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DESCRIPTION

PARTIES TO JOINT RESEARCH AGREEMENT

[0001] The invention described herein was created subject to a Joint Research Agreement between Sienna Labs, Inc. and nanoComposix, Inc.

BACKGROUND

Field of the Invention

[0002] The invention relates to a method for preparing high optical density solutions of silver platelet nanoparticles (e.g., nanoplates) and to nanoparticles, solutions and substrates prepared by said methods.

Description of the Related Art

[0003] Nanoparticles, including nanospheres, nanorods, nanowires, nanocubes, nanoplates, as well as other shapes can be synthesized from a range of materials. In one embodiment, a platelet nanoparticle is a nanoplate. Nanoparticles made from metals including gold and silver have unique optical properties which can be tuned to interact with light throughout the electromagnetic spectrum due to the localized surface plasmon resonance supported by these nanomaterials. Technologies that take advantage of the unique optical properties of silver nanoparticles include, but are not limited to, diagnostic, photonic, medical, and obscurant technologies. A subset of these technologies including photothermal tumor ablation, hair removal, acne treatment, wound healing, and antimicrobial applications among others, may use solutions of nanoparticles with high optical densities. Silver nanoplates, which are also known as silver platelet nanoparticles or nanoprisms, are of particular interest for technologies that utilize nanoparticle optical properties due to their tunable spectral peaks and extremely high optical efficiencies. While methods of fabricating silver nanoplates via photoconversion (Jin et al. 2001; Jin et al. 2003), pH-controlled photoconversion (Xue 2007), thermal growth (Hao et al. 2004; Hao 2002; He 2008; Metraux 2005), templated growth (Hao et al. 2004; Hao 2002),and seed mediated growth (Aherne 2008; Chen; Carroll 2003; Chen; Carroll 2002, 2004; Chen et al. 2002; He 2008; Le Guevel 2009; Xiong et al. 2007) have been developed, these methods generate relatively dilute solutions with correspondingly low visible and near-infrared optical density.

SUMMARY

[0004] For many silver nanoplate applications, a more concentrated solution of the silver nanoplates is of utility and can be particularly advantageous. In some instances, when as-fabricated solutions of silver nanoplates are concentrated to yield a higher particle density under previously developed methods, the shape of the nanoparticle can undergo a change resulting in a shift in optical properties, such as optical density. In many cases, these changes result in an undesirable degradation of the nanoparticle's optical properties. Accordingly, several embodiments of the present invention provide methods of preparing silver nanoplates solutions in higher concentrations with increased optical density while reducing degradation of the silver nanoplates' optical properties. In various embodiments, methods of the present invention provide for preparing high optical density solutions of silver nanoplates from dilute silver nanoplate solutions that partially, substantially, or fully preserve the shape and optical properties of the fabricated silver nanoplates when the particle concentration is increased.

[0005] Various embodiments of the invention provide methods for preparing high optical density solutions of silver nanoplates, as well as the nanoparticles and solutions prepared by those methods. In one embodiment, the process comprises the replacement of one or more original components (e.g., chemical or biological agents) bound to, or otherwise coupled to, the nanoparticle surface with a stabilizing agent. In another embodiment, the stabilizing agent does not replace the original component but rather supplements or alters the original component. The stabilizing agent can be a biological or chemical agent that stabilizes the nanoplates before, during, and/or after concentration, thereby allowing for the production of a stable, high optical density solution of silver nanoplates. The process also comprises a method of increasing the concentration of silver nanoplates within the solution, and thus increasing the solution optical density. In several embodiments, the stability (e.g., the characteristics of the nanoparticles in the solution, such as shape, size, optical properties, peak response, plasmonic properties, etc.) of the high optical density solution is unaffected or substantially unaffected during the process. Several embodiments of the invention comprise a high optical density solution of silver nanoplates that have been stabilized with stabilizing agents (e.g., surface bound molecules, chemical agents, and/or biological agents). In one embodiment, the invention comprises a solution of silver nanoplates that have been surface functionalized with chemical or biological agents that are physisorbed to the surface, molecularly bound to the surface through specific interactions, or encapsulate each nanoparticle.

[0006] In one embodiment, a high optical density solution of silver nanoplates is associated with a substrate. In one embodiment, a portion of the nanoplates in solution bind to the substrate to create a nanoplate-substrate composite. The high optical density solutions of silver nanoplates can be exposed to substrates to generate nanoplate composites where a substantial portion of the surface area of a substrate is coated with nanoplates. In the invention the substrate comprises fibers.

[0007] In several embodiments, a process for increasing the optical density of a stable, silver nanoplate solution, comprises (i) providing a solution comprising a plurality of silver nanoplates having a plate shape; (ii) adding a stabilizing agent to the solution, wherein the stabilizing agent comprises a polyvinyl based polymer and a borate; (iii) concentrating the solution to form a concentrated solution, wherein the concentrated solution comprises a plurality of silver nanoplates having the plate shape, and wherein the concentrated solution has a peak optical density greater than 10 cm^{-1}.

[0008] Also described is a method for producing a stable, high optical density solution of silver nanoplates comprises the following: (i) adding a stabilizing agent to a solution of silver nanoplates, (ii) adding a buffer (e.g., such as a buffer containing a water soluble salt) to the solution of silver nanoplates, (iii) mixing the stabilizing agent with the buffer and the silver nanoplates over a period of time sufficient for the stabilizing agent to interact with the water soluble salt in the buffer on the surface of the silver nanoplates, and (iv) concentrating the solution to a peak optical density greater than 10 cm^{-1} (e.g., 50-1500 cm^{-1}).

[0009] The stabilizing agents include a poly vinyl based polymer (such as polyvinyl alcohol (PVA) and/or polyvinylpyrrolidone (PVP)) and a borate, and can further include one or more of sodium citrate, a water soluble polymer, (such as polystyrene sodium sulfonate and/or a hydrocarbon polymer derivatized with sulfonate), polyethylene glycol, polyacrylic acid, dextran, a water soluble salt including one or more of the sulfates, carbonates, chromates, phosphates, and sulfites, acetates, and nitrates. In various embodiments, the combination of the stabilizing agent provides stabilization to the nanoplate formulation, wherein one of the components of the salt can interact with the stabilizing agent to crosslink the stabilizing agent and increase the stability of a coating on the silver nanoplate. In one embodiment an initial solution of silver nanoplates can be produced from a solution comprising one or more stabilizing agents and a silver source (e.g., such as a silver salt, silver seeds), and in which chemical agents, biological agents, mixing, electromagnetic radiation, and/or heat are used to reduce the silver source (e.g., photoconversion, pH controlled photoconversion, thermal growth, templated growth, and/or seed mediated growth).

[0010] In various embodiments, a process for concentrating a solution of silver nanoplates includes the steps of providing a solution comprising a plurality of silver nanoplates having a peak optical density below 10 cm^{-1} (e.g., 0.1 - 9.9 cm^{-1}, 1-9 cm^{-1}, 3-7 cm^{-1}, 1-5 cm^{-1}, and/or 5-10 cm^{-1}), adding a stabilizing agent to the solution, and concentrating the solution to a peak optical density greater than 10 cm^{-1} (e.g., 80-150 cm^{-1}, 900 - 1100 cm^{-1}, 100 cm^{-1}, 1000 cm^{-1} or more). In various embodiments, the peak optical density in increased by 10%, 50%, 100%, 200%, 500%, 1,000%, 10,000% or more, and/or increased by a ratio of 1:1.5, 1:2, 1:5, 1:10 or more, and/or increased by a factor of 1, 1.5, 2, 5, 10, 25, 50, 100, 1000 or more.

[0011] In various embodiments, the silver nanoplates have an aspect ratio of between 1.5 and 50 (e.g., 1.5 - 10, 25-50). In one embodiment, the silver nanoplates comprise an edge length between 10 nm and 300 nm (e.g., 50-250, 65-100 nm). In various embodiments, the stabilizing agent further comprises sodium citrate, or at least one water soluble polymer selected from the

group consisting of polystyrene sodium sulfonate and a hydrocarbon polymer derivatized with sulfonate. In some embodiments, the water soluble salt further comprises one or more of sulfates, carbonates, chromates, phosphates, and
sulfites, acetates, and nitrates. In one embodiment, the stabilizing agent further comprises at least one of the group consisting of polyvinyl pyrollidone, polyvinyl alcohol, polyethylene glycol, polyacrylic acid, and dextran. In one embodiment, the stabilizing agent further comprises a thiol-containing molecule. The thiol-containing molecule can comprise a dihydrolipoic acid or a derivative thereof. The process optionally includes the steps of isolating the concentrated nanoplates and encapsulating the isolated concentrated nanoplates (e.g., with silica or another material). The process includes the step of concentrating the encapsulated nanoplates to an optical density greater than 10 cm^{-1} (e.g., 100 cm^{-1}, 1000 cm^{-1} or more). The stabilizing agent is added prior to the formation of the silver nanoplates. In one embodiment, the nanoplates are concentrated by tangential flow filtration. In one embodiment, the silver concentration is greater than 1.0 mg/mL (e.g., 1-1000, 10-300 mg/mL).

[0012] In various embodiments, a process for generating metal oxide coated silver nanoplates is provided. The method can include the steps of providing a solution of silver nanoplates having a peak absorption spectrum between 500 and 1500 nm (e.g., 600-1400, 800-1200 nm) and an optical density greater than 10 cm^{-1} (e.g., 100 cm^{-1}, 1000 cm^{-1} or more) and contacting this solution with a solution of metal oxide or metal oxide precursor in an amount sufficient to form a metal oxide coating on an exterior surface of the silver nanoplates. In certain embodiments the silver nanoplates are associated with a stabilizing polymer (e.g., polyvinyl pyrollidone, polyvinyl alcohol, or a combination thereof) prior to contact with the metal oxide precursor, such as by disposing the stabilizing polymer on an exterior surface of the silver nanoplates. In various embodiments, the metal oxide is silica or includes silica.

[0013] In various embodiments, a process for generating a solution of silver nanoplates includes the steps of providing a solution comprising a reducing agent, a stabilizing agent, a water soluble polymer, and a silver salt, forming a plurality of silver seeds from the solution, growing the plurality of silver seeds into a plurality of silver nanoplates in the solution to form a silver nanoplate solution, adding a stabilizing agent to the silver nanoplate solution, adding a buffer containing a water soluble salt to the silver nanoplate solution, and concentrating the silver nanoplate solution to a peak optical density greater than 10 cm^{-1} (e.g., 100 cm^{-1}, 1000 cm^{-1} or more).

[0014] In various embodiments, a composition comprises or consists essentially of a solution of silver nanoplates, wherein the silver nanoplates comprise a poly vinyl polymer. In some embodiments, the poly vinyl polymer comprises polyvinyl pyrollidone or polyvinyl alcohol. The composition (e.g., solution) comprises borates and, optionally, one or more salts, such as water soluble salts (e.g., sulfates, carbonates, chromates, phosphates, and sulfites, acetates, and nitrates).

[0015] In various embodiments, the poly vinyl polymer is associated with the salt, the poly vinyl polymer coats at least a portion of the silver nanoplates, and/or the poly vinyl polymer is disposed on an exterior surface of the silver nanoplates. In one embodiment, the solution comprises silver nanoplates in a concentration effective to adhere to a non-metal coating material present in the solution. The solution may be formulated to be concentrated. In some embodiments, the optical density of the solution or of the silver nanoplates is greater than 10 cm^{-1} (e.g., 100 cm^{-1}, 1000 cm^{-1} or more). The solution may contain borate and, optionally, another salt (sulfates, carbonates, chromates, phosphates, and sulfites, acetates, and nitrates) at a concentration greater than 0.1 mM (e.g., 0.1 mM to 10 mM). In one embodiment, the solution has a pH greater than 7 (e.g., 8 - 13). In some embodiments, an absorption spectrum of the silver nanoplates comprises a peak wavelength of between 500 and 1500 nm (e.g., 600-1400, 550-1100, 810-830, 1000-1100 nm). In one embodiment, the solution additionally comprises bicarbonate. The silver nanoplates may be silica-coated. The silver nanoplates can have edge lengths between 10 nm and 500 nm (e.g., 50-300, 100-150 nm).

