethoxysilane, isopropenylphenyl methyl dimethoxysilane, 2-(meth)acryloyloxyethyl methyl dimethoxysilane, 2-(meth)acryloyloxyethyl methyl diethoxysilane, 3-(meth)acryloyloxypropyl methyl dimethoxysilane, 3-(meth)acryloyloxypropyl methyl diethoxysilane, 3-(meth)acryloyloxypropyl methyl bis(2-methoxyethoxy)silane, 3-[2-(allyloxy)carbonyl]phenylcarbonyloxypropyl methyl dimethoxysilane, 3-(vinyl phenylamino)propyl methyl dimethoxysilane, 3-(vinylphenylamino)propyl methyl diethoxysilane, 3-(vinylbenzylamino)propyl methyl diethoxysilane, 3-[2-(N-vinylphenylmethylamino)ethyl amino]propyl methyl dimethoxysilane, 3-[2-(N-isopropenylphenylmethylamino)ethyl amino]propyl methyl dimethoxysilane, 2-(vinylloxy)ethyl methyl dimethoxysilane, 3-(vinylloxy)propyl methyl dimethoxysilane, 4-(vinylloxy)butyl methyl diethoxysilane, 2-(isopropenyloxy)ethyl methyl dimethoxysilane, 3-(allyloxy)propyl methyl dimethoxysilane, 10-(allyloxycarbonyl)decyl methyl dimethoxysilane, 3-(isopropenylmethoxy)propyl methyl dimethoxysilane, 10-(isopropenylmethoxycarbonyl)decyl methyl dimethoxysilane, 3-[(meth)acryloyloxypropyl]methyl dimethoxysilane, 3-[(meth)acryloyloxypropyl]methyl diethoxysilane, 3-[(meth)acryloyloxymethyl]methyl dimethoxysilane, 3-[(meth)acryloyloxymethyl]methyl diethoxysilane, γ -glycidoxypropyl methyl dimethoxysilane, N-[3-(meth)acryloyloxy-2-hydroxypropyl]-3-aminopropyl methyl diethoxysilane, O-[(meth)acryloyloxyethyl]-N-(methyl-diethoxysilylpropyl)urethane, γ -glycidoxypropyl methyl diethoxysilane, β -(3,4-epoxycyclohexyl)ethyl methyl dimethoxysilane, γ -aminopropyl methyl diethoxysilane, γ -aminopropyl methyl dimethoxysilane, 4-amino-butyl methyl diethoxysilane, 11-amino-undecyl methyl diethoxysilane, m-aminophenyl methyl dimethoxysilane, p-aminophenyl methyl dimethoxysilane, 3-aminopropyl methyl-bis(methoxyethoxy)silane, 2-(4-pyridylethyl)methyl diethoxysilane, 2-(methyl dimethoxysilyl)ethylpyridine, N-(3-methyl dimethoxysilylpropyl)pyrrole, 3-(m-aminophenoxy)propyl methyl dimethoxysilane, N-(2-aminoethyl)-3-aminopropyl methyl dimethoxysilane, N-(2-aminoethyl)-3-aminopropyl methyl diethoxysilane, N-(6-aminoethyl)amino-methyl methyl diethoxysilane, N-(6-aminoethyl)aminopropyl methyl dimethoxysilane, N-(2-aminoethyl)-11-amino-undecyl methyl dimethoxysilane, (aminoethyl aminomethyl)phenethyl methyl dimethoxysilane, N-3-[(amino(polypropyleneoxy))]aminopropyl methyl dimethoxysilane, n-butylaminopropyl methyl dimethoxysilane, N-ethylaminoisobutyl methyl dimethoxysilane, N-methyl-aminopropyl methyl dimethoxysilane, N-phenyl- γ -aminopropyl methyl dimethoxysilane, N-phenyl- γ -aminomethyl methyl diethoxysilane, (cyclohexylaminomethyl) methyl diethoxysilane, N-cyclohexylaminopropyl methyl dimethoxysilane, bis(2-hydroxyethyl)-3-aminopropyl methyl diethoxysilane, diethylaminomethyl methyl diethoxysilane, diethylaminopropyl methyl dimethoxysilane, dimethylaminopropyl methyl dimethoxysilane, N-3-methyl dimethoxysilylpropyl-m-phenylenediamine, N,N-bis[3-(methyl dimethoxysilyl)propyl]-ethylenediamine, bis(methyl-diethoxysilylpropyl)amine, bis(methyl dimethoxysilylpropyl)amine, bis[(3-methyl dimethoxysilyl)propyl]-ethylenediamine, bis[3-(methyl diethoxysilyl)propyl]urea, bis(methyl dimethoxysilylpropyl)urea, N-(3-methyl-diethoxysilylpropyl)-4,5-dihydroimidazole, ureidopropyl methyl diethoxysilane, ureidopropyl methyl dimethoxysilane, acetamidopropyl methyl dimethoxysilane, 2-(2-pyridylethyl)thiopropyl methyl dimethoxysilane, 2-(4-pyridylethyl)thiopropyl methyl dimethoxysilane, bis[3-(methyl diethoxysilyl)propyl]disulfide, 3-(methyl diethoxysilyl)propylsuccinic acid anhydride, γ -mercaptopropyl methyl dimethoxysilane, γ -mercaptopropyl methyl diethoxysilane, isocyanatopropyl methyl dimethoxysilane, isocyanatopropyl methyl diethoxysilane, isocyanatoethyl methyl diethoxysilane, isocyanatomethyl methyl diethoxysilane, carboxyethyl methylsilane diol sodium salt, N-(methyl dimethoxysilylpropyl)ethylenediamine triacetic acid trisodium salt, 3-(methyl dihydroxysilyl)-1-propanesulfonic acid, diethyl phosphatoethyl methyl diethoxysilane, 3-methyl-dihydroxysilylpropyl methylphosphonate sodium salt, bis(methyl-diethoxysilyl)ethane, bis(methyl dimethoxysilyl)ethane, bis(methyl diethoxysilyl)methane, 1,6-bis(methyl diethoxysilyl)hexane, 1,8-bis(methyl diethoxysilyl)octane, p-bis(methyl dimethoxysilyl)benzene, p-bis(methyl dimethoxysilyl)benzene, 3-methoxypropyl methyl dimethoxysilane, 2-[methoxy(polyethyleneoxy)propyl]methyl dimethoxysilane, methoxytriethyleneoxypropyl methyl dimethoxysilane, tris(3-methyl dimethoxysilylpropyl)isocyanurate, [hydroxy(polyethyleneoxy)propyl]methyl diethoxysilane, N,N'-bis(hydroxyethyl)-N,N'-bis(methyl dimethoxysilylpropyl)ethylenediamine,

bis-[3-(methyldiethoxysilylpropyl)-2-hydroxypropoxy]polyethylene oxide, bis[N,N'-(methyl-diethoxysilylpropyl)aminocarbonyl]polyethylene oxide, and bis(methyldiethoxysilylpropyl)polyethylene oxide.

