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(54) **Title**: ELECTROSPINNING APPARATUSES & PROCESSES

(57) **Abstract**: Provided herein are electrospinning systems, apparatuses, components, and processes for the preparation of nanofibers, including high throughput systems, apparatuses, and processes for producing high performance nanofibers.

ELECTROSPINNING APPARATUSES & PROCESSES

CROSS-REFERENCE

[0001] This application claims the benefit of U.S. Provisional Application No. 61/781,260, filed March 14, 2013, which is incorporated herein by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] A technique used to prepare fine polymer fibers is the method of electro-spinning. When an external electrostatic field is applied to a conducting fluid (e.g., a charged semi-dilute polymer solution or a charged polymer melt), a suspended conical droplet is formed, whereby the surface tension of the droplet is in equilibrium with the electric field. Electro-spinning occurs when the electrostatic field is strong enough to overcome the surface tension of the liquid. The liquid droplet then becomes unstable and a tiny jet is ejected from the surface of the spinneret tip. As it reaches a grounded target, the jet stream can be collected as an interconnected web of fine sub-micron size fibers. The resultant films from these non-woven nanoscale fibers (nanofibers) have very large surface area to volume ratios.

SUMMARY OF THE INVENTION

[0003] Provided herein is a nozzle or a multi-nozzle system (comprising a plurality of nozzles) for producing nanofibers. In some embodiments, the nozzle or multi-nozzle system allows for high throughput nanofiber processing. In certain embodiments, the nozzle or multi-nozzle system also provides for the preparation of high performance nanofibers – e.g., nanofibers having uniform structures and components. In certain embodiments, such nanofibers allow for the production of nanofibers that have narrow, uniform diameters. For example, in some instances, the standard deviation of nanofibers provided, or prepared according to systems and processes described, herein is less than 50% of the average diameter.

[0004] Provided in certain embodiments herein are nozzles for producing nanofibers. Generally, such nozzles are suitable or configured for use in an electrospinning apparatus. In some embodiments, a nozzle provided herein comprises a first conduit and a second conduit, the first conduit positioned inside the second conduit (e.g., as illustrated in the figures). In specific embodiments, a nozzle (e.g., electrospinning nozzle) provided herein comprises:

a. a first conduit, the first conduit being enclosed along the length of the conduit by a first wall having an interior and an exterior surface (e.g., the interior surface facing the first conduit and at least a portion of the exterior surface facing the second conduit), and the first conduit having a first inlet (or supply) end and a first outlet end; and

b. a second conduit, the second conduit being enclosed along the length of the conduit by a second wall having an interior surface, and the second conduit having a second inlet (or supply) end and a second outlet end.

[0005] In some embodiments, the first conduit is positioned inside the second conduit for a conduit overlap length (e.g., as illustrated by $\mathbf{l}^1$ in the figures). In certain embodiments, the conduit overlap length is any suitable length, such as about 5 mm or more, or about 5 mm to about 100 mm. In specific embodiments, the conduit overlap length is about 15 mm to about 100 mm. In more specific embodiments, the conduit overlap length is about 20 mm to about 50 mm, e.g., about 30 mm. In some instances, the first conduit is longer than the second conduit and in other instances, the second conduit is longer than the first conduit. And in yet other instances, both conduits are the same length. In some embodiments, the first outlet end extends beyond the second outlet end by a suitable amount (e.g., as illustrated by $\mathbf{l}^2$ in the figures, described herein as the protrusion length – e.g., of the first conduit). In specific instances, the first outlet end extends beyond the second outlet end by about -0.5mm to about 1.5 mm. In more specific instances, the first outlet end extends beyond the second outlet end by about 0 mm to about 0.8 mm. In still more specific embodiments, the first outlet end extends beyond the second outlet end by about 0.1 mm to about 0.5 mm.

[0006] In some embodiments, the first conduit has a first diameter (e.g., diameter of the interior surface of the first walls) and the second conduit has a second diameter (e.g., diameter of the interior surface of the second walls). Generally, given the configuration of the first conduit inside the second conduit, the second diameter is larger than the first diameter. In some embodiments, the first diameter is any suitable diameter. In specific embodiments, the first diameter is about 0.05 mm to about 3 mm. In more specific embodiments, the first diameter is 0.3 to 3 mm, about 0.5 mm to about 1 mm, or about 0.6 mm to about 0.9 mm. In some embodiments, the walls surrounding the first conduit have a first wall diameter of about 0.1 to about 4 mm, e.g., about 0.5 mm to about 3.8 mm. In more specific embodiments, the first wall diameter is about 0.8 mm to about 1.8 mm, or about 1 mm to about 1.5 mm. In some embodiments, the second diameter is any suitable diameter. In specific embodiments, the second diameter is about 0.1 mm to about 5 mm. In more specific embodiments, the second diameter is about 0.8 to 4 mm, about 1 mm to about 2.5 mm, about 0.8 mm to 2 mm (such as when the third conduit inside which the second conduit is positioned is present), or about 1.3 mm to 1.6 mm.