[0016] In various embodiments, a composition comprises or consists essentially of a solution of silver nanoplates bonded to a shell material comprising a poly vinyl polymer. In one embodiment, the silver nanoplates are substantially coated with the poly vinyl polymer. In various embodiments, the composition includes a metal oxide, the metal oxide comprises silica, the poly vinyl polymer comprises polyvinyl alcohol or polyvinylpyrrolidone, the silver nanoplates are bonded to polyvinyl alcohol and silica, and/or the silver nanoplates are bonded to polyvinylpyrrolidone and silica, or any combination thereof. In one embodiment, the composition includes a moiety selected from an amine moiety and a mercapto moiety. In one embodiment, the moiety is bound to the silica. In one embodiment, the optical density of the solution is greater than 10 cm^{-1} (e.g., 100 - 1100 cm^{-1}, or more). In one embodiment, the optical density of the silver nanoplates is greater than 10 cm^{-1} (e.g., 100 cm^{-1}, 1000 cm^{-1}, 11-5000 cm^{-1}, or more). In some embodiments, the solution comprises borate and, optionally, another water soluble salt (such as sulfates, carbonates, chromates, phosphates, and sulfites, acetates, and nitrates) at a concentration greater than 0.1 mM (e.g., 0.5 mM to 2 mM, 0.1 mM to 10 mM). In one embodiment, the pH is greater than 7 (e.g., 8, 9, 10, 11, 12, 13). In one embodiment, the silver nanoplates comprise a peak wavelength of between 500 and 1500 nm (e.g., 700-1300, 810-830, 1000-1100 nm).

[0017] In various embodiments, a composition includes silver nanoplates at least partially coated by a shell material that includes a poly vinyl polymer, wherein the mean thickness of the shell material is between 1 nm and 50 nm (e.g., 5, 15, 40 nm). In one embodiment, the silver nanoplates have at least one edge length of between 10 nm and 500 nm. (e.g., 25, 100, 250, 300 nm).

[0018] Also disclosed is, a kit comprising or consisting essentially of one or more containers comprising nanoplates with an optical density greater than 10 cm^{-1} (e.g., 100 cm^{-1}, 1000 cm^{-1} or more), a solution suitable for coating nanoplates with a shell of metal oxide, and instructions for use thereof.

[0019] In various embodiments, a solution includes silver nanoplates at least partially coated by a silica coating, wherein the silver nanoplates comprise a peak optical density of greater than 10 cm^{-1} (e.g., 11-5000 cm^{-1}, 90 - 1100 cm^{-1}, or more). In one embodiment, the silica coating has a shell thickness between 2 and 100 nm (e.g., 10-70, 30-90, 40-60 nm). In one embodiment, the solution comprises borate and, optionally, another water soluble salt (e.g., sulfates, carbonates, chromates, phosphates, and sulfites, acetates, and nitrates) at a concentration greater than 0.1 mM (e.g., 0.1 mM to 10 mM). In one embodiment, the solution has a pH greater than 7 (e.g., 9, 12, 13). In one embodiment, the silver nanoplates have a peak absorption spectrum comprising a peak wavelength between 500 nm and 1500 nm (e.g., 800-1400 nm). In one embodiment, the silica coating is disposed on an exterior surface of the silver nanoplates. In one embodiment, the coating includes an amine moiety or a mercapto moiety. Also disclosed is a coating further including aluminum. Also disclosed is a coating including bicarbonate. In one embodiment, the coating includes polyvinylpyrrolidone. Also disclosed are silver nanoplates comprising a thickness between 1 nm and 50 nm (e.g., 10-40, 15-25, 5-30). Also disclosed are silver nanoplates comprising at least one edge length between 10 nm and 500 nm (e.g., 20-400, 50-250, 300-450).

[0020] In some embodiments, a process for generating a solution of silver nanoplates with extremely high optical density includes the steps of (i) adding a concentration stabilizing chemical agent to a solution of silver nanoplates or precursor reagents and (ii) increasing the concentration of silver nanoplates to increase the optical density of the solution, using centrifugation, evaporation, filtration, dialysis or tangential flow filtration.

[0021] Within this disclosure, the silver nanoplates have an aspect ratio of between 1.5 and 25 (e.g., 1.5 - 10, 1.5-5, 10-30, 25-50); and/or the nanoplate has an edge length between about 10 nm and 250 nm (e.g., 25-180, 50-150 nm); and/or the nanoplate is triangular in cross section; and/or the nanoplate is circular in cross section. Within this disclosure, the perimeter of the nanoplate cross section has between 4 and 8 edges (e.g., 5, 6, 7). The solution of silver nanoplates is formed using a seed mediated growth method. Also disclosed are one or more of a photoconversion method, a pH-controlled photoconversion method, a thermal growth method, and/or a solution comprising a shape stabilizing agent or agents and a silver source. Within this disclosure, chemical or biological agents, and/or electromagnetic radiation, and/or heat, or a combination thereof are used to reduce the silver source. Within this disclosure, the solution of silver nanoplates is formed from some combination of a reducing agent, a shape stabilizing agent, a light source, a heat source, and a silver source.

[0022] Within this disclosure, an acid, base, or buffer (also termed a "buffering agent") is added to change the solution pH. Within this disclosure, the concentration stabilizing chemical agent is added prior to, during, and/or after the formation of the silver nanoplates. Within this disclosure, the concentration stabilizing chemical agent acts as a shape stabilizing agent. Within this disclosure, the concentration stabilizing chemical agent acts as a reducing agent. Within this disclosure, the concentration stabilizing chemical agent acts as an agent to change the solution pH.

[0023] In one embodiment, the concentration stabilizing chemical agent comprises a water soluble polymer and a borate. The polymer is any one or more of a derivative of a poly vinyl polymer, and a polyvinyl alcohol (PVA). In various embodiments, the PVA has a molecular weight of less than about 80,000 Dalton, between about 80,000 Dalton and 120,000 Dalton, and/or more than about 120,000 Dalton. In one embodiment, the polymer is polyvinylpyrrolidone (PVP). In various embodiments, the PVP has a molecular weight of less than about 20,000 Dalton, more than about 20,000 Dalton, between about 20,000 Dalton and 60,000 Dalton, and/or more than about 60,000 Dalton. In one embodiment, the polymer is an ethylene oxide derivative.

[0024] In one embodiment, the polymer is a polyethylene glycol (PEG). In various embodiments, the PEG has a molecular weight of less than about 5,000 Dalton, between about 5,000 Dalton and 10000 Dalton, and/or more than about 10000 Dalton. In one embodiment, the PEG contains a single functional group. In one embodiment, the PEG contains two functional groups. According to some embodiments, the functional group or groups consist of one or more of the following: an amine, thiol, acrylate, alkyne, maleimide, silane, azide, hydroxyl, lipid, disulfide, fluorescent molecule, and/or biotin, or combinations thereof. In one embodiment, the functional group or groups can be any one or more of an amine, thiol, acrylate, alkyne, maleimide, silane, azide, hydroxyl, lipid, disulfide, fluorescent molecule, and/or biotin. In one embodiment, the concentration stabilizing agent is a carbohydrate derivative. In various embodiments, the polymer is a monosaccharide, a disaccharide, an oligosaccharide, a polysaccharide, and/or dextran. In various embodiments, the dextran has a molecular weight that is less than about 2000 Dalton (e.g., 500, 1000, 1500 Dalton), between about 2000 Dalton and 5000 Dalton (e.g., 3000, 4000 Dalton), and/or more than about 5000 Dalton (e.g., 6000, 8000, 10000 Dalton or more).

[0025] Also disclosed, is a concentration stabilizing chemical agent that is any one or more of a phenol, a monomeric phenol, a dimeric phenol, a trimeric phenol, a polyphenol, a tannic acid, is gum Arabic, a biological molecule, a protein, a bovine serum albumin, streptavidin, biotin, a peptide, an oligonucleotide, a naturally occurring oligonucleotide, a synthetic oligonucleotide, a metal or metalloid oxide, and/or a silicon dioxide shell, wherein the silicon dioxide shell may range in thickness from about
less than 1 nm to about 100 nm (e.g., 2-90, 5-25, 30-70). Within this disclosure, a combination of stabilizing agents is used.

[0026] Within this disclosure, the solvent can be one or more of water, an alcohol, ethanol, isopropyl alcohol, t-butanol, a mixture of a water and an alcohol.

[0027] In one embodiment, the concentration of silver nanoplates is increased using tangential flow filtration. In one embodiment, the tangential flow filtration is performed using a tangential flow filter membrane. In one embodiment, the tangential flow membrane is made from a cellulose ester or mix of cellulose esters.

[0028] In various embodiments, the tangential flow membrane is made from one or more of polyetheresulfone and/or polysulfone. In various embodiments, the tangential flow membrane has a molecular weight cut off of less than about 10 kD (e.g., 1, 5, 8 kD), of between about 10 kD and 500 kD (e.g., 50, 250, 400 kD), of more than about 500 kD (e.g., 750, 1000, 5000 kD or more), of less than about 0.05 µm (e.g., 0.01, 0.03 µm), of between about 0.05 µm and 0.5 µm (e.g., 0.1, 0.25, 0.4 µm), and/or of more than about 0.5 µm (e.g., 1.0, 2, 5, 10, 100 µm).

[0029] In various embodiments, the silver nanoplate solution is concentrated to produce a solution with an optical density of greater than about 10 cm^{-1}, greater than about 50 cm^{-1}, greater than about 75 cm^{-1}, greater than about 100 cm^{-1}, and/or greater than about 500 cm^{-1} (e.g., 100-1000, 100-2000 cm^{-1}).

[0030] In one embodiment, the solvent of the concentrated solution is exchanged using tangential flow filtration. In one embodiment, the concentrated solution is processed to remove residual chemicals using tangential flow filtration.

[0031] In various embodiments, a solution of nanoparticles comprising silver nanoparticles is coated with a polymer with an optical density greater than 100 cm^{-1} (e.g., 200, 500, 700, 1500 cm^{-1}, or more) In one embodiment, the solution of silver nanoplates is incubated with a substrate. In one embodiment, the substrate is removed from the solution of silver nanoplates and dried.

[0032] One embodiment of the present invention provides processes for making solutions of plasmonic nanoparticles, such as e.g., silver nanoplates, that are suitable for performing thermomodulation of a target tissue region. Thermomodulation of a target tissue can be achieved when a composition comprising a plurality of plasmonic nanoparticles is administered to a subject under conditions such that an effective amount of the plasmonic nanoparticles localize to a domain of the target tissue region, and exposing the target tissue region to energy delivered from a excitation surface plasmon resonance source in an amount effective to induce thermomodulation of the domain of the target tissue region. In various embodiments, materials described herein are useful for performing targeted ablative or non-ablative heating of tissue. For example, described herein is a method for performing targeted ablative or non-ablative heating of a tissue to treat a mammalian subject in need thereof, comprising the steps of (i) topically administering to a skin surface of the subject the composition of plasmonic nanoparticles including silver nanoplates; (ii) providing penetration means to redistribute the plasmonic particles from the skin surface to a component of dermal tissue; and (iii) causing irradiation of the skin surface by light.

[0033] In several embodiments, the invention comprises compositions that, when used with appropriate methods of administration and excitation with a light-based energy source, can achieve noninvasive or minimally-invasive treatment of skin and underlying tissues, or other accessible tissue spaces with the use of nanoparticles. Use of optical density solutions of plasmonic nanoparticles, such as e.g., silver nanoplates, with short pulse width laser excitation (e.g. pulse widths from 0.1ms to 1s) can create steep transient heat gradients that selectively target ablative or non-ablative heat to structures within several cell layers of where particles are localized, e.g.. pilosebaceous unit for acne treatment and pore size reduction, targeted epidermal and dermal layers for skin resurfacing and small profile scar remodeling, and hair follicle for permanent hair removal. The treatment can include, but is not limited to, hair removal, hair growth and regrowth, and skin rejuvenation or resurfacing, acne removal or reduction, wrinkle reduction, pore reduction, ablation of cellulite and other dermal lipid depositions, wart and fungus removal, thinning or removal of scars including hypertrophic scars, atrophic scars, and keloids, abnormal pigmentation (such as port wine stains), tattoo removal, and/or skin inconsistencies (e.g. in texture, color, tone, elasticity, hydration). Other therapeutic or preventative methods include, but are not limited to, treatment of hyperhidrosis, anhidrosis, Frey's Syndrome (gustatory sweating), Horner's Syndrome, and Ross Syndrome, actinici keratosis, keratosis follicularis, dermatitis, vitiligo, pityriasis, psoriasis, lichen planus, eczema, alopecia, psoriasis, malignant or non-malignant skin tumors.