[0093] In a case in which a is 3, the compound of Formula (II) is a trifunctional organo alkoxysilane, and may be chosen in the group constituted by: methyl trimethoxysilane, ethyl trimethoxysilane, propyl trimethoxysilane, methyl triethoxysilane, ethyl triethoxysilane, propyl triethoxysilane, γ -chloropropyl triethoxysilane, γ -chloropropyl trimethoxysilane, chloromethyl triethoxysilane, (p-chloromethyl)phenyl trimethoxy silane, γ -bromopropyl trimethoxysilane, acetoxymethyl triethoxysilane, acetoxymethyl trimethoxysilane, acetoxypentyl trimethoxy silane, benzoyloxypropyl trimethoxysilane, 2-(carbomethoxy)ethyl trimethoxysilane, phenyl trimethoxysilane, phenyl triethoxysilane, phenyl tripropoxysilane, hydroxymethyl triethoxysilane, N-(triethoxysilylpropyl)-O-polyethylene oxido urethane, N-(3-triethoxysilylpropyl)-4-hydroxybutyl amide, N-(3-triethoxysilylpropyl)gluconamide, vinyl trimethoxysilane, vinyl triethoxysilane, vinyl tributoxysilane, isopropenyl trimethoxysilane, isopropenyl triethoxysilane, isopropenyl tributoxysilane, vinyl tris(2-methoxyethoxy)silane, allyl trimethoxysilane, vinyldecyl trimethoxy silane, vinylloctyl trimethoxysilane, vinylphenyl trimethoxysilane, isopropenylphenyl trimethoxysilane, 2-(meth)acryloyloxyethyl trimethoxysilane, 2-(meth)acryloyloxyethyl triethoxysilane, 3-(meth)acryloyloxypropyl trimethoxysilane, 3-(meth)acryloyloxypropyl trimethoxysilane, 3-(meth)acryloyloxypropyl tris(2-methoxyethoxy)silane, 3-[2-(allyloxycarbonyl)phenylcarbonyloxy]propyl trimethoxysilane, 3-(vinylphenylamino)propyl trimethoxysilane, 3-(vinylphenylamino)propyl triethoxysilane, 3-(vinylbenzylamino)propyl triethoxysilane, 3-(vinylbenzylamino)propyl triethoxysilane, 3-[2-(N-vinylphenylmethylamino)ethylamino]propyl trimethoxysilane, 3-[2-(N-isopropenylphenylmethylamino)ethylamino]propyl trimethoxysilane, 2-(vinylloxy)ethyl trimethoxysilane, 3-(vinylloxy)propyl trimethoxysilane, 4-(vinylloxy)butyl triethoxysilane, 2-(isopropenyloxy)ethyl trimethoxysilane, 3-(allyloxy)propyl trimethoxysilane, 10-(allyloxycarbonyl)decyl trimethoxysilane, 3-(isopropenyl methyloxy)propyl trimethoxysilane, 10-(isopropenylmethyloxycarbonyl)decyl trimethoxysilane, 3-[(meth)acryloyloxy]propyl trimethoxysilane, 3-[(meth)acryloyloxy]propyl triethoxysilane, (meth)acryloyloxymethyl trimethoxysilane, (meth)acryloyloxymethyl triethoxysilane, γ -glycidoxypropyl trimethoxysilane, N-[3-(meth)acryloyloxy-2-hydroxypropyl]-3-aminopropyl triethoxysilane, O-[(meth)acryloyloxyethyl]-N-(triethoxysilylpropyl)urethane, γ -glycidoxypropyl triethoxysilane, β -(3,4-epoxycyclohexyl)ethyl trimethoxysilane, γ -aminopropyl triethoxysilane, γ -aminopropyl trimethoxysilane, 4-aminobutyl triethoxysilane, 11-aminoundecyl triethoxysilane, m-aminophenyl trimethoxysilane, p-aminophenyl trimethoxysilane, 3-amino propyl tris(methoxyethoxy)silane, 2-(4-pyridyl)ethyl triethoxysilane, 2-(trimethoxysilyl)pyridine, N-(3-trimethoxysilylpropyl)pyrrole, 3-(m-amino-phenoxy)propyl trimethoxysilane, N-(2-aminoethyl)-3-aminopropyl trimethoxysilane, N-(2-aminoethyl)-3-aminopropyl triethoxysilane, N-(6-aminoethyl)aminomethyl triethoxy silane, N-(6-aminoethyl)aminopropyl trimethoxysilane, N-(2-aminoethyl)-11-aminoundecyl trimethoxysilane, (aminoethylaminomethyl)phenethyl trimethoxysilane, 3-N-[(amino (polypropyleneoxy))]aminopropyl trimethoxysilane, n-butylaminopropyl trimethoxy silane, N-ethylaminoisobutyl trimethoxy silane, N-methylaminopropyl trimethoxysilane, N-phenyl- γ -aminopropyl trimethoxysilane, N-phenyl- γ -aminomethyl triethoxysilane, (cyclohexylaminomethyl)triethoxysilane, N-cyclohexylaminopropyl trimethoxysilane, bis(2-hydroxyethyl)-3-aminopropyl triethoxysilane, diethylaminomethyl triethoxysilane, diethylaminopropyl trimethoxy silane, dimethylaminopropyl trimethoxysilane, N-3-trimethoxysilylpropyl-m-phenylenediamine, N,N-bis[3-(trimethoxysilyl)propyl]ethylenediamine, bis(triethoxysilylpropyl)amine, bis(trimethoxysilylpropyl)amine, bis [(3-trimethoxysilyl)propyl]-ethylenediamine, bis[3-(triethoxysilyl)propyl]urea, bis(trimethoxysilylpropyl)urea, N-(3-triethoxysilylpropyl)-4,5-dihydroimidazole, ureidopropyltriethoxysilane, ureidopropyltrimethoxysilane, acetamidopropyl trimethoxysilane, 2-(2-pyridylethyl)thiopropyl trimethoxysilane, 2-(4-pyridylethyl)thiopropyl trimethoxysilane, bis[3-(triethoxysilyl)propyl]disulfide, 3-(triethoxysilyl)propylsuccinic acid anhydride, γ -mercaptopropyl trimethoxysilane, γ -mercaptopropyl triethoxysilane, isocyanatopropyl trimethoxysilane, isocyanatopropyl triethoxysilane, isocyanatoethyl triethoxysilane, isocyanatomethyl triethoxysilane, carboxyethylsilanetriol sodium salt, N-(trimethoxysilyl propyl)ethylenediamine triacetic acid trisodium salt, 3-(trihydroxysilyl)-1-propanesulfonic acid, diethyl phosphatoethyl triethoxysilane, 3-trihydroxysilylpropyl methyl phosphonate sodium salt, bis(triethoxysilyl)ethane, bis(trimethoxysilyl)ethane, bis(triethoxysilyl)methane, 1,6-bis(triethoxysilyl)hexane, 1,8-bis(triethoxysilyl)octane, p-bis(trimethoxysilyl)benzene, p-bis(trimethoxysilyl)methylbenzene, 3-methoxypropyl trimethoxysilane, 2-[methoxy(polyethyleneoxy)propyl]trimethoxysilane, methoxytriethyleneoxypropyl trimethoxysilane, tris(3-trimethoxysilylpropyl)isocyanurate, [hydroxy(polyethyleneoxy)propyl]triethoxysilane, N,N'-bis(hydroxyethyl)-N,N'-bis(trimethoxysilylpropyl)ethylenediamine, bis-[3-(triethoxysilylpropyl)-2-hydroxypropoxy]polyethylene oxide, bis[N,N'-(triethoxysilylpropyl)aminocarbonyl]polyethylene oxide, 3-methacryloxypropyl-trimethoxysilane, 3-methacryloxypropyl-triethoxysilane, and bis(triethoxysilylpropyl)polyethylene oxide.