BRIEF DESCRIPTION OF THE DRAWINGS

[0034] Further objects, features and advantages of the invention(s) will become apparent from the following detailed description taken in conjunction with the accompanying figures showing illustrative embodiments of the invention, in which the following is a description of the drawings. The drawings are examples, and should not be used to limit the embodiments. Moreover, recitation of embodiments having stated features is not intended to exclude other embodiments having additional features or other embodiments incorporating different combinations of the stated features. Further, features in one embodiment (such as in one figure) may be combined with descriptions (and figures) of other embodiments.

FIG. 1 illustrates the optical spectrum of a silver nanoplate solution fabricated using a photoconversion method. As fabricated, these silver nanoplates, in one embodiment, have a peak optical density of less than 1 cm^{-1} (e.g., approximately 0.8 cm^{-1})

FIG. 2 illustrates the optical spectrum of a silver nanoplate solution fabricated using a seeded growth method according to the present invention. As fabricated, these silver nanoplates have a peak optical density of less than 3 cm^{-1}.

FIG. 3A is a transmission electron microscope image of a silver nanoplate solution fabricated using a photoconversion method.

FIG. 3B is a transmission electron microscope image of a silver nanoplate solution fabricated using a seeded growth method according to the present invention.

FIG. 4 is the optical spectra of silver nanoplates without the addition of a stabilizing agent and water soluble salt before tangential flow concentration and after tangential flow concentration.

FIG. 5 is the normalized optical spectra of silver nanoplates without the addition of a stabilizing agent and water soluble salt before tangential flow concentration and after concentration.

FIG. 6 is the optical spectra according to the invention of silver nanoplates combined with polyvinyl alcohol and a water soluble salt before concentration and after concentration.

FIG. 7 is the normalized optical spectra according to the invention of silver nanoplates combined with polyvinyl alcohol and a water soluble salt before concentration and after concentration.

FIG. 8 illustrates an optical extinction spectra of high optical density nanoplate solutions processed using the methods described in the invention.

FIG. 9 illustrates steps for producing silver nanoplates by fabricating the silver nanoplates, adding stabilizing agents, concentrating the nanoplates and optionally coating the nanoplates with silica.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0035] The present invention comprise processes for making solutions of plasmonic nanoparticle including silver nanoplates that are suitable for performing thermomodulation of a target tissue region. For example, thermomodulation of a target tissue can be achieved when a composition comprising a plurality of plasmonic nanoparticles is administered to a subject under conditions such that an effective amount of the plasmonic nanoparticles localize to a domain of the target tissue region. The target tissue region is exposed to energy delivered from a excitation surface plasmon resonance source. The energy is delivered in an amount effective to induce thermomodulation of the domain of the target tissue region.

[0036] Optical Density (O.D.), which is used herein as a synonym for absorbance, is defined to be the logarithmic ratio of the radiation incident on a material to the radiation transmitted through the material (O.D. = $-\log_{10}(I_1/I_0)$ where I_1 is the intensity of transmitted light and I_0 is the intensity of the incident light). For solutions, the optical density is a function of the path length through the liquid sample and is expressed in units of cm^{-1}. In some instances, optical density is expressed without the unit cm^{-1} - such as in instances in which a standard path length of 1 cm is used. In some traditional methods of manufacturing silver nanoplates, the maximum optical density of silver nanoplates in as-synthesized solutions without any additional processing is typically less than 10 cm^{-1} (e.g., 0.1 - 9.9 cm^{-1}, 1-9 cm^{-1}, 3-7 cm^{-1}, 1-5 cm^{-1}, and/or 5-10 cm^{-1}). However, according to the present invention, silver nanoplates can be produced with increased optical densities. Generally, optical densities of solutions containing plasmonic particles including silver nanoplates are most effective with an optical density that is higher than 10 cm^{-1} (e.g., 11-5000 cm^{-1}, 15-2000 cm^{-1}, 20-1000 cm^{-1}, 80-150 cm^{-1}, 90-110 cm^{-1}, 900 - 1100 cm^{-1}, 100 cm^{-14}, 1000 cm^{-1} or more) and formulated into a pharmaceutical or cosmetic carrier and stable for days, months, weeks, or years without alterations in particle shape and/or properties. In one embodiment, optical densities of solutions containing plasmonic particles including silver nanoplates are higher than 10 cm^{-1} (e.g., 11-5000 cm^{-1}, 15-2000 cm^{-1}, 20-1000 cm^{-1}, 80-150 cm^{-1}, 90-110 cm^{-1}, 900 - 1100 cm^{-1}, 100 cm^{-1}, 1000 cm^{-1} or more) and formulated into a pharmaceutical or cosmetic carrier and stable for days, months, weeks, or years without alterations in particle shape and/or properties. Described herein are carriers and compositions suitable for topical administration to the skin of a mammalian subject, such that the plasmonic nanoparticles are present in an effective amount for selective thermomodulation of a component of the skin.

[0037] Described herein are nanoparticle formulations that can be formulated for application by a sponge applicator, cloth applicator, direct contact via a hand or gloved hand, spray, aerosol, vacuum suction, high pressure air flow, or high pressure liquid flow, roller, brush, planar surface, semi-planar surface, wax, ultrasound and other sonic forces, mechanical vibrations, hair shaft manipulation (including pulling, massaging), physical force, thermal manipulation, and/or other treatments. Such nanoparticle formulation treatments are performed alone, in combination, sequentially or repeated 1-24 times, or more. Described herein are plasmonic nanoparticles capable of selectively localizing to a first component of the skin, where physical massage or pressure, ultrasound, or heat increase the selective localization of the nanoparticles to this first component. Additionally, the nanoparticles are selectively removable from components of the skin other than the first component, such removal can be accomplished with acetone, alcohol, water, air, peeling of the skin, chemical peeling, waxing, or reduction of the plasmonic compound. Further described are nanoparticles having a coat layer to increase solubility of the nanoparticles in the carrier and/or reduce "stickiness" and accumulation in non-target areas.
Within this disclosure, at least a portion of an exterior surface of the nanoparticle may be modified, such as to include a layer of a polymer, polar monomer, non-polar monomer, biologic compound, a metal (e.g., metallic thin film, metallic composite, metal oxide, or metallic salt), a dielectric, or a semiconductor. In one embodiment, the exterior surface modification is polar, non-polar, charged, ionic, basic, acidic, reactive, hydrophobic, hydrophilic, agonistic, and/or antagonistic. Also within the disclosure, at least one dimension of at least one nanoparticle within a solution of plasmonic nanoparticles may be below 50-100 nm (e.g., 1, 5, 10, 25, 40, 60, 75, 90 nm), and the nanoparticle surface can be coated with a matrix (e.g. silica) of 10-100 nm thickness or more (e.g., 20, 50, 75, 150, 200, 500 nm) in order to increase that dimension or particle to 50-100 nm or more (e.g., 75, 80, 110, 140, 200, 800 nm). This increased dimension size can increase the delivery of all nanoparticles to a target region (e.g., hair follicle, pore, skin, etc.) and limit delivery to non-target region (e.g. dermis).

[0038] Materials described herein may be useful for performing targeted ablative or non-ablative heating of tissue. For example, in a method for performing targeted ablative or non-ablative heating of a tissue to treat a mammalian subject in need thereof, comprising the steps of (i) topically administering to a skin surface of the subject the composition of plasmonic nanoparticles including silver nanoplates; (ii) providing penetration means to redistribute the plasmonic particles from the skin surface to a component of dermal tissue; and (iii) causing irradiation of the skin surface by light. Further described is a method wherein the light source comprises excitation of mercury, xenon, deuterium, or a metal-halide, phosphorescence, incandescence, luminescence, light emitting diode, or sunlight. Still further described is a method wherein the penetration means comprises high frequency ultrasound, low frequency ultrasound, massage, iontophoresis, high pressure air flow, high pressure liquid flow, vacuum, pre-treatment with fractionated photothermolysis or dermabrasion, or a combination thereof. Still further described is a method wherein the irradiation comprises light having a wavelength of light between about 200 nm and about 10,000 nm (e.g., 300-9000, 700-1300, 800-1200, 800-1300, 900-1100, 550-1100, 810-830, 1000-1100 nm), a fluence of about 1 to about 100 joules/cm^2 (e.g., 5-20, 40-70, 10-90), a pulse width of about 1 femptosecond to about 1 second, and a repetition frequency of about 1 Hz to about 1 THz (e.g., 1-10, 10-100, 100-1000, 1000-10000, 10000-100000 Hz or more).

[0039] Described herein are compositions, that when used with appropriate methods of administration and excitation with a light-based energy source can achieve noninvasive and minimally-invasive treatment of skin and underlying tissues, or other accessible tissue spaces with the use of nanoparticles. Use of optical density solutions of plasmonic nanoparticles, such as e.g., silver nanoplates, with short pulse width laser excitation (e.g. pulse widths from 0.1ms to 1s) can create steep transient heat gradients that selectively target ablative or non-ablative heat to structures within several cell layers of where particles are localized, e.g.. pilosebaceous unit for acne treatment and pore size reduction, targeted epidermal and dermal layers for skin resurfacing and small profile scar remodeling, and hair follicle for permanent hair removal. The treatment can include, but is not limited to, hair removal, hair growth and regrowth, and skin rejuvenation or resurfacing, acne removal or reduction, wrinkle reduction, pore reduction, ablation of cellulite and other dermal lipid depositions, wart and fungus removal, thinning or removal of scars including hypertrophic scars, atrophic scars, and keloids, abnormal pigmentation (such as port wine stains), tattoo removal, and/or skin inconsistencies (e.g. in texture, color, tone, elasticity, hydration). Other therapeutic or preventative methods include, but are not limited to, treatment of hyperhidrosis, anhidrosis, Frey's Syndrome (gustatory sweating), Horner's Syndrome, and Ross Syndrome, actinici keratosis, keratosis follicularis, dermatitis, vitiligo, pityriasis, psoriasis, lichen planus, eczema, alopecia, psoriasis, malignant or non-malignant skin tumors.

Silver Nanoplate Physical Description

[0040] Described herein are nanoplates, such as silver nanoplates, that are characterized by lengths along the three principle axes wherein: the axial length of two of the principle axes is at least two times greater than the axial length of the shortest principle axis, and the shortest principal axial length is less than about 500 nm (e.g., 450. 400, 350, 300, 250, 100, 150, 50, 30, 20, 10 nm). The "edge length" of the nanoplate is defined to be the average of the length of the two longer principle axes. The "thickness" of the nanoplate is defined to be the shortest principal axis.

[0041] The ratio of the edge length to the thickness is referred to as the "aspect ratio". Herein, the average aspect ratio of the silver nanoplates may be greater than 1.5, 2, 3, 4, 5, 7, 10, 20, 30, or 50 and any range therein. Herein, the average aspect ratio of the silver nanoplates may be between 1.5 and 25, 2 and 25, 1.5 and 50, 2 and 50, 3 and 25, and/or 3 and 50.

[0042] Herein, a nanoplate may have edge lengths less than 500 nm, 250 nm, 200 nm, 150 nm, 100 nm, 80 nm, 60 nm or 50 nm. Herein, the nanoplate may have edge lengths greater than 5 nm, 10 nm, 20 nm, 30 nm, 50 nm or 100 nm. In various embodiments the edge length is from 30 nm to 100 nm, 20 nm to 150 nm, 10 nm to 200 nm, 10 nm to 300 nm.Herein, the nanoplate may have a thickness that is less than 500 nm, 300 nm, 200 nm, 100 nm, 80 nm, 60 nm, 50 nm, 40 nm, 30 nm, 20 nm, and/or 10 nm and any range therein. Herein, the nanoplate thickness may be from 5 nm to 20 nm, 5 nm to 30 nm, 10 nm to 30 nm, 10 nm to 50 nm, 10 nm to 100 nm.

[0043] The silver nanoplates described herein may have a variety of different cross sectional shapes including (but not limited to) circular, triangular, or shapes that have any number of discrete edges. For example, the nanoplates can be shaped as circular, ovals, squares, rectangles, rods, stars, tubes, pyramids, prisms, triangles, branches, or comprised of a planar surface. For example, the nanoplates may have less than 20, 15, 10, 8, 6, 5, or 4 edges, and/or any number between 20 and 1. The nanoplates described herein can have between 1 and 20, 15, 10, 8, 6, 5, 4, or 3 edges. For example, the nanoplates may have more than 2, 3, 4, or 5 edges. For example, the silver nanoplates may have sharp corners or the corners may be rounded. In some of the silver nanoplates described herein, there are a variety of different cross sectional shapes within the same sample. In the invention, silver nanoplate solutions greater than 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, or 90% of the number of particles in solution are silver nanoplates with the other particles having different shapes including but not limited to spherical, cubic, and irregular. In various embodiments, a silver nanoplate solution has a percentage of silver nanoplates, with other particles in the solution having different shapes, including but not limited to spherical, cubic, and/or irregular. In various embodiments, a silver nanoplate solution has 5% to 100%, 10% to 50%, 50% to 100%, 30% to 60%, 60% to 100%, 40% to 70%, 70% to 100%, 50% to 80%, 80% to 100%, 60% to 90%, and/or 90% to 100% of the number of particles in solution are silver nanoplates with the other particles having different shapes including but not limited to spherical, cubic, and/or irregular. The claimed methods can enhance the stability of silver nanoplates to facilitate increased optical density while retaining at least 50%, 60%, 70%, 80%, 90%, 95%, 98% or more of the silver nanoplate shape while undergoing a concentrating process. Also described are methods that can enhance the stability of silver nanoplates to facilitate increased optical density while changing shape from the nanoplate to another shape (e.g., spherical, cubic, and/or irregular) in less than 50%, 40%, 30%, 25%, 20%, 10%, 5%, 3,%, 2%, 1% of the silver nanoplates while undergoing a concentrating process. Described herein are nanoplates that can have one, two, or more flat sides. Also described are nanoplates that are pyramidal.

[0044] Silver nanoplates have distinct advantages over other plasmonic nanoparticle shapes and compositions. For example, silver nanoplates have advantages over plasmonic nanoparticle shapes and compositions including gold nanoshells and gold nanorods due to potential for lower production costs (less reaction waste and lower material costs). Furthermore, optical density (O.D.) per weight of metal is greater for sliver nanoplates relative to gold nanorods when randomly oriented in solution and irradiated with non-polarized light because the planar surface of a nanoplate resonates with both polarizations of incident light. Additionally, absorbance of silver nanoplates is higher than that of gold nanoshells for the same weight of metal as a greater fraction of light is absorbed versus scattered with a nanoplate architecture relative to a nanoshell. For many applications, these benefits in cost and absorbance can only be realized if nanoplates are stabilized at high concentration and for long periods of time.

Silver Nanoplate Fabrication

[0045] Modern nanoparticle synthesis techniques have enabled the development of materials with unique optical properties for a wide range of applications including diagnostic, obscurant, and therapeutic applications. Silver nanoplates, as fabricated by current traditional methods including photoconversion, pH controlled photoconversion, thermal growth, and/or seed mediated growth methods typically have optical densities ranging from 0.1 to 10 cm^{-1} (e.g., 0.1 - 9.9 cm^{-1}, 1-9 cm^{-1}, 3-7 cm^{-1}, 1-5 cm^{-1}, and/or 5-10 cm^{-1}). A number of technologies seek higher optical density solutions of silver nanoplates. The present invention describe a novel and non-obvious method for concentrating silver nanoplates and generating higher optical density silver nanoplate solutions. For example, the methods can increase the optical density of silver nanoplate solutions to greater than 10 cm^{-1}, 20 cm^{-1}, 30 cm^{-1}, 50 cm^{-1}, 80 cm^{-1}, 100 cm^{-1}, 150 cm^{-1}, 200 cm^{-1}, 300 cm^{-1}, 400 cm^{-1}, 500 cm^{-1}, 600 cm^{-1}, 700 cm^{-1}, 800 cm^{-1}, 900 cm^{-1}, and/or 1000 cm^{-1}, or more.

[0046] Silver nanoplates may be fabricated using photoconversion (Jin et al. 2001; Jin et al. 2003), pH controlled photoconversion (Xue 2007), thermal growth (Hao et al. 2004; Hao 2002; He 2008; Metraux 2005), templated growth (Hao et al. 2004; Hao 2002), seed mediated growth (Aherne 2008; Chen; Carroll 2003; Chen; Carroll 2002, 2004; Chen et al. 2002; He 2008; Le Guevel 2009; Xiong et al. 2007), or alternative methods. Alternative methods include methods in which the silver nanoplates are formed from a solution comprising one or more stabilizing agents and a silver source, and in which chemical agents, biological agents, mixing, electromagnetic radiation, and/or heat are used to reduce the silver source.

[0047] An optical spectrum of silver nanoplates fabricated using a photoconversion method is shown in FIG 1. The peak wavelength of the optical spectra (100) is at a wavelength of 775 nm with an optical density of 0.74 cm^{-1}. The optical spectra of silver nanoplates fabricated using one embodiment of a seed mediated growth method is shown in FIG 2. The peak wavelength of the optical spectra (200) is at a wavelength of 930 nm with an optical density of 2.58 cm^{-1}. A transmission electron microscope image of silver nanoplates made using a photoconversion method is shown in FIG. 3A. A transmission electron microscope image of silver nanoplates made using a seed mediated growth method is shown in FIG 3B.

[0048] In one embodiment, when as-fabricated nanoplates are concentrated using tangential flow filtration, the shape of many of the nanoplates can shift to nanospheres, reducing the formulation efficacy, as evidenced by an increased peak height at ~400 nm which is the peak optical resonance of spherical silver nanoparticles. FIG. 4 shows the optical density of a solution of the nanoplates in the absence of a concentration stabilization agent before (400) and after (410) concentration. The optical resonance peak that corresponds to the plasmon resonance of the nanoplates shifts from 815 nm (420) to 745 nm (430) demonstrating that the average edge length of the nanoplates is reduced.

[0049] FIG. 5 shows a normalized plot of the nanoplate spectra shown in FIG. 4. For this solution of nanoplates, the intensity of the peak in the 700 nm - 850 nm range is correlated to the number of nanoplates in solution. The intensity of the peak in the 400 nm range is correlated to the number of spheroidal particles in solution. Before concentration the ratio of the longer wavelength peak (520) to the shorter wavelength peak (540) is 3. After concentration the ratio of the longer wavelength peak (530) to the shorter wavelength peak (550) is 0.8. This changing ratio demonstrates that the silver nanoplates are changing shape and that the number of nanoplates in solution is reduced.

[0050] In one embodiment, a solution of nanoplates can be stabilized. FIG. 6 shows the optical density of one embodiment of a solution of nanoplates that have been stabilized by polyvinyl alcohol in a solution of borate (e.g., sodium borate, potassium tetraborate, etc.). The peak wavelength of the nanoplate peak is the same for both the unconcentrated (620) and concentrated (630) solutions indicating that the edge length of the nanoplates is the same before concentration (600) and after concentration (610). FIG. 7 shows the normalized spectrum which demonstrates that the spectral shape of the peak does not change before concentration (700) and after concentration (710), thereby indicating that in one embodiment, a surface coating is sufficient to prevent the shape of the nanoparticles from shifting. Greater than 10%, greater than 20%, greater than 30% or greater than 50% of the silver nanoplates may change shape without a surface protection. In other embodiments less than 20%, less than 10% or less than 5% of the silver nanoplates undergo a shape change if the nanoplates are coated with a protective surface coating. In one embodiment, a spectrum of a nanoplate solution concentrated to have a peak optical density of ~900 cm^{-1} is shown in FIG. 8.

[0051] In one embodiment, the silver nanoplates are formed in a multi-step process. In one embodiment, the steps to concentrating nanoplates are shown in FIG. 9 and comprise of fabricating the silver nanoplates (900), adding stabilizing agents (910), concentrating the nanoplates (920) and optionally coating the nanoplates with silica (930). In various embodiments, the steps can be taken in any order. In one embodiment, a first step forms silver seeds from an aqueous solution comprising a reducing agent, a stabilizing agent, a water soluble polymer and a silver salt. The reducing agent, stabilizing agent and water soluble polymer may be mixed prior to the addition of a silver source. In the invention, the reducing agent used in the silver seed formation step is sodium borohydride. In various embodiments, the reducing agent may be present at a concentration of at least 0.1 mM, 1 mM, or 3mM. In various embodiments the reducing agent may be present at a concentration from 0.1 mM to 1 mM, 0.3 mM to 3 mM, 0.5 mM to 2 mM, 0.1 mM to 2 mM, 0.1 mM to 10 mM.

[0052] The stabilizing agent may be a salt, a polymer, or a biomolecule. In the invention, the stabilizing agent is trisodium citrate or another citrate derivative.

[0053] The water soluble polymer may be a polyanionic polymer including, but not limited to, polymers derivatized with sulphonate, derivatives of polystyrene sulphonate such as an inorganic salt of polystyrene sulphonate, or a monovalent salt of polystyrene sulphonate. In the invention, the water soluble polymer is poly (sodium styrenesulphonate) (PSSS). In one embodiment the PSSS has a molecular weight between about 3 kDa and about 1,000 kDa. In various embodiments the PSSS has a molecular weight of from 3 kDa to 10 kDa, 5 kDa to 50 kDa, 10 kDa to 100k Da, 30 kDa to 300 kDa, 50 kDa, to 500 kDa, 100 kDa to 1000 kDa, 300 kDa to 100 kDa, 500 kDa, to 1000 kDa.

[0054] The silver salt may be any water soluble silver salt including but not limited to silver acetate, silver perchlorate, silver nitrate, silver trifluoroacetate, or silver triflate. In the invention, the silver salt is silver nitrate.

[0055] In one embodiment, a step for the formulation of silver nanoplates includes having the seeds grown into silver nanoplates in an aqueous solution comprising silver seeds, an acidic reducing agent and a silver salt. In the invention, the acidic reducing agent is ascorbic acid. The silver salt for the step where seeds are grown into silver nanoplates may be any water soluble silver salt including silver acetate,
silver perchlorate, silver nitrate, silver trifluoroacetate, silver triflate, or combinations thereof. In the invention, the silver salt is silver nitrate.

[0056] Within this disclosure, the silver nanoplates may be stirred at a shear flow rate between 1 s^{-1} and 100,000 s^{-1} (e.g., at least 10, 50, 100, 200, 300, 400, 500, 1000, 2000, 5000, 10000, 20000, 50000, 75000, 90000 s^{-1}). Also within this disclosure, the silver nanoplates may be stirred at a shear flow rate from between 10 s^{-1} and 100 s^{-1}, 50 s^{-1} and 500 s^{-1}, 100 s^{-1} and 300 s^{-1}, 200 s^{-1} and 500 s^{-1}, 100 s^{-1} and 400 s^{-1}, 500 s^{-1} and 1000 s^{-1}, 1000 s^{-1} and 10000 s^{-1}, 2000 s^{-1} and 5000 s^{-1}, 1000 s^{-1} and 2000 s^{-1}, 5000 s^{-1} and/or 10000 s^{-1}.

Silver Nanoplate Coating

[0057] In one embodiment, silver nanoplates have molecules that are adsorbed or otherwise bound to the particle surface. The molecules on the surface are the reactants or reactant by-products of the synthesis. One object of this invention is to partially or fully exchange the molecules that are bound to the surface of the silver nanoplates with other molecules that more fully protect the particles from changing shape during concentration. Another object of the invention is to use a stabilizing agent during fabrication that generates plate shapes and also stabilizes the plates during subsequent concentration.

[0058] Stabilizing agents described herein include chemical or biological agents that are physisorbed (e.g., absorbed by non-molecular binding forces) to the surface, molecularly bound to the surface through specific interactions (e.g. thiol or amine), or encapsulate the surface (e.g. a metal oxide or metalloid oxide shell). Specific chemical agents described herein include polymers, such as polysulphonates. The stabilizing polymer described herein may be derivatized with sulfonates or vinyl polymers, carbohydrates, ethylene oxides, phenols, and carbohydrates may be employed. Polymers of the invention include polystyrene sodium sulfonate, polyvinyl alcohol (PVA), polyvinyl pyrrolidone (PVP), and polyethylene glycol (PEG) including PEG molecules which contain one or more chemical groups (e.g. amine, thiol, acrylate, alkyne, maleimide, silane, azide, hydroxyl, lipid, disulfide, fluorescent molecule, or biomolecule moieties). Other molecules described herein include proteins, peptides, oligonucleotides, biotin, alkane thiols, lipoic and dihydrolipoic acid and derivatives of these acids, bovine serum albumin, streptavidin,
neutravidin, wheat germ agglutinin, naturally occurring and synthetic oligonucleotides and peptides, including synthetic oligonucleotides which have one or more chemical functionalities (e.g. amine, thiol, dithiol, acrylic phosphoramidite, azide, digoxigenin, alkynes, or biomolecule moieties). Specific encapsulating chemical agents of the invention include the metal oxide shells SiO_2 and TiO_2. Stabilizing agents may be added prior to the formation of silver nanoplates, during the formation of silver nanoplates, or after the formation of silver nanoplates. An additional chemical agent described herein is gum arabic. Within this disclosure, the stabilizing agent may modify the pH of the solution.