[0094] Preferable examples of the specific alkoxide compound include tetramethoxysilane, tetraethoxysilane, 3-glycidoxypropyltrimethoxysilane, diethyldiethoxysilane, 3-methacryloxypropyl-trimethoxysilane, 3-methacryloxypropyl-triethoxysilane.

[0095] Preferably, the polysiloxane-based layer comprises a reaction product obtained by reacting:

- at least one compound of Formula (I) chosen in the group constituted by: tetramethoxysilane and tetraethoxysilane; and
- optionally at least one compound of Formula (II) chosen in the group constituted by: 3-glycidoxypropyltrimethoxysilane

lane, diethyldiethoxysilane, 3-methacryloxypropyl-trimethoxysilane, 3-methacryloxypropyl-triethoxysilane.

[0096] The specific alkoxide can be easily procured from commercially available products, or can be obtained using a well-known synthesis method, for example, a reaction between each of the metal chlorides and an alcohol.

[0097] As the specific alkoxide, one compound may be solely used, or a combination of two or more compounds may be used.

[0098] Examples of the combination include a combination of at least one compound of Formula (I) and at least one compound of Formula (II). For a conductive layer including, as the matrix, a cured sol-gel substance obtained by hydrolyzing and polycondensing a combination of two specific alkoxide compounds, the properties can be modified using the mixing ratio.

[0099] A polysiloxane-based layer comprising the specific cured sol-gel substance as the matrix can be provided on the conductive layer by coating an aqueous solution comprising the specific alkoxide compound as a coating liquid (hereinafter, also referred to as "sol-gel coating liquid") on the conductive layer so as to form a coated film, causing reactions of hydrolysis and polycondensation of the specific alkoxide compound in the coated film, and, furthermore, as necessary, heating and evaporating water which is used as a solvent, thereby drying the coated film.

[0100] In order to accelerate the hydrolysis and polycondensation reactions, it is practically preferable to jointly use an acidic catalyst or a basic catalyst since the reaction efficiency increases. Any substance can be used as the catalyst as long as the substance accelerates the hydrolysis and polycondensation reactions of the alkoxide compound. Examples of the catalyst include acidic compounds and basic compounds. The acidic compounds and the basic compounds can be used as they are, and may be used in a state in which the compounds are dissolved in a solvent such as water or an alcohol. The kind of the acidic catalyst or the basic catalyst is not particularly limited; however, in a case in which it is necessary to use a catalyst having a high concentration, it is preferable to select a catalyst made of an element that rarely remains in the layer. Specific examples of the acidic catalyst include hydrogen halides such as hydrochloric acid; inorganic acids such as nitric acid, sulfuric acid, sulfurous acid, hydrogen sulfide, perchloric acid, hydrogen perchloride and carbonic acid; carboxylic acids such as formic acid and acetic acid; substituted carboxylic acids such as benzenesulfonic acid; and the like, and specific examples of the basic catalyst include quaternary ammonium salt compounds such as ammonia water and tetramethylammonium hydroxide; organic amines such as ethylamine and aniline; and the like.

[0101] An organic solvent may be included as desired in the sol-gel coating liquid in order to ensure the uniform formability of a coating liquid film on the conductive layer. Examples of the organic solvent include ketone-based solvents such as acetone, methyl ethyl ketone and diethyl ketone; alcohol-based solvents such as methanol, ethanol, 2-propanol, 1-propanol, 1-butanol and tert-butanol; chlorine-based solvents such as chloroform and methylene chloride; aromatic solvents such as benzene and toluene; ester-based solvents such as ethyl acetate, butyl acetate and isopropyl acetate; ether-based solvents such as diethyl ether, tetrahydrofuran and dioxane; glycol ether-based solvents such as ethylene glycol monomethyl ether and ethylene glycol dimethyl ether; and the like. The organic solvent may be added in a range of preferably from 10 to 90% by mass, more preferably from 25 to 75% by mass with respect to the total mass of the sol-gel coating liquid.

[0102] The heating temperature for accelerating the sol-gel reaction is appropriate in a range of from 30°C to 200°C, and more preferably in a range of from 50°C to 180°C. The heating and drying time is preferably from 10 seconds to 300 minutes, and more preferably from 1 minute to 120 minutes.

[0103] According to one embodiment of the present invention, at least a compound of formula (I), and optionally at least a compound of formula (II) is mixed with a polar solvent and a catalyst to thereby prepare the solution by sol-gel type hydrolysis.

[0104] The molar ratio of compound(s) of formula (I) and compound(s) of formula (II) may be in the range from 1:5 to 10:1, preferably from 1:1 to 7:1.

[0105] The content ratio of the compound of Formula (I)/compound of Formula (II) may be in a range of from 0.01/1 to 100/1, and more preferably in a range of from 0.05/1 to 50/1 by mass ratio.

[0106] The solution may be coated on the surface of the conductive layer by spin coating, dip coating, roll coating, screen coating, spray coating, spin casting, flow coating, screen printing, ink-jetting, drop casting, and the like with a thickness usually comprised between 0.03 and 0.1 μm , followed by heat curing or photocuring, to thereby form a layer.

[0107] The thickness of the polysiloxane-based layer is preferably from 10 nm to 1000 nm, more preferably 20 to 500 nm, particularly 30 to 150 nm, notably 40 to 100 nm. This thickness may be determined by a person skilled in the art considering the type of rod to apply the coating to determine the wet thickness and the solid content of the coating formulation.

Electrode assembly

[0108] The electrode assembly according to the present invention can attain excellent one or more optical and electrical

properties which are often required for various applications of such transparent conductor.

[0109] Accordingly, the electrode assembly of the present invention may possess at least one, preferably two, more preferably all of the following characteristics:

- a transparency to visible light from 60 to 99 %, preferably from 75 to 98 %, and even more preferably from 88 to 95 %;
- a sheet resistance from 0.1 to 1000000 Ω /square, preferably from 5 to 200 Ω /square, even more preferably from 30 to 80 Ω /square;
- a haze from 0.1 to 20 %, preferably, from 0.4 to 4 %, even more preferably from 0.6 to 1.1 %; and
- a contact angle 50 to 80°, preferably from 65 to 75°.