Carrier Solutions

[0059] The silver nanoplates described herein may be fabricated in aqueous solutions. Alternatively, they may be fabricated in other solutions that can include ethanol, isopropanol, or organic solvents such as heptane, toluene, or butanol.

[0060] In this disclosure, an acid, base or buffering agent may be added to change the solution pH either before, during, or after the addition of a stabilant. For example, a buffer, typically containing a water soluble salt, is added. In the invention, the water soluble salt comprises borate. In one embodiment, the water soluble salt comprises sodium borate. In one embodiment the nanoplates are suspended in a sodium borate buffer. In this disclosure, the pH of the solution after addition of the pH modifying agent may be greater than pH 6, pH 7, pH 8, pH 9, or pH 10. For example, the pH of the solution after addition of the pH modifying agent may be from pH 6 to pH 8, pH 6.0 to pH 9, pH 7 to pH 10, pH 7 to pH 11, pH 8 to pH 10, pH 8 to pH 11, or pH 7 to pH 12.

[0061] The combination of a nanoplate coating and a water soluble salt present in a buffer may provide stabilization to the nanoplate formulation. For example, one of the components of the salt can interact with the nanoplate coating or stabilizing agent to crosslink the coating and increase the stability of the coating. Such crosslinking can include non-covalent bonds (e.g., ionic bonds, hydrophobic interactions, hydrogen bonds and van der Waals forces including dispersion attractions, dipole-dipole and dipole-induced dipole interactions) and/or covalent bonds between the nanoplate surface, water soluble salts, and/or coating materials/stabilizing agents. The presence of the water-soluble salt present in a buffer may change the binding affinity of a stabilizing agent or coating material to the nanoplate surface, e.g., by modifying the zeta potential and/or charges on the surface of the nanoplate. Alternatively, the water-soluble salt present in a buffer changes the binding affinity of a stabilizing agent or coating material to itself through covalent or non-covalent binding. For example, the presence of the water-soluble salt intermediates changes the binding of a stabilizing agent to the surface of a particle by becoming physisorbed to the particle surface in association with the stabilizing agent. In a further example the water-soluble salt intermediates change the binding of polymer to itself by associating with units of the stabilizing agent or coating materials and lowering the free energy necessary for the coating materials to order on or around a nanoplate surface. For example, the nanoplate coating is a polymer and the crosslinking produces a viscoelastic gel surrounding all or a portion of the nanoplate. In another example, the stabilizing agent is mixed with a buffer containing a water-soluble salt, and both the stabilizing agent and a component of the water soluble salt bind to the surface of the nanoplate. In the invention, a polyvinyl based polymer such as polyvinylalcohol or polyvinylpyrrolidone is mixed with a borate salt such as sodium borate. Polyvinylalcohol and borate are can be complexed to form gels via hydrogen bonding (Schultz 1969). In one embodiment, FIG. 6 and FIG. 7 show the effect of stabilizing silver nanoplates with polyvinyl alcohol and sodium borate before concentration to preserve the shape of the nanoparticles.

Surface Stabilization

[0062] Stabilizing agents can be solid or liquid formulations that are added to the silver nanoplate solution are described herein. The stabilizing agents have an affinity for the surface of the silver nanoplates and are able to associate with the plate surface at wide ranges of relative concentrations. For example, bound molecules on the silver nanoplates may be displaced by a stabilizing agent. Alternatively, a stabilizing agent, such as a polymer, may be covalently attached to a silver atom present on the surface of the nanoplate. The polymer coating may extend over all or a portion of the exterior surface of a silver nanoplate. For example, at least 5%, 10%, 15%, 20%, 25%, 50%, 75%, 80%, 90%, 95%, 99%, 99.9% or greater than 99.9% of the exterior surface of a silver nanoplate is coated with one type of polymer or a plurality of different polymer types. In the invention, the stabilizing species is added after the synthesis of the silver nanoplates. Thus, provided are compositions containing polymer-coated silver nanoplates, and solutions containing these compositions having an optical density greater than 10 cm^{-1}; these solutions can be achieved by concentrating or purifying polymer-coated silver nanoplates present in a more dilute solution. In this disclosure, the stabilants can be added to the as-fabricated silver nanoplate solution. Alternatively, the solution of nanoplates is washed, or the residual reactants are otherwise removed. For example, the suspending solution may be exchanged one or more times with one or more solution, e.g., to wash the nanoplates or to alter the pH of the solution, before the stabilizing agents are added. Also described are kits containing, in one or more containers, nanoplates in a solution having an optical density greater than 10 cm^{-1} and a metal oxide-containing solution or a metal oxide precursor-containing suitable for coating the nanoplates with a shell (or coating) of the metal oxide. Preferably, the containers are provided with instructions for use thereof. The kits may contain nanoplates having a coating containing a poly vinyl polymer. The poly vinyl polymer may contain borate. Nanoplates having a stabilizer coating are characterized as provided herein or otherwise known in the art, such as by particle analyzers or emission detectors such as NMR, Fourier transform spectroscopy, mass spectrometry, or similar assays.

[0063] Once the stabilizing agent is added, the mixture of the stabilant and the silver nanoplates can undergo a number of different processes including heating, boiling, boiling under reflux, rotary evaporation, vacuum, stirring, stirring with magnetic stir bars, stirring with overhead mixers, stirring with homogenizers, shaking, microfluidization, refrigeration, and freezing.

Washing and Concentrating

[0064] After the stabilization step is complete, the silver nanoplates can be washed to remove residual reactants or to exchange the solution with another solution. The exchange of solution can be accomplished using dialysis, centrifugation, filtration, or tangential flow filtration (also known as cross flow filtration). For example, the number of wash volumes exchanged within the sample is zero, 1, 2, 3, 4, 5, 1 and 5, 5 to 10, 10 to 20, or more than 20 wash volumes, inclusive.

[0065] Nanoparticle solutions with optical densities greater than 10 cm^{-1} (e.g., 11-5000 cm^{-1}, 15-2000 cm^{-1}, 20-1000 cm^{-1}, 80-150 cm^{-1}, 90-110 cm^{-1}, 900 - 1100 cm^{-1}, 100 cm^{-1}, 1000 cm^{-1} or more) can be fabricated using centrifugation, evaporation, filtration, dialysis or tangential flow filtration. One embodiment of this invention utilizes tangential flow filtration as the process of concentrating the silver nanoplate solution. The filter membrane utilized may be formed from a variety of materials. For example, specific filter membrane materials of interest can include cellulose esters, polysulfone, and polyetheresulfone. In various embodiments, the filter membrane utilized may have pores with a molecular weight cutoff of less than about 10 kD, between 10 kD to 500 kD, or more than about 500 kD, and/or pore sizes of less than about 0.05 µm, between 0.05 µm and 0.5 µm, or larger than about 0.5 µm. In various embodiments, the filter membrane utilized may have pores with a molecular weight cutoff between 10 kD, to 100kD, 10kD to 500kD, 20kD to 500kD, 20kD to 250kD and/or pore sizes between 0.02 µm and 0.1 µm, 0.05 µm and 0.2 µm, 0.05 µm and 0.5 µm, 0.10 µm and 0.2 µm, 0.1 µm and 0.5 µm. Tangential flow filtration can also be utilized to change the solvent in which the silver nanoplates are dispersed. In various embodiments, specific solvents of interest include water and alcohols (e.g. t-butanol, ethanol, and isopropyl alcohol), as well as other polar or non-polar solvents. Additionally, tangential flow filtration can be utilized to remove residual chemicals. FIG. 8 shows an embodiment of a solution of nanoplates that has been concentrated to a peak optical absorbance of 930 cm^{-1}.

[0066] In various embodiments, the silver nanoplate solution concentration is increased to produce a final solution with optical densities of greater than about 10 cm^{-1}, greater than about 50 cm^{-1}, greater than about 75 cm^{-1}, greater than about 100 cm^{-1}, greater than about 500 cm^{-1}, and/or greater than about 1000 cm^{-1}. In various embodiments, the silver nanoplate solution concentration is increased to produce a final solution with optical densities from between 10 cm^{-1} to 100 cm^{-1}, 30 cm^{-1} to 300 cm^{-1}, 50 cm^{-1} to 500 cm^{-1}, 100 cm^{-1} to 1000 cm^{-1}, 300 cm^{-1} to 3000 cm^{-1}, or 500 cm^{-1} to 5000 cm^{-1}. One embodiment of the invention is where the silver nanoplate solution concentration is increased to above 10^6, 10^7, 10^8, 10^9, 10^{10}, 10^{11}, 10^{12} or 10^{13} particles per milliliter. In various embodiments, the silver nanoplate solution concentration is increased to be between 10^6 and 10^{13}, 10^7 and 10^{13}, 10^8 and 10^{13}, 10^9 and 10^{13}, 10^{10} and 10^{13}, 10^{11} and 10^{13}, or 10^{12} and 10^{13} particles per milliliter. In various embodiments, the silver concentration is greater than 0.1, 1.0, 2, 4, 5, 7, 8, 9, and/or 10 mg/mL. In various embodiments, the silver concentration is between 0.1 to 1.0, 0.3 to 3.0, 0.5 to 5.0, 1.0 to 10.0, 3.0 to 30.0, 5.0 to 50.0, 10.0 to 200.0, 1.0 to 200.0, 1.0 to 500.0, or 10.0 to 500.0 mg/mL.

Silica Coating and Shelling

[0067] In one embodiment, the concentrated silver nanoplates are encapsulated with a shell of silica. The coating may extend over all or a portion of the exterior surface of a silver nanoplate. For example, at least 5%, 10%, 15%, 20%, 25%, 50%, 75%, 80%, 90%, 95%, 99%, 99.9% or greater than 99.9% of the exterior surface of a silver nanoplate is coated with silica. The concentrated plates can be mixed with an alcohol (e.g. ethanol or isopropanol). In one embodiment an aminosilane or mercaptosilane is added to the solution to bind silane molecules to the surface of the nanoplates. The binding of silane molecules to the surface of nanoplates is specific to the surface coating on the nanoplates. Some nanoparticle coatings that stabilize the nanoplates during processing will not be compatible with the formation of a silica shell. In one embodiment, the surface of the nanoplates is coated with a molecule that has an affinity for silane molecules in solution. In one embodiment a polyvinyl based polymer such as polyvinylalcohol or polyvinylpyrrolidone is bound to the surface of the nanoplate before the addition of silane molecules. In other embodiments, a polyvinyl based polymer surface is complexed with a borate before the addition of silane molecules. In other embodiments mercaptohexadecanoic acid, mercaptoundecanoic acid, or other thiol containing acids are bound to the surface of the nanoplates. Once there are initial silanes bound to the surface of the nanoplate, additional silane can be added to the solution in the presence of a base to form a silica shell. In one embodiment, the nanoplates coated with a silica shell can be transferred to water and concentrated using a concentration method such as tangential flow filtration.

[0068] It is an object of this invention to fabricate a solution that comprises a concentrated solution of silver nanoplates coated with a silica shell. In this disclosure, the peak optical density of the solution as measured in a 1 cm path length cuvette may be above 10, 20, 50, 100, 500, or 1000.For example, the peak optical density of the solution as measured in a 1 cm path length cuvette is between 10-100, 20-200, 30-300, 50-500, 100-1000, 200-1000, 300-1000, 500-1000, and/or 200-2000, and any combinations therein. In this disclosure, the silver concentration may be above 0.1 mg/mL, 1 mg/mL or above 10 mg/mL. For example, the silver concentration is between 0.1 to 1.0, 0.3 to 3.0, 0.5 to 5.0, 1.0 to 10.0, 3.0 to 30.0, 5.0 to 50.0, 10.0 to 200.0, 1.0 to 200.0, 1.0 to 500.0, and/or 10.0 to 500.0 mg/mL, and any combinations therein. In one embodiment, the silica shell thickness is between 1 and 100 nm, for example between 5 and 50 nm. In other examples, the silica shell thickness is between 3 and 20 nm, 5 and 20 nm, 10 and 20 nm, 10 and 50 nm, 10 and 100 nm, 1 and 10nm, 3 and 30nm, 5 and 50nm, and/or 5 and 100nm, and any combinations therein. The silica shell can be fabricated from a mixture of silanes including but not limited to aminopropyl triethoxy silane, mercaptopropyl triethoxy silane and tetraethylorthosilicate. The silica shell can contain nitrogen or sulfur atoms. The silica shell can contain amine moieties or mercapto moieties. The silica shell can contain aluminum or sodium atoms.