[0110] In the present invention, the transparency (transmission) to visible light can be measured by using UV-VIS spectrometer at wavelength range from 400 nm to 800 nm. For instance, Haze-gard plus instrument (transparency function) available from BYK-Gardner (ASTM D 1003) can be used.

[0111] In the present invention, the sheet resistance can be measured using 4-point probes using R-CHEK Surface Resistivity Meter (Model #RC3175) available from EDTM Inc.

[0112] In the present invention, the haze can be measured using a haze-meter, for instance Haze-gard plus instrument available from BYK-Gardner (ASTM D 1003).

[0113] In the present invention, the assessment for contact angle can be measured by measurement of water contact angle thru SEO Phoenix 150 (Surface electro optics Co, Korea) at 26.5°C and RH35%.

[0114] The transparent electrode assembly according to the present invention may be subject to one or more subsequent fabrication process. For instance, the transparent electrode assembly can be patterned and/or over-coated with one or more layer. For the methodologies of the patterning, reference can be made to the disclosures of the United States Patent Application Publication No. US 2014/0203223 A, which, by its entirety, is incorporated herein by reference.

[0115] The transparent electrode assembly of the present invention and/or its fabricated structure, especially patterned structure thereof, can be used in various electronic devices in which a transparent electrode assembly is suitably utilized.

[0116] The invention also concerns an electronic device comprising at least an electrode assembly comprising at least:

- a substrate;
- a conductive layer formed on the substrate comprising at least a metal nanowires; and
- a polysiloxane-based layer formed on the conductive layer.

[0117] Examples of the application include touch panels, various electrodes for display devices, such as liquid crystal display (LCD), light emitting diode (LED) display plasma displays, and organic light-emitting diode (OLED) displays, electroluminescent display displays (ELD), electrophoretic display (EPD), LED lighting, OLED lighting, antistatic layers, electromagnetic interference (EMI) shields, touch-panel-embedded display devices, and photovoltaic (PV) cells, but the present invention is not limited thereto. The electrode assembly of the present invention is particularly useful when used in touch panel and display applications.

[0118] Thus, still further aspect of the present invention concerns an electronic device at least comprising the electrode assembly, such as notably the transparent electrode assembly, according to the present invention.

EXPERIMENTAL PART

[0119] The disclosure will now be illustrated with working examples, which is intended to illustrate the working of disclosure and not intended to take restrictively to imply any limitations on the scope of the present disclosure. Other examples are also possible which are within the scope of the present disclosure.

Preparation of PEDOT formulation

[0120] 350g PEDOT:PSS (1wt% Verasol WED-SM from SOKEN) has been put on 2L Vessel, then 100g of isopropyl alcohol, 50g Dimethyl sulfoxide and 500g deionized water have been added. The mixture was stirred by direct stirrer at 100rpm. 8.3g of Synergex® (N-Butylethanolamine from TAMICO) as neutral agent has been added when the mixture goes from low pH to reach a pH of 9.4. This mixture was 0.35wt% solid contents.

Preparation of AgNW formulation with PEDOT:PSS

[0121] 14.25g of PEDOT formulation was put in 250mL Nalgene bottle, and 60.75g of deionized water and 10g of isopropyl alcohol have been then added. 15g of AgNW (1wt% dispersion in water from N&B) and 0.07g Dynol 607(from Air-product) as leveling agent have been added after the mixture shakes by vortex mixer. The mixture has been shaken

by roll-mixer during 1 hour.

Preparation of AgNW formulation

[0122] 5g of cellulose (Mw 4000, B4K, Lotte Fine Chemicals) has been dissolved in 995g D.I water as stirring during 24hr. 14.25g of cellulose solution has been put in 250mL Nalgene bottle, and 60.75g of deionized water and 10g of isopropyl alcohol have been added. 15g AgNW (1wt% dispersion in water from N&B) has been added and the mixture has been shaken by vortex mixer during 1 hour.

Preparation of polysiloxane by using TEOS

[0123] 205g of TEOS (tetramethyl orthosilicate) has been put on 2L reactor vessel and 624.8g of ethanol and 156.2g of deionized water have been added. 14g of acetic acid has been added into the vessel. The mixture has been stirred then under N₂ gas during 24hr at room temperature. After finished sol-gel synthesis, the mixture has been kept in freezer at below -12°C.

Preparation of polysiloxane by using TEOS and GPTMS

[0124] 164g of TEOS (tetramethyl orthosilicate) and 41g of GPTMS (glycidoxypopyl trimethoxysilane) have been put on 2L reactor vessel and 624.8g of ethanol and 156.2g of deionized water have been then added. 14g of acetic acid has been then added into the vessel. The mixture has been stirred then under N₂ gas during 24hr at room temperature. After finished sol-gel synthesis, the mixture has been kept in freezer at below -12°C.

Preparation of polysiloxane by using 3-methacryloxypropyl-trimethoxysilane and GPTMS

[0125] 164g of 3-methacryloxypropyl-trimethoxysilane and 41g of GPTMS (glycidoxypopyl trimethoxysilane) have been put on 2L reactor vessel and 624.8g of ethanol and 156.2g of deionized water have been then added. 14g of acetic acid has been then added into the vessel. The mixture has been stirred then under N₂ gas during 24hr at room temperature. After finished sol-gel synthesis, the mixture has been kept in freezer at below -12°C.

Comparative example 1 of UV coating on surface coated AgNW formulation.

[0126] AgNW formulation has been first coated on PET substrate by bar coater (#8) and get dry on condition of 130°C/60sec (at convection oven). This coated film shows properties on Transmittance 92% and Haze 0.64%. Then UV coating solution (Urethane Acrylate - PET-1006, Headong UV polymer, Korea. 27 wt%) has been diluted on ethyl cellosolve (2-ethoxy ethanol) as the ratios 1 to 10 (10g of solution for 100g of ethyl cellosolve), and then shook by vortex mixer. This solution has 2.45 wt% of solid contents. This solution has been then coated on the AgNW formulation film with 500mJ UV-radiation under broad band UV mercury lamp after drying at 130°C/60min. This coated film shows properties on Transmittance 91.9%, Haze 0.89. All bar coater used in these experiments are wire wound rods from RDS with Wire Size #.

Comparative example 2 of UV coating on surface coated AgNW formulation with PEDOT:PSS.

[0127] AgNW formulation has been first coated on PET substrate by bar coater (#8) and get dry on condition of 130°C/60sec (at convection oven). This coated film shows properties on Transmittance 89.4% and Haze 1.05%. Then UV coating solution (Urethane Acrylate - PET-1006, Headong UV polymer, Korea. 27 wt%) has been diluted on ethyl cellosolve as the ratios 1 to 10 (10g of solution for 100g of ethyl cellosolve), and then shook by vortex mixer. This solution has 2.45wt% of solid contents. This solution has been then coated on the AgNW formulation film with 500mJ UV-radiation under broad band UV mercury lamp after drying at 130°C/60min. This coated film shows properties on Transmittance 88.7%, Haze 1.37.

Example 1 of polysiloxane A by TEOS on each AgNW electrodes

[0128] Each of AgNW formulations has been coated on PET substrate by bar coater(#8) gets dry on condition of 130°C/60sec (at convection oven). The polysiloxane mixture is then diluted in ethanol as a ratio of 1g of polysiloxane mixture with 2g of ethanol, and then shook by vortex mixer. The mixture is then coated on the AgNW layer by bar coater(#5) and then dried under drying condition of 130°C/10min. Film of AgNW formulation has transmittance 92.6% and haze 0.82%. Film of AgNW formulation with the polysiloxane layer has transmittance 90.5% and haze 1.03%.

Example 2 of polysiloxane B by using TEOS and GPTMS on each AgNW electrode

[0129] Each of AgNW formulations has been coated on PET substrate by bar coater(#8) gets dry on condition of 130°C /60sec. The polysiloxane mixture is then diluted in ethanol as a ratio of 1g of polysiloxane mixture with 2g of ethanol, and then shook by vortex mixer. The mixture is then coated on the AgNW layer by bar coater(#5) and then dried under drying condition of 130°C/10min. Film of AgNW formulation has transmittance 92.6% and haze 0.55%. Film of AgNW formulation with the polysiloxane layer has transmittance 91% and haze 0.83%.

Example 3 of polysiloxane C by using 3-methacryloxypropyl-trimethoxysilane and GPTMS on each AgNW electrode.

[0130] Each of AgNW formulations has been coated on PET substrate by bar coater(#8) gets dry on condition of 130°C /60sec. The polysiloxane mixture is then diluted in ethanol as a ratio of 1g of polysiloxane mixture with 2g of ethanol, and then shook by vortex mixer. The mixture is then coated on the AgNW layer by bar coater(#5) and then dried under drying condition of 130°C/10min. Film of AgNW formulation has transmittance 92.3% and haze 0.73%. Film of AgNW formulation with the polysiloxane layer has transmittance 88.9% and haze 1.49%.

Optical properties and contact angle

[0131] Table 1 shows optical properties and contact angle after treatment.

Table 1

Case	Comp. example 1	Comp. example 2	Example 1		Example 2	
AgNW formulation	AgNW + cellulose	AgNW + PEDOT	AgNW + cellulose	AgNW + PEDOT	AgNW + cellulose	AgNW + PEDOT
Without treatment layer	Tr 92% Haze 0.64%	Tr 89.4% Haze 1.05%	Tr 92% Haze 0.64%	Tr 89.4% Haze 1.05%	Tr 92% Haze 0.64%	Tr 89.4% Haze 1.05%
Treatment layer	UV coating	UV coating	POS A	POS A	POS B	POS B
With treatment layer	Tr 91.9% Haze 0.89%	Tr 88.7% Haze 1.37%	Tr 92.6% Haze 0.82%	Tr 90.5% Haze 1.03%	Tr 92.6% Haze 0.55%	Tr 91% Haze 0.83%
Contact angle (°)	52.64	52.64	69.46	69.46	70.53	70.53

[0132] It appears that polysiloxane layer provides a higher contact angle and lower haze in comparison with a classical UV coating. The use of a polysiloxane layer also permit to increase the transmittance of the film in comparison with the AgNW formulation layer alone, while the use of a classical UV coating is substantially decreasing the transmittance in comparison with the use of the AgNW formulation layer alone.

[0133] Transmittance and haze were measured by averaging the value in 9 points on the coated PET film (A4 size) by using, respectively, UV-VIS spectrometer at wavelength range from 400 nm to 800 nm and Haze-gard plus instrument from BYK-Gardner in accordance with ASTM D 1003.

[0134] The assessment for contact angle on each sample has been made as follows: measurement of water contact angle thru SEO Phoenix 150 (Surface electro optics Co, Korea) by using coated film as upper description (26.5°C/RH35%).

Sheet resistance

[0135] Sheet resistance was measured by averaging the value in 12 points in the coated PET film (A4 size) with 4-point probes using R-CHEK Surface Resistivity Meter (Model #RC3175) from EDTM Inc.

[0136] The test condition keeps under 65°C and relative humidity 90%. For this test, test equipment uses a thermo hygrostat from Enx science, Korea. It determines the results of change rates on sheet-resistance after having done

during 250hr. Here in, sample size is 7.5cm by 7.5cm on each condition. The initial sheet-resistance is around 50Ω/sq.
 $\Delta \text{sheet-resistance} = (\text{sheet-resistance after test} / \text{sheet-resistance before test}) \times 100\%$.

[0137] Table 2 shows the test results for reliability under 65°C and relative humidity 90%.

Table 2

Case	Comp. example 1	Comp. example 2	Example 1		Example 2		Example 3	
	AgNW + cellulose	AgNW + PEDOT	AgNW	AgNW + PEDOT	AgNW	AgNW + PEDOT	AgNW	AgNW + PEDOT
Δ sheet- resistance (%)	34	23	9	6	7	3	17	15

[0138] It appears that the application of a polysiloxane layer lead to better performance after durability test of high humidity and high temperature (at 65°C/90%).

Claims

1. An electrode assembly comprising at least:

- a substrate;
- a conductive layer formed on the substrate comprising at least a metal nanowires; and
- a polysiloxane-based layer formed on the conductive layer.

2. The electrode assembly according to claim 1, wherein the substrate has a total visible light transmittance from 60% to 100%.

3. The electrode assembly according to claim 1 or 2, wherein the substrate is a glass substrate or a transparent solid polymer chosen in the group constituted by: polycarbonates, polyesters, acryl resins, polyvinyl resins, aromatic polyamide resins, polyamideimides, polyethylene naphthalene dicarboxylate, polysulphones, polyimides (PI), cyclic olefin copolymers (COC), styrene copolymers, polyethylene, polypropylene, cellulose ester bases and any combination thereof

4. The electrode assembly according to anyone of claim 1 to 3, wherein the aspect ratio of the metallic nanowires is from 300 and 2000.

5. The electrode assembly according to anyone of claim 1 to 4, wherein the metal of metal nanowires is chosen in the group constituted by: copper, silver, gold, platinum, palladium, nickel, tin, cobalt, rhodium, iridium, iron, ruthenium, osmium, manganese, molybdenum, tungsten, niobium, tantalum, titanium, bismuth, antimony, lead, alloys thereof and the like.

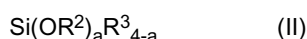
6. The electrode assembly according to anyone of claim 1 to 5, wherein the metal nanowires is chosen in the group constituted by: metal nanowires include, but are not limited to, silver nanowires, gold nanowires, copper nanowires, nickel nanowires, gold-plated silver nanowires, platinum nanowires, and palladium nanowires.