[0069] In another embodiment the solution contains a buffer, that includes a borate and, optionally, another water soluble salt (e.g., one or more of the sulfates, carbonates, chromates, phosphates, and sulfites, acetates, and nitrates) at a concentration greater than 0.1 mM, 1.0 mM or 10.0 mM. For example, the water soluble salt concentration may be from 0.1mM to 1mM, 0.3mM to 3mM, 0.5mM to 5mM, 1mM to 10 mM, 1 mM to 30 mM, 1 mM to 50 mM, 1 mM to 1000 mM, and any combinations therein. The solution can have a peak absorption wavelength between 500 nm and 1500 nm, 500 nm to 1200 nm, 500 nm to 1000nm, 600nm to 1200nm, 700nm to 1200nm, 700nm to 1500nm, 700nm to 900nm, and/or 900 to 1100 nm, and any combinations therein.

Storage

[0070] In this disclsoure, the concentrated particles may be stored at temperatures below -10, 0, 4, 6, 10, or 20 degrees C.For example, the particles may be frozen and dried under vacuum. For example, the particles may be freeze dried or supercritically dried. An additional stabilant or other cryoprotectant may be added to the solution before the particles are heat dried or freeze dried.

Composites

[0071] In one embodiment of the invention, high optical density solutions of silver nanoplates are associated with a substrate, wherein the substrates include fibers. Other examples of substrates disclosed include cloth, mesh, bandages, socks, wraps, other articles of clothing, sponges, high porosity substrates, particles with edge lengths greater than 1 micron, beads, hair, skin, paper, absorbent polymers, foam, wood, cork, slides, roughened surfaces, biocompatible substrates, filters, or medical implants. Solutions of silver nanoplates at a concentration of at least 1 mg/mL, 10 mg/mL, and/or 100 mg/mL may be incubated with the substrate. For example, the silver nanoplate concentration incubated with the substrate may be between 0.1 to 1.0, 0.3 to 3.0, 0.5 to 5.0, 1.0 to 10.0, 3.0 to 30.0, 5.0 to 50.0, 10.0 to 20.0, 5.0 to 50.0, 3.0 to 50.0, 1.0 to 100.0 mg/mL, 10.0 to 100.0, 20.0 to 100.0, 30.0 to 100.0 mg/mL. In another example, the solutions of silver nanoplates incubated with the substrate may be between 10^6 and 10^{13}, 10^7 and 10^{13}, 10^8 and 10^{13}, 10^9 and 10^{13}, 10^{10} and 10^{13}, 10^{11} and 10^{13}, 10^{12} and 10^{13} or greater than 10^{13} particles per milliliter. In another example, the silver nanoplates may be prepared at an optical density of at least 100, 300, 500, 1000 and/or 2000 cm^{-1} before incubating with the substrate. For example, the silver nanoplates may be prepared at an optical density of between 100-200, 100-300, 100-500, 100-1000, 200-1000, 300-1000, 500-1000, or 200-2000. In another part of the disclosure, the substrate is chemically treated to increase the binding of the nanoplates to the substrate. For example, the substrate could be functionalized with a molecule that yielded a positively or negatively charged surface. In another part of the disclosure, the pH of the incubating solution is selected in order to optimize binding. In another part of the disclosure, the silver nanoplates cover at least 5%, 10%, 20%, 30%, 50% or 75% of the substrate.For example, the silver nanoplates may cover between 5% to 10%, 10% to 100%, 10% to 50%, 50% to 100%, 30% to 100%, 30% to 70%, 40% to 80%, 50% to 90%, 60% to 100%, 70% to 100%, 80% to 100%, 90% to 100%, 0% to 5%, 0% to 10%, 0% to 20%, 0% to 30%, or 0% to 50% of the substrate. In another part of the disclosure, other solvents or chemicals are added to the incubation solution. In another part of the disclosure a biological linker (e.g. antibodies, peptides, DNA) is used to bind the high optical density silver nanoplates to
the surface of the substrate. Inthis disclosue, the incubation may be for less than 1 minute, 5 minutes, 20 minutes, 60 minutes, or 120 minutes. For example, the incubation may be between 0 to 1 minute, 1 minute to 120 minutes, 5 minutes to 120 minutes, 20 minutes to 120 minutes, 60 minutes to 120 minutes, 5 minutes to 60 minutes, 10 minutes to 60 minutes, 20 minutes to 60 minutes, 0 minutes to 10 minutes, 0 minutes to 20 minutes, or 0 minutes to 5 minutes.

[0072] In this disclosure, the substrate may be separated from the incubating solution and dried. The substrate can be dried using air drying, heat drying, freeze drying, or supercritical drying. In another part of the disclosure, the dried substrate can be further processed by soaking the substrate in another material, painting the substrate with another material, or exposing the substrate to another material that is in the vapor phase.

[0073] It is intended that the specification and examples be considered as disclosing certain embodiments of the invention only, with the scope of the invention being indicated by the following claims.

[0074] The subject matter described herein may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The foregoing embodiments are therefore to be considered in all respects illustrative rather than limiting. While embodiments are susceptible to various modifications, and alternative forms, specific examples thereof have been shown in the drawings and are herein described in detail. It should be understood, however, that the invention is not to be limited to the particular forms or methods disclosed, but to the contrary, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the various embodiments described and the appended claims. Any methods disclosed herein need not be performed in the order recited.

[0075] The methods disclosed herein include certain actions taken by a practitioner; however, they can also include any third-party instruction of those actions, either expressly or by implication. For example, actions such as "identifying a target region of skin tissue" include "instructing the identification of a target region of skin tissue."

[0076] The ranges disclosed herein also encompass any and all overlap, sub-ranges, and combinations thereof. Language such as "up to," "at least," "greater than," "less than," "between," and the like includes the number recited. Numbers preceded by a term such as "about" or "approximately" or "substantially" include the recited numbers. For example, "about 3 mm" includes "3 mm." The terms "approximately", "about" and/or "substantially" as used herein represent an amount or characteristic close to the stated amount or characteristic that still performs a desired function or achieves a desired result. For example, the terms "approximately", "about", and "substantially" may refer to an amount that is within less than 10% of, within less than 5% of, within less than 1% of, within less than 0.1 % of, and within less than 0.01 % of the stated amount or characteristic.

Examples

[0077] The description of specific examples below are intended for purposes of illustration only and are not intended to limit the scope of the invention disclosed herein.

Example 1: Silver Nanoplates

[0078] Silver nanoplates were synthesized using silver seeds prepared through the reduction of silver nitrate with sodium borohydride in the presence of sodium citrate tribasic and poly sodium styrene sulfonate under aqueous conditions. Silver seed preparation: 21.3 mL of an aqueous 2.5 mM sodium citrate tribasic solution was allowed to mix under magnetic stirring. 1

mL of a 2 g/L poly styrene sodium sulfonate (PSSS) solution was then prepared in a separate beaker. 21.3 mL of a 0.5 mM silver nitrate solution was then prepared by dissolving the salt in water. Once the above solutions have been prepared, 1.33 mL of a 0.5 mM sodium borohydride solution was prepared in 4°C water. The borohydride and PSSS solutions were then added to the beaker containing the citrate and allowed to mix. The silver nitrate solution was then pumped into the citrate solution using a peristaltic pump at a rate of 100 mL/min. This seed solution was then allowed to stir overnight at room temperature. Silver nanoplates were prepared by mixing 1530 mL Milli-Q water with 35 mL of a 10 mM ascorbic acid solution. Once the solution was sufficiently mixed, the prepared silver seed was added to the reactor. 353 mL of a 2 mM silver nitrate solution was pumped into the reactor at a rate of 100 mL/min. The reaction was mixed for two hours. TEM analysis showed that over 70% of the particles are nanoplates. The optical density of the solution was 2.8 cm^{-1}.

Example 2: Concentrated Silver Nanoplates

[0079] 15 L of silver nanoplates with a peak optical density of about 5 cm^{-1} were mixed with 3.5 g of polyvinylalcohol (PVA) and sodium borate, concentrated using tangential flow filtration using a 500 kD polysulfone tangential flow membrane with 3100 cm^2 of surface area. The solution was concentrated for approximately 90 minutes, and the final solution volume was reduced from 15 L to 0.5 L. The silver nanoplate solution optical density was increase to about 150 cm^{-1}. Thus, according to one embodiment, a method for increasing a silver nanoplate solution from 5 cm^{-1} to 150 cm^{-1} (e.g., an increase of roughly 30 times the optical density) comprises the steps of adding PVA and sodium borate to silver nanoplates, and concentrating the solution with tangential flow filtration.

Example 3: Concentrated Silver Nanoplates

[0080] In one example of concentrating silver nanoplates, 1.2 L of silver nanoplates with a peak optical density of about 4 cm^{-1} were mixed with 4 L of anhydrous ethanol and about 49 mL of ammonium hydroxide solution. 0.6 mL of a dilute aminopropyltriethoxysilane (APTES) was added to the solution. After 15 minutes of incubation, 6.5 mL of tetraethylorthosilicate (TEOS) solution was added. After 24 hours 1 L of the solution was concentrated using a 500 kD polysulfone tangential flow membrane with 1050 cm^2 of surface area. The final solution volume was decreased to 150 mL, increasing the silver nanoparticle solution optical density to about 40 cm^{-1}. Thus, according to one embodiment, a method for increasing a silver nanoplate solution from 4 cm^{-1} to 40 cm^{-1} (e.g., an increase of roughly 10 times the optical density) comprises the steps of adding anhydrous ethanol, ammonium hydroxide solution, aminopropyltriethoxysilane (APTES), and tetraethylorthosilicate (TEOS) to the silver nanoplates, and concentrating the solution with tangential flow filtration.

Example 4: Nanoplates with a Silica Shell

[0081] A silica shell was grown on the surface of 800 nm resonant (-75 nm edge length) polyvinylpyrrolidone (PVP) capped silver nanoplates. 400 mL of a solution of 800 nm resonant PVP capped silver nanoplates at a concentration of 2 mg/mL (20 cm^{-1} O.D.) was added to 2.3 L of reagent grade ethanol and 190 mL Milli-Q water under constant stirring. 4.3 mL of dilute aminopropyl triethoxysilane (215 uL APTES in 4.085 mL isopropanol) was then added to the solution, followed immediately by the addition of 44 mL of 30% ammonium hydroxide. After 15 minutes of incubation, 31 mL of dilute tetraethylorthosilicate (1.55 mL TEOS in 29.45 mL isopropanol) was added to the solution. The solution was then left to stir overnight. The nanoplates were then centrifuged on an Ultra centrifuge at 17000 RCF for 15 minutes and reconstituted in Milli-Q water each time and repeated twice. The silica shell thickness was 15 nm. The optical density of the concentrated material was 2040 cm^{-1}.

Example 5

[0082] A 40 mL solution of 40 O.D. solution of concentrated silver nanoplates stabilized with polyvinylalcohol and sodium borate was spun at 3000 RCF for 30 minutes. The supernatant was removed and the pellet was re-dispersed with bath sonication. The concentrated silver nanoplates had an optical density greater than 900 O.D. as is shown in FIG. 8.

Example 6: Concentrated Nanoplates on a Substrate

[0083] A 5 mL solution of 1000 O.D. silver nanoplates was added to a 3" x 3" section of absorbent cloth (Absorber Synthetic Drying Chamois, Clean Tools). After addition, the substrate was allowed to air dry. Once dried, the silver nanoplates were bound to the surface of the absorbent cloth and were not released when the cloth was subsequently wet and water removed by applying pressure.