7. The electrode assembly according to anyone of claim 1 to 6, wherein the metal nanowires have an average diameter of 10 nm to 30 nm and an average length of 10 to 30 μm.

8. The electrode assembly according to anyone of claim 1 to 7, wherein the conductive layer comprises at least one π -conjugated conductive polymer.

9. The electrode assembly according to anyone of claim 1 to 8, wherein the conductive layer comprises at least one π -conjugated conductive polymer chosen in the group constituted by polyaniline polymers, polypyrrole polymers, polythiophene polymers, and any combination thereof.

10. The electrode assembly according to anyone of claim 1 to 9, wherein the conductive layer comprises poly(3,4-ethylenedioxythiophene) polymer.
11. The electrode assembly according to anyone of claim 1 to 10, wherein the conductive layer comprises at least one amine compound.
12. The electrode assembly according to claim 11, wherein the amine compound is an alkanol amine.
13. The electrode assembly according to claim 11 or 12, wherein the amine compound is a compound comprising at least one secondary amine function or a tertiary amine function and at least one hydroxyl function.
14. The electrode assembly according to anyone of claims 11 to 13, wherein the amine compound has a boiling point from 180-300 °C.
15. The electrode assembly according to anyone of claims 1 to 14, wherein the conductive layer comprises at least one polysaccharide.
16. The electrode assembly according to anyone of claims 1 to 15, wherein the polysiloxane-based layer comprises a reaction product obtained by reacting at least one compound of Formula (I) and optionally at least one compound of Formula (II) as follows:



wherein:

- a plurality of R^1 may be the same as or different from each other and each of R^1 independently represents a hydrogen atom or a hydrocarbon group
- a plurality of R^2 and a plurality of R^3 may be the same as or different from each other, and each of R^2 and each of R^3 independently represent a hydrogen atom or a hydrocarbon group, and
- a represents an integer of 1 to 3.

17. The electrode assembly according to claim 16, wherein the compounds of Formula (I) are chosen in the group constituted by: tetramethoxysilane, tetraethoxysilane, tetrapropoxysilane, tetrabutoxysilane, methoxytriethoxysilane, ethoxytrimethoxysilane, methoxytripropoxysilane, ethoxytripropoxysilane, propoxytrimethoxysilane, propoxytriethoxysilane, and dimethoxydiethoxysilane.
18. The electrode assembly according to claim 16, wherein the compounds of Formula (II) when a is 2, are chosen in the group constituted by: dimethyl dimethoxysilane, diethyl dimethoxysilane, propyl methyl dimethoxysilane, dimethyl diethoxysilane, diethyl diethoxysilane, dipropyl diethoxysilane, γ -chloropropyl methyl diethoxysilane, γ -chloropropyl methyl dimethoxysilane, (p-chloromethyl)phenyl methyl dimethoxysilane, γ -bromopropyl methyl dimethoxysilane, acetoxymethyl methyl diethoxysilane, acetoxymethyl methyl dimethoxysilane, acetoxy propyl methyl dimethoxysilane, benzyloxypropyl methyl dimethoxysilane, 2-(carbomethoxy) ethyl methyl dimethoxysilane, phenyl methyl dimethoxysilane, phenyl ethyl diethoxysilane, phenyl methyl di-propoxysilane, hydroxymethyl methyl diethoxysilane, N-(methyl-diethoxysilyl-propyl)-O-polyethylene oxide urethane, N-(3-methyl-diethoxysilylpropyl)-4-hydroxy-butylamide, N-(3-methyl-diethoxysilylpropyl) gluconamide, vinyl methyl dimethoxysilane, vinyl methyl diethoxysilane, vinyl methyl dibutoxysilane, isopropenyl methyl dimethoxysilane, isopropenyl methyl diethoxysilane, isopropenyl methyl dibutoxysilane, vinyl methyl bis(2-methoxyethoxy)silane, allyl methyl dimethoxysilane, vinyldecyl methyl dimethoxysilane, vinyloctyl methyl dimethoxysilane, vinylphenyl methyl dimethoxysilane, isopropenylphenyl methyl dimethoxysilane, 2-(meth)acryloyloxyethyl methyl dimethoxysilane, 2-(meth)acryloyloxyethyl methyl diethoxysilane, 3-(meth)acryloyloxypropyl methyl dimethoxysilane, 3-(meth)acryloyloxypropyl methyl diethoxysilane, 3-(meth)acryloyloxypropyl methyl bis(2-methoxyethoxy)silane, 3-[2-(allyloxy-carbonyl)phenylcarbonyloxy]propyl methyl dimethoxysilane, 3-(vinyl phenylamino)propyl methyl dimethoxysilane, 3-(vinylphenylamino)propyl methyl diethoxysilane, 3-(vinylbenzylamino)propyl methyl diethoxysilane, 3-(vinylbenzylamino)propyl methyl diethoxysilane, 3-[2-(N-vinylphenylmethylamino)ethyl amino]propyl methyl dimethoxysilane, 3-[2-(N-isopropenylphenylmethylamino)ethyl amino]propyl methyl dimethoxysilane, 2-(vinylloxy)ethyl methyl dimethoxysilane, 3-(vinylloxy)propyl methyl dimethoxysilane, 4-(vinylloxy)butyl methyl diethoxysilane, 2-(isopropenylloxy)ethyl methyl dimethoxysilane, 3-(allyloxy)propyl

methyl dimethoxysilane, 10-(allyloxycarbonyl)decyl methyl dimethoxysilane, 3-(isopropenylmethyloxy)propyl methyl dimethoxysilane, 10-(isopropenylmethyloxycarbonyl)decyl methyl dimethoxysilane, 3-[(meth)acryloyloxypropyl]methyl dimethoxysilane, 3-[(meth)acryloyloxypropyl]methyl diethoxysilane, 3-[(meth)acryloyloxymethyl]methyl dimethoxysilane, 3-[(meth)acryloyloxymethyl]methyl diethoxysilane, γ -glycidoxypropyl methyl dimethoxysilane, N-[3-(meth)acryloyloxy-2-hydroxypropyl]-3-aminopropyl methyl diethoxysilane, O-[(meth)acryloyloxyethyl]-N-(methyldiethoxysilylpropyl)urethane, γ -glycidoxypropyl methyl diethoxysilane, β -(3,4-epoxycyclohexyl)ethyl methyl dimethoxysilane, γ -aminopropyl methyl diethoxysilane, γ -aminopropyl methyl dimethoxysilane, 4-amino-butyl methyl diethoxysilane, 11-amino-undecyl methyl diethoxysilane, m-aminophenyl methyl dimethoxysilane, p-aminophenyl methyl dimethoxysilane, 3-aminopropyl methyl-bis(methoxyethoxy)silane, 2-(4-pyridylethyl)methyl diethoxysilane, 2-(methyldimethoxysilylethyl)pyridine, N-(3-methyldimethoxysilylpropyl)pyrrole, 3-(m-aminophenoxy)propyl methyl dimethoxysilane, N-(2-aminoethyl)-3-aminopropyl methyl dimethoxysilane, N-(2-aminoethyl)-3-aminopropyl methyl diethoxysilane, N-(6-aminoethyl)amino-methyl methyl diethoxysilane, N-(6-aminoethyl)amino-propyl methyl dimethoxysilane, N-(2-aminoethyl)-11-amino-undecyl methyl dimethoxysilane, (aminoethyl aminomethyl)phenethyl methyl dimethoxysilane, N-3-[(amino(polypropyleneoxy))]aminopropyl methyl dimethoxysilane, n-butylaminopropyl methyl dimethoxysilane, N-ethylaminoisobutyl methyl dimethoxysilane, N-methyl-aminopropyl methyl dimethoxysilane, N-phenyl- γ -aminopropyl methyl dimethoxysilane, N-phenyl- γ -aminomethyl methyl diethoxysilane, (cyclohexylaminomethyl) methyl diethoxysilane, N-cyclohexylaminopropyl methyl dimethoxysilane, bis(2-hydroxyethyl)-3-aminopropyl methyl diethoxysilane, diethylaminomethyl methyl diethoxysilane, diethylaminopropyl methyl dimethoxysilane, dimethylaminopropyl methyl dimethoxysilane, N-3-methyldimethoxysilylpropyl-m-phenylenediamine, N,N-bis[3-(methyldimethoxysilyl)propyl]-ethylenediamine, bis(methyl-diethoxysilylpropyl)amine, bis(methyldimethoxysilylpropyl)amine, bis[(3-methyldimethoxysilyl)propyl]-ethylenediamine, bis[3-(methyldiethoxysilyl)propyl]urea, bis(methyldimethoxysilylpropyl)urea, N-(3-methyl-diethoxysilylpropyl)-4,5-dihydroimidazole, ureidopropyl methyl diethoxysilane, ureidopropyl methyl dimethoxysilane, acetamidopropyl methyl dimethoxysilane, 2-(2-pyridylethyl)thiopropyl methyl dimethoxysilane, 2-(4-pyridylethyl)thiopropyl methyl dimethoxysilane, bis[3-(methyldiethoxysilyl)propyl]disulfide, 3-(methyldiethoxysilyl)propylsuccinic acid anhydride, γ -mercaptopropyl methyl dimethoxysilane, γ -mercaptopropyl methyl diethoxysilane, isocyanatopropyl methyl dimethoxysilane, isocyanatopropyl methyl diethoxysilane, isocyanatoethyl methyl diethoxysilane, isocyanatomethyl methyl diethoxysilane, carboxyethyl methylsilane diol sodium salt, N-(methyldimethoxysilylpropyl)ethylenediamine triacetic acid trisodium salt, 3-(methyl dihydroxysilyl)-1-propanesulfonic acid, diethyl phosphatoethyl methyl diethoxysilane, 3-methyl-dihydroxysilylpropyl methylphosphonate sodium salt, bis(methyldiethoxysilyl)ethane, bis(methyldimethoxysilyl)ethane, bis(methyldiethoxysilyl)methane, 1,6-bis(methyldiethoxysilyl)hexane, 1,8-bis(methyldiethoxysilyl)octane, p-bis(methyldimethoxysilylethyl)benzene, p-bis(methyldimethoxysilyl)benzene, 3-methoxypropyl methyl dimethoxysilane, 2-[methoxy(polyethyleneoxy)propyl]methyl dimethoxysilane, methoxytriethyleneoxypropyl methyl dimethoxysilane, tris(3-methyldimethoxysilylpropyl)isocyanurate, [hydroxy(polyethyleneoxy)propyl]methyl diethoxysilane, N,N'-bis(hydroxyethyl)-N,N'-bis(methyldimethoxysilylpropyl)ethylenediamine, bis-[3-(methyldiethoxysilylpropyl)-2-hydroxypropoxy]polyethylene oxide, bis[N,N'-(methyl-diethoxysilylpropyl)aminocarbonyl]polyethylene oxide, and bis(methyldiethoxysilylpropyl)polyethylene oxide.

19. The electrode assembly according to claim 16, wherein the compounds of Formula (II) when a is 3, are chosen in the group constituted by: methyl trimethoxysilane, ethyl trimethoxysilane, propyl trimethoxysilane, methyl triethoxysilane, ethyl triethoxysilane, propyl triethoxysilane, γ -chloropropyl triethoxysilane, γ -chloropropyl trimethoxysilane, chloromethyl triethoxysilane, (p-chloromethyl)phenyl trimethoxy silane, γ -bromopropyl trimethoxysilane, acetoxymethyl triethoxysilane, acetoxymethyl trimethoxysilane, acetoxypropyl trimethoxy silane, benzoyloxypropyl trimethoxysilane, 2-(carbomethoxy)ethyl trimethoxysilane, phenyl trimethoxysilane, phenyl triethoxysilane, phenyl tripropoxysilane, hydroxymethyl triethoxysilane, N-(triethoxysilylpropyl)-O-polyethylene oxido urethane, N-(3-triethoxysilylpropyl)-4-hydroxybutyl amide, N-(3-triethoxysilylpropyl)gluconamide, vinyl trimethoxysilane, vinyl triethoxysilane, vinyl tributoxysilane, isopropenyl trimethoxysilane, isopropenyl triethoxysilane, isopropenyl tributoxysilane, vinyl tris(2-methoxyethoxy)silane, allyl trimethoxysilane, vinyldecyl trimethoxy silane, vinyloctyl trimethoxysilane, vinylphenyl trimethoxysilane, isopropenylphenyl trimethoxysilane, 2-(meth)acryloyloxyethyl trimethoxysilane, 2-(meth)acryloyloxyethyl triethoxysilane, 3-(meth)acryloyloxypropyl trimethoxysilane, 3-(meth)acryloyloxypropyl trimethoxysilane, 3-(meth)acryloyloxypropyl tris(2-methoxyethoxy)silane, 3-[2-(allyloxycarbonyl)phenylcarbonyloxy]propyl trimethoxysilane, 3-(vinylphenylamino)propyl trimethoxysilane, 3-(vinylphenylamino)propyl triethoxysilane, 3-(vinylbenzylamino)propyl triethoxysilane, 3-(vinylbenzylamino)propyl triethoxysilane, 3-[2-(N-vinylphenylmethylamino)ethylamino]propyl trimethoxysilane, 3-[2-(N-isopropenylphenylmethylamino)ethylamino]propyl trimethoxysilane, 2-(vinylloxy)ethyl trimethoxysilane, 3-(vinylloxy)propyl trimethoxysilane, 4-(vinylloxy)butyl triethoxysilane, 2-(isopropenyloxy)ethyl trimethoxysilane, 3-(allyloxy)propyl trimethoxysilane, 10-(allyloxycarbonyl)decyl trimethoxysilane, 3-(isopropenyl methyloxy)propyl trimethoxysilane, 10-(isopropenylmethyloxycarbonyl)decyl trimethoxysilane, 3-[(meth)acryloyloxy]propyl trimethoxysilane, 3-[(meth)acryloyloxy]propyl triethoxysilane, (meth)acryloy-