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PATENTKRAV

1. Fremgangsmåde til fremstilling af koncentrerede sølvnanoplader i en opløsning, der bevarer form efter opkoncentrering, mens opløsningens optiske densitet øge, hvilken fremgangsmåde omfatter:

tilsætning af et stabiliseringsmiddel til en forkoncentreret opløsning, hvor den forkoncentrerede opløsning omfatter sølvnanoplader, hvor hver af sølvnanopladerne har en pladeform,

hvor den forkoncentrerede opløsning har en maksimal optisk densitet ved en første bølgelængde;

hvor stabiliseringsmidlet omfatter en polyvinyl-baseret polymer og et borat; og

øgning af en koncentration af sølvnanopladerne i den forkoncentrerede opløsning, ved anvendelse af centrifugering, fordampning, filtrering, dialyse eller filtrering med krydsende strømning, for at generere en koncentreret opløsning,

hvor den forkoncentrerede opløsning har en maksimal optisk densitet ved en første bølgelængde,

hvor den koncentrerede opløsning har en maksimal optisk densitet ved en anden bølgelængde,

hvor den koncentrerede opløsnings maksimale optiske densitet er større end 10 cm^{-1}, og hvor den koncentrerede opløsnings maksimale optiske densitet er større end den forkoncentrerede opløsnings maksimale optiske densitet, og

hvor mindst 50 % af sølvnanopladerne i den forkoncentrerede opløsning bevarer pladeformen i den koncentrerede opløsning.

2. Fremgangsmåde ifølge krav 1,

hvor øgning af koncentrationen udføres ved anvendelse af filtrering med krydsende strømning,

hvor den koncentrerede opløsnings maksimale optiske densitet er mindst ti gange større end den forkoncentrerede opløsnings maksimale optiske densitet,

hvor den koncentrerede opløsnings maksimale optiske densitet er mindst 100 cm^{-1},

hvor den polyvinyl-baserede polymer omfatter mindst en fra gruppen bestående af: en polyvinylpyrrolidon (PVP) og en polyvinylalkohol (PVA), hvor boratet omfatter natriumborat.

3. Fremgangsmåde ifølge krav 1 eller krav 2,

hvor bølgelængden for den koncentrerede opløsnings maksimale optiske densitet ligger i et interval mellem 500 nm og 1500 nm, og

hvor bølgelængden for den forkoncentrerede opløsnings maksimale optiske densitet i alt væsentligt er den samme som bølgelængden for den koncentrerede opløsnings maksimale optiske densitet,

hvor mindst én optisk egenskab for den koncentrerede opløsning i alt væsentligt er den samme som den forkoncentrerede opløsning, idet den forkoncentrerede opløsnings maksimale optiske densitet og den koncentrerede opløsnings maksimale optiske densitet ligger ved i alt væsentligt den samme bølgelængde.

4. Fremgangsmåde ifølge et hvilket som helst af kravene 1 - 3 ,

hvor sølvnanopladerne fremstilles via en seed-medieret vækstmekanisme,

hvor den seed-medierede vækstmekanisme omfatter:

kombinering af citrat, polystyrennatriumsulfonat (PSSS) og natriumborhydrid i en første opløsning,

tilsætning af sølvnitrat til den første opløsning for at danne en seed-opløsning, tilsætning af en del af seed-opløsningen til en anden opløsning, hvor den anden opløsning omfatter ascorbinsyre, og

tilsætning af sølvnitrat til den anden opløsning for at danne den forkoncentrerede opløsning.

5. Fremgangsmåde ifølge krav 1,

hvor øgning af koncentrationen udføres ved anvendelse af filtrering med krydsende strømning,

hvor der ved filtrering med krydsende strømning anvendes en filtermembran med porer med en molekylvægtgrænse i et interval mellem 10 kDa og 0,05 mikron,

hvor den koncentrerede opløsnings maksimale optiske densitet er mindst ti gange større end den forkoncentrerede opløsnings maksimale optiske densitet,

hvor den koncentrerede opløsnings maksimale optiske densitet er mindst 100 cm^{-1},

og/eller hvor forkoncentreret opløsning centrifugeres efter øgning af koncentrationen ved anvendelse af filtrering med krydsende strømning.

6. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, der endvidere omfatter coating af sølvnanopladerne med silica, hvor coating af sølvnanopladerne med silica omfatter:

tilsætning af ethanol til den forkoncentrerede opløsning, tilsætning af en base til den forkoncentrerede opløsning og

tilsætning af en silan til den forkoncentrerede opløsning.

7. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor stabiliseringsmidlet omfatter mindst et fra gruppen bestående af: en polyvinylpyrrolidon (PVP), en polyvinylalkohol (PVA) og en polyethylenglycol (PEG).

8. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, der endvidere omfatter dannelse af en metaloxidkappe på overfladen af sølvnanopladen, og fortrinsvis

hvor metaloxidkappen er en hvilken som helst fra gruppen bestående af: en silicakappe og en titandioxidkappe, hvor metaloxidkappen har en tykkelse i et interval mellem 1 nm til 100 nm.

9. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor stabiliseringsmidlet endvidere omfatter en kemisk thiolgruppe, og fortrinsvis hvor den kemiske thiolgruppe omfatter mindst en fra gruppen bestående af: en liponsyre, en mercaptohexadecansyre, en mercaptoundecansyre og en dihydroliponsyre.

10. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor delen af de koncentrerede sølvnanoplader, der bevarer pladeformen efter øgning af koncentrationen, er større end 80 % eller større end 90 %.

11. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, hvor den forkoncentrerede opløsning inkuberes med et substrat, hvor substratet omfatter en fiber.

12. Sammensætning, der omfatter:

en flerhed af sølvnanoplader i en opløsning, der omfatter en optisk densitet, hvor sølvnanopladerne omfatter en coating på en overflade af sølvnanopladerne,

hvor den optiske densitet er større end 100 cm^{-1}, og

hvor coatingen omfatter et borat og mindst ét middel, der er udvalgt fra gruppen bestående af: en polyvinyl-baseret polymer og et thiol-holdigt molekyle.

13. Sammensætning ifølge krav 12, hvor boratet omfatter mindst en fra gruppen bestående af: et natriumborat og et kaliumtetraborat.

14. Sammensætning ifølge krav 12 eller krav 13, hvor coatingen omfatter den polyvinyl-baserede polymer, hvor den polyvinyl-baserede polymer er udvalgt fra gruppen bestående af: en polyvinylpyrrolidon (PVP) og en polyvinylalkohol (PVA).

15. Sammensætning ifølge et hvilket som helst af kravene 12 - 14, hvor coatingen omfatter det thiol-holdige molekyle, hvor det thiol-holdige molekyle omfatter mindst en fra gruppen bestående af: en liponsyre, en mercaptohexadecansyre, en mercaptoundecansyre og en dihydroliponsyre.

16. Sammensætning ifølge et hvilket som helst af kravene 12 - 15, hvor coatingen endvidere omfatter en metaloxidkappe, og fortrinsvis hvor metaloxidkappen er en hvilken som helst fra gruppen bestående af: en silicakappe og en titandioxidkappe, hvor metaloxidkappen har en tykkelse i et interval mellem 1 nm til 100 nm.

DRAWINGS

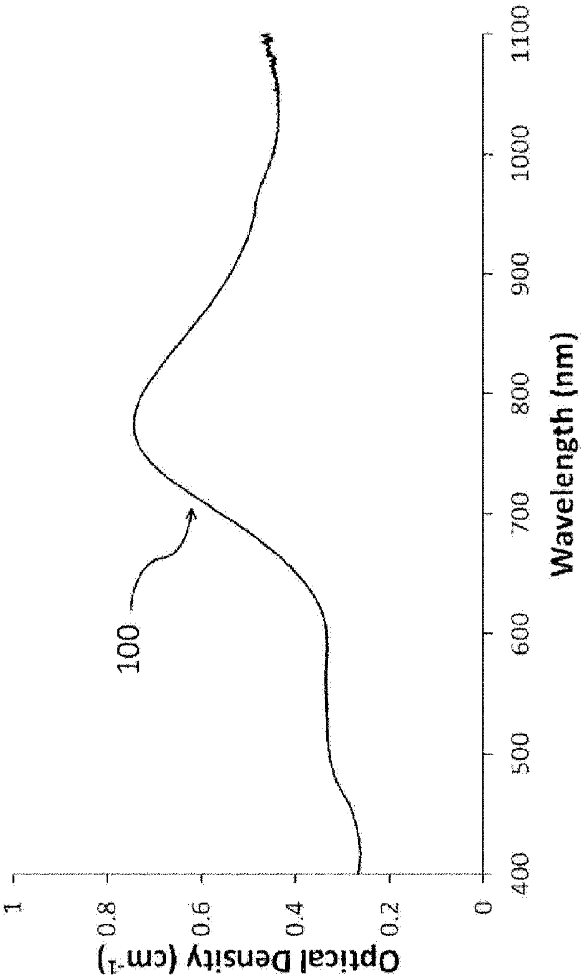

Figure 1

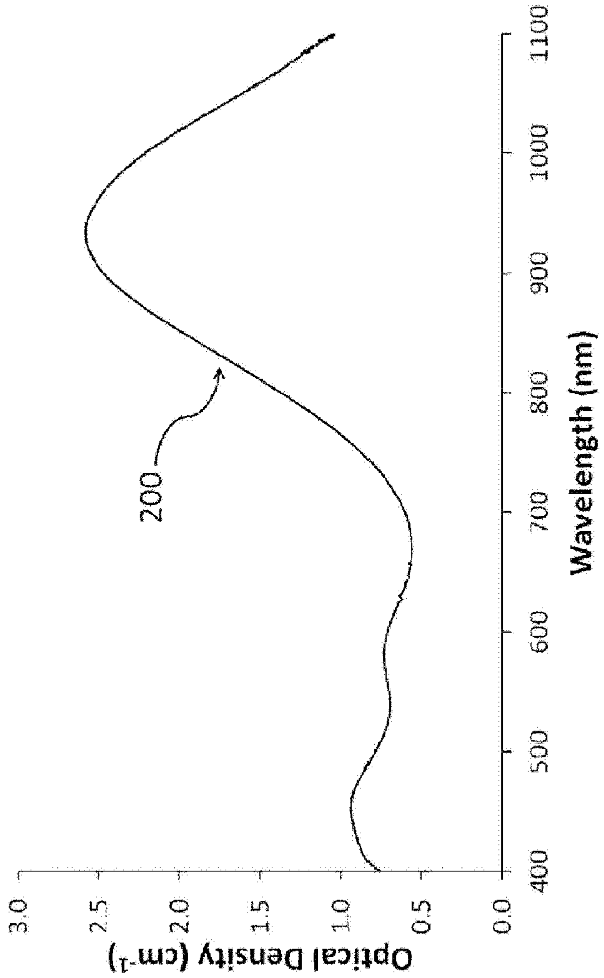
200
Optical Density (cm-1)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
400
500
600
700
800
900
1000
1100
Wavelength (nm)