loxymethyl trimethoxysilane, (meth)acryloyloxymethyl triethoxysilane, γ -glycidoxypropyl trimethoxysilane, N-[3-(meth)acryloyloxy-2-hydroxypropyl]-3-aminopropyl triethoxysilane, O-[(meth)acryloyloxyethyl]-N-(triethoxysilylpropyl)urethane, γ -glycidoxypropyl triethoxysilane, β -(3,4-epoxycyclohexyl)ethyl trimethoxysilane, γ -aminopropyl triethoxysilane, γ -aminopropyl trimethoxysilane, 4-aminobutyl triethoxysilane, 11-aminoundecyl triethoxysilane, m-aminophenyl trimethoxysilane, p-aminophenyl trimethoxysilane, 3-amino propyl tris(methoxyethoxyethoxy)silane, 2-(4-pyridyl)ethyl triethoxysilane, 2-(trimethoxysilyl)ethylpyridine, N-(3-trimethoxysilylpropyl)pyrrole, 3-(m-aminophenoxy)propyl trimethoxysilane, N-(2-aminoethyl)-3-aminopropyl trimethoxysilane, N-(2-aminoethyl)-3-aminopropyl triethoxysilane, N-(6-aminoethyl)aminomethyl triethoxy silane, N-(6-aminoethyl)aminopropyl trimethoxysilane, N-(2-aminoethyl)-11-aminoundecyl trimethoxysilane, (aminoethylaminomethyl)phenethyl trimethoxysilane, 3-N-[(amino (polypropyleneoxy))]aminopropyl trimethoxysilane, n-butylaminopropyl trimethoxy silane, N-ethylaminoisobutyl trimethoxy silane, N-methylaminopropyl trimethoxysilane, N-phenyl- γ -aminopropyl trimethoxysilane, N-phenyl- γ -aminomethyl triethoxysilane, (cyclohexylaminomethyl)triethoxysilane, N-cyclohexylaminopropyl trimethoxysilane, bis(2-hydroxyethyl)-3-aminopropyl triethoxysilane, diethylaminomethyl triethoxysilane, diethylaminopropyl trimethoxy silane, dimethylaminopropyl trimethoxysilane, N-3-trimethoxysilylpropyl-m-phenylenediamine, N,N-bis[3-(trimethoxysilyl)propyl]ethylenediamine, bis(triethoxysilylpropyl)amine, bis(trimethoxysilylpropyl)amine, bis[(3-trimethoxysilyl)propyl]-ethylenediamine, bis[3-(triethoxysilyl)propyl]urea, bis(trimethoxysilylpropyl)urea, N-(3-triethoxysilylpropyl)-4,5-dihydroimidazole, ureidopropyltriethoxysilane, ureidopropyltrimethoxysilane, acetamidopropyl trimethoxysilane, 2-(2-pyridylethyl)thiopropyl trimethoxysilane, 2-(4-pyridylethyl)thiopropyl trimethoxysilane, bis[3-(triethoxysilyl)propyl]disulfide, 3-(triethoxysilyl)propylsuccinic acid anhydride, γ -mercaptopropyl trimethoxysilane, γ -mercaptopropyl triethoxysilane, isocyanatopropyl trimethoxysilane, isocyanatopropyl triethoxysilane, isocyanatoethyl triethoxysilane, isocyanatomethyl triethoxysilane, carboxyethylsilanetriol sodium salt, N-(trimethoxysilylpropyl)ethylenediamine triacetic acid trisodium salt, 3-(trihydroxysilyl)-1-propanesulfonic acid, diethyl phosphatoethyl triethoxysilane, 3-trihydroxysilylpropyl methyl phosphonate sodium salt, bis(triethoxysilyl)ethane, bis(trimethoxysilyl)ethane, bis(triethoxysilyl)methane, 1,6-bis(triethoxysilyl)hexane, 1,8-bis(triethoxysilyl)octane, p-bis(trimethoxysilyl)benzene, p-bis(trimethoxysilyl)methylbenzene, 3-methoxypropyl trimethoxysilane, 2-[methoxy(polyethyleneoxy)propyl]trimethoxysilane, methoxytriethyleneoxypropyl trimethoxysilane, tris(3-trimethoxysilylpropyl)isocyanurate, [hydroxy(polyethyleneoxy)propyl]triethoxysilane, N,N'-bis(hydroxyethyl)-N,N'-bis(trimethoxysilylpropyl)ethylenediamine, bis-[3-(triethoxysilylpropyl)-2-hydroxypropoxy]polyethylene oxide, bis[N,N'-(triethoxysilylpropyl)aminocarbonyl]polyethylene oxide, 3-methacryloxypropyl-trimethoxysilane, 3-methacryloxypropyl-triethoxysilane, and bis(triethoxysilylpropyl)polyethylene oxide.

20. The electrode assembly according to claim 16, wherein the polysiloxane-based layer comprises a reaction product obtained by reacting:

- at least one compound of Formula (I) chosen in the group constituted by: tetramethoxysilane and tetraethoxysilane; and
- optionally at least one compound of Formula (II) chosen in the group constituted by: 3-glycidoxypropyltrimethoxysilane, diethyldiethoxysilane, 3-methacryloxypropyl-trimethoxysilane, 3-methacryloxypropyl-triethoxysilane.

21. The electrode assembly according to anyone of claims 16 to 20, wherein the molar ratio of compound(s) of formula (I) and compound(s) of formula (II) is from 1:5 to 10:1.

22. The electrode assembly according to anyone of claims 1 to 21, wherein:

- the thickness of the conductive layer is from 10 to 1000 nm;
- the thickness of the polysiloxane-based layer is from 10 to 1000 nm.

23. The electrode assembly according to anyone of claims 1 to 22, wherein said electrode assembly possess at least one, preferably two, more preferably all of the following characteristics:

- a transparency to visible light from 60 to 99 %, preferably from 75 to 98 %, and even more preferably from 88 to 95 %;
- a sheet resistance from 0.1 to 1000000 Ω /square, preferably from 5 to 200 Ω /square, and even more preferably from 30 to 80 Ω /square;
- a haze from 0.1 to 20 %, preferably from 0.4 to 4 %, and even more preferably from 0.6 to 1.1 %; and
- a contact angle 50 to 80°, preferably from 65 to 75°.

24. A method for the production of an electrode assembly comprising at least the steps of:

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- forming a conductive layer formed on all or a part of a substrate; said conductive layer comprising at least a metal nanowires; and
- forming a polysiloxane-based layer on all or a part of the conductive layer.

5 **25.** An electronic device comprising at least an electrode assembly comprising at least:

- a substrate;
- a conductive layer formed on the substrate comprising at least a metal nanowires; and
- a polysiloxane-based layer formed on the conductive layer.

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EUROPEAN SEARCH REPORT

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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 7 June 2017	Examiner Lehnert, Andreas
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