Figure 2

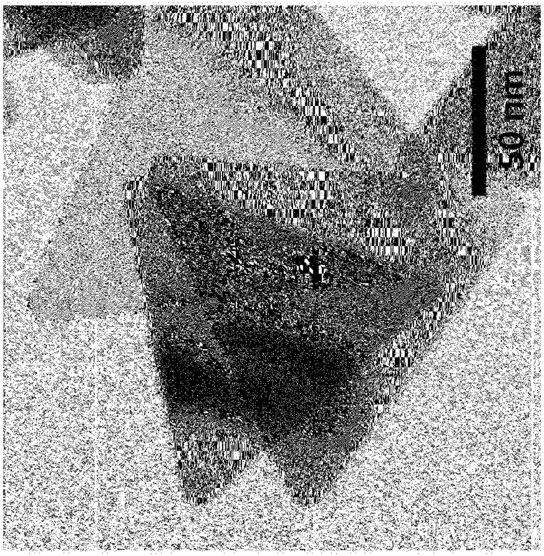

Figure 3A

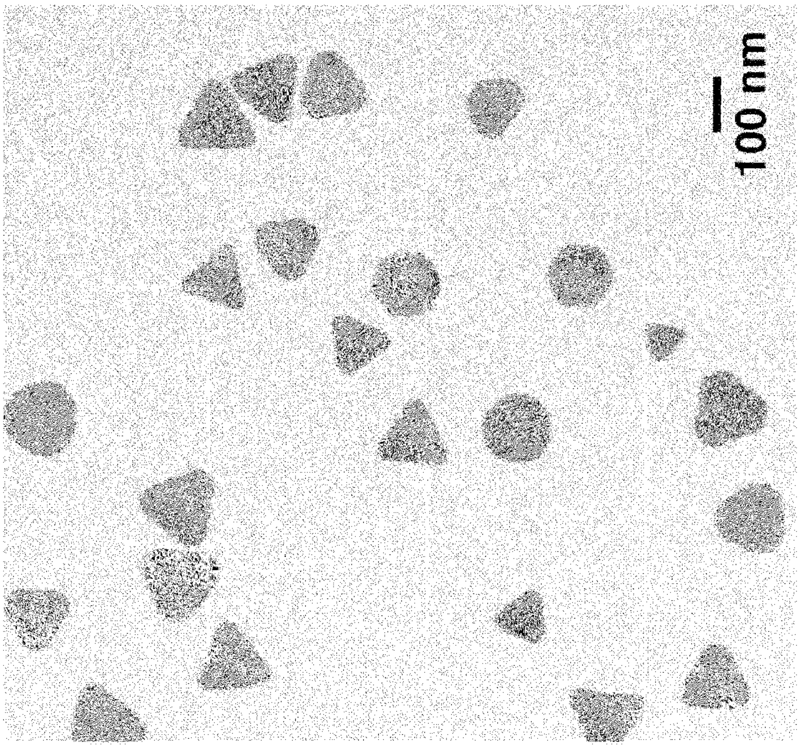

Figure 3B

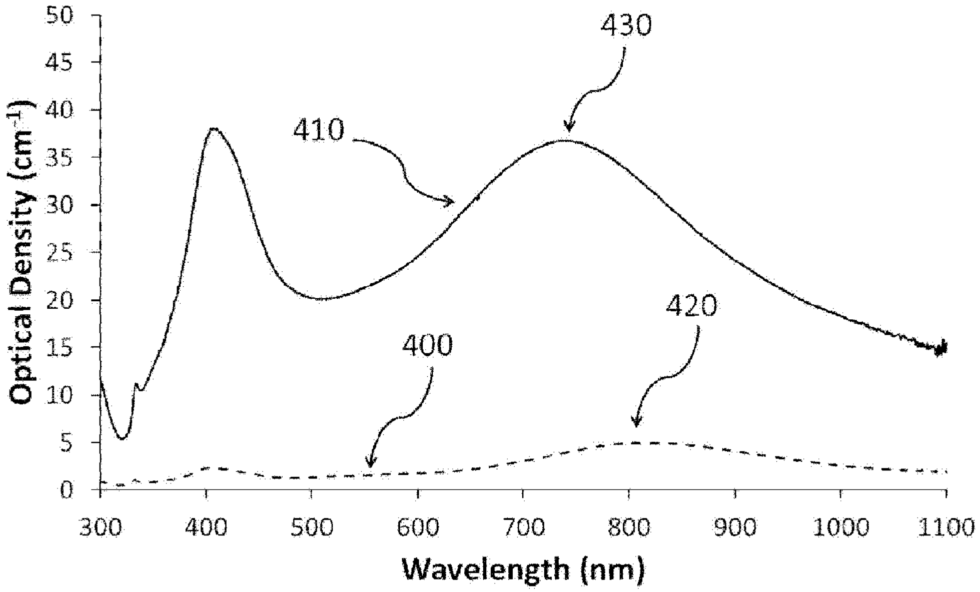
Optical Density (cm^{-1})
50
45
40
35
30
25
20
15
10
5
0
430
410
420
400
300
400
500
600
700
800
900
1000
1100
Wavelength (nm)

Figure 4

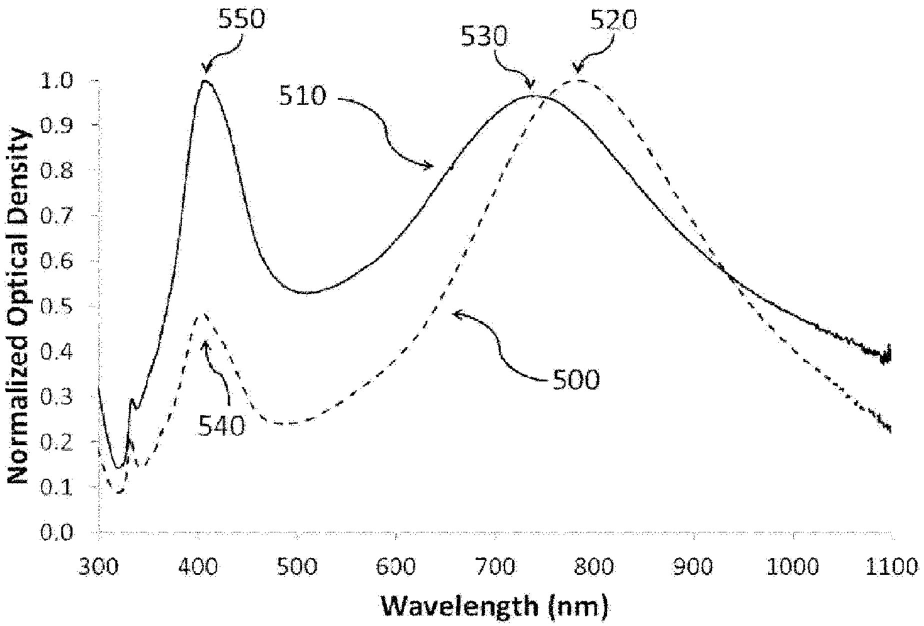
550
530
520
510
500
540
Normalized Optical Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
300
400
500
600
700
800
900
1000
1100
Wavelength (nm)

Figure 5

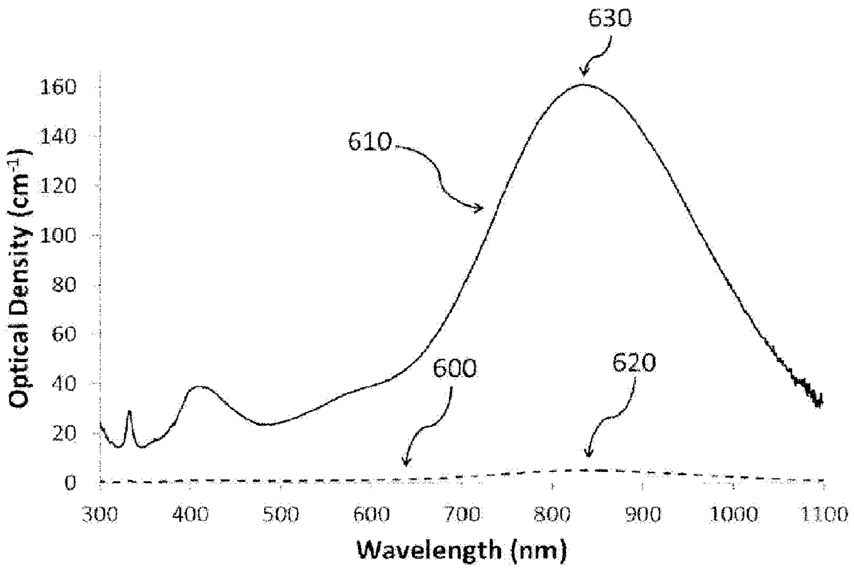
630
610
600
620
Optical Density (cm-1)
160
140
120
100
80
60
40
20
0
300
400
500
600
700
800
900
1000
1100
Wavelength (nm)

Figure 6

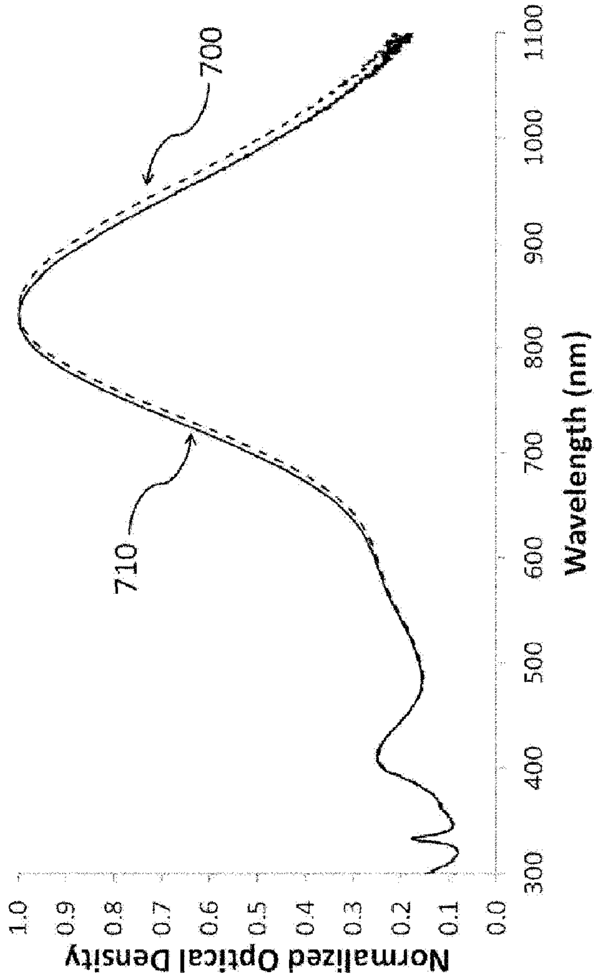
Normalized Optical Density
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
300
400
500
600
700
800
900
1000
1100
Wavelength (nm)
700
710

Figure 7

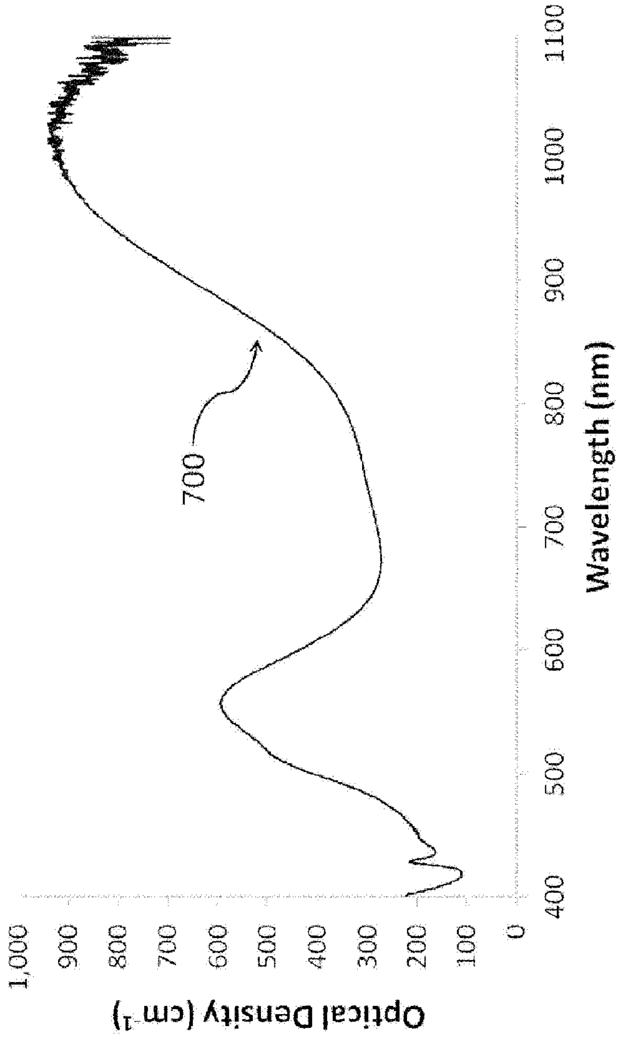
Optical Density (cm^{-1})
1,000
900
800
700
600
500
400
300
200
100
0
400
500
600
700
800
900
1000
1100
Wavelength (nm)
700

Figure 8

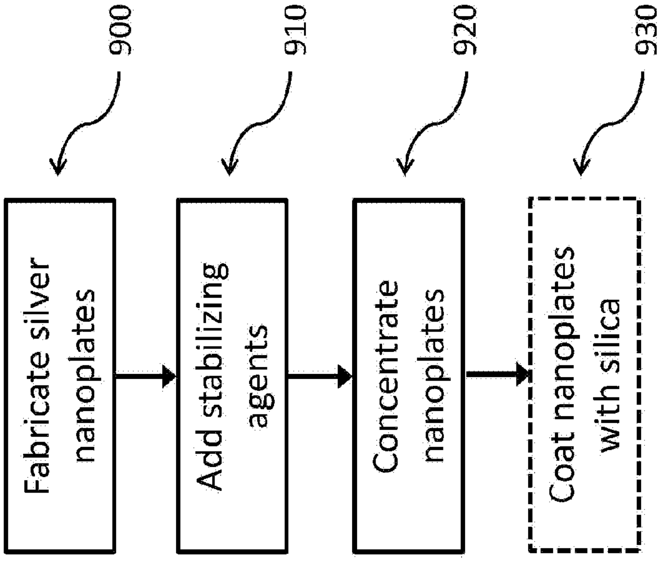
900
Fabricate silver nanoplates
910
Add stabilizing agents
920
Concentrate nanoplates
930
Coat nanoplates with silica

Figure 9