[0007] In various embodiments, the conduits described herein have any suitable shape. In some embodiments, the conduits are cylindrical (e.g., oval or circular cylinders), prismatic (e.g., an octagonal prism), conical (e.g., a truncated cone), pyramidal (e.g., a truncated pyramid, such as a truncated octagonal pyramid), or the like. In specific embodiments, the conduits are cylindrical (e.g., wherein the conduits and walls enclosing said conduits form needles). In certain embodiments, the walls of a conduit are parallel, or within about 1 or 2 degrees of parallel (e.g., wherein the conduit forms a cylinder or prism). In other embodiments, the walls of a conduit are not parallel (e.g., wherein the diameter is wider at the inlet end than the outlet end, such as when the conduit forms a cone (e.g., truncated cone) or pyramid (e.g., truncated pyramid)). In certain embodiments, the walls of a conduit are within about 15 degrees of parallel, or within about 10 degrees of parallel. In specific embodiments, the walls of a conduit are within about 5 degrees of parallel (e.g., within about 3 degrees or 2 degrees of parallel). In some instances, conical or pyramidal conduits are utilized. In such embodiments, the diameters for conduits not having parallel walls refer to the average width or diameter of said conduit. In certain embodiments, the angle of the cone or pyramid is about 15 degrees or less, or about 10 degrees or less. In specific embodiments, the angle of the cone or pyramid is about 5 degrees or less (e.g., about 3 degrees or less).

[0008] In some embodiments, the distance between the exterior surface of the first wall and the interior surface of the second wall (the conduit gap thereof) is any suitable distance. In some embodiments, the distance is on average less than 0.5 mm. In specific embodiments, the distance between the exterior surface of the first wall and the interior surface of the second wall is on average less than 0.3 mm. In more specific embodiments, the distance is on average about 0.01 mm to about 0.3 mm. In still more specific embodiments, the distance is on average about 0.05 mm to about 0.3 mm.

[0009] In certain embodiments, provided herein is a nozzle component comprising a ratio of the conduit overlap length (e.g., as illustrated by l^1)-to-second diameter (e.g., as illustrated by d^2) of at least 5. In specific embodiments, the ratio is about 10 or more. In more specific embodiments, the ratio is about 13 or more. In still more specific embodiments, the ratio is about 15 or more, e.g., about 17 or more. In still more specific embodiments, the ratio is about 18 or more, e.g., about 19.

[0010] In some embodiments, provided herein is a nozzle component comprising a ratio of the average distance between the exterior surface of the first wall and the interior surface of the second wall (also described herein as the conduit gap, and, e.g., illustrated in the figures by $\mathbf{d^4}$) to the second diameter (e.g., illustrated in the figures as $\mathbf{d^2}$) of less than 0.25, e.g., about 0.2 or less. In specific embodiments, the ratio of the conduit gap-to-second diameter is less than 0.15. In more specific embodiments, the ratio is less than 0.1. In still more specific embodiments, the ratio is about 0.05 or less, e.g., about 0.04.

[0011] In some embodiments, provided herein is a nozzle component comprising a ratio of the protrusion length of the first conduit (e.g., as illustrated by l2 in the figures)-to-second diameter (e.g., as illustrated by d2 in the figures) of less than 1. In specific embodiments, the ratio is less than 0.5. In more specific embodiments, the ratio is about 0.3 or less.

[0012] In some embodiments, provided herein is a multi-nozzle configuration comprising a ratio of the distance between two adjacent nozzles-to-second diameter (e.g., as illustrated by $\mathbf{d^2}$ in the figures) of about 0.5 to about 50. In some embodiments, the ratio is about 0.5 to about 25, or about 0.5 to about 10, e.g., about 1 to about 5. In specific embodiments, the ratio is about 1. In other specific embodiments, the ratio is about 5.

[0013] In certain embodiments, a nozzle provided herein comprises a first conduit that is fluidly connected (e.g., via the inlet or supply end) to a first supply chamber, the first supply chamber configured to provide liquid polymer (e.g., polymer melt or polymer solution) to the first conduit. In some embodiments, a nozzle provided herein comprises a second conduit that is fluidly connected (e.g., via the inlet or supply end thereof) to a second supply chamber, the second supply chamber configured to provide pressurized (or high velocity) air to the second conduit. In some embodiments, the second supply chamber is a pressurized air tank, an air pump, a chamber containing a fan, or the like. In certain embodiments, the first and second supply chambers are present in a manifold described in more detail herein. In certain embodiments, a nozzle component described herein is configured to receive a voltage (e.g., sufficient to produce an electric field strong enough to overcome the surface tension of a liquid polymer – e.g., a polymer solution or polymer melt).

[0014] In specific embodiments, provided herein is a nozzle, or an electrospinning apparatus comprising a nozzle, the nozzle comprising:

a. a first conduit, the first conduit being enclosed along the length of the conduit by a first wall having an interior and an exterior surface (e.g., the interior surface facing the first conduit and at least a portion of the exterior surface facing the second conduit), the first conduit having a first inlet (or supply) end and a first outlet end, and the first conduit having a first diameter (e.g., defined by the diameter of the interior surface of the first walls); and

b. a second conduit, the second conduit being enclosed along the length of the conduit by a second wall having an interior surface, the second conduit having a second inlet (or supply) end and a second outlet end, and the second conduit having a second diameter (e.g., defined by the diameter of the interior surface of the second walls);

the first and second conduit having a conduit overlap length, wherein the first conduit is positioned inside the second conduit, the exterior surface of the first wall and the interior surface of the second wall being separated by a conduit gap, the first outlet end protruding beyond the second outlet end by a protrusion length, and wherein:

i. the ratio of the conduit overlap length-to-second diameter is about 10 or more (e.g., about 13 or more, or about 18 or more),

ii. the ratio of the average conduit gap-to-second diameter about 0.2 or less (e.g., about 0.1 or less, or about 0.05 or less), and/or

iii. the ratio of the protrusion length-to-second diameter is about 0.3 or less.

[0015] In some embodiments, provided herein is a nozzle, or an electrospinning apparatus comprising a nozzle, the nozzle comprising:

a. an inner conduit, the inner conduit being enclosed along the length of the conduit by an inner wall having an interior and an exterior surface (e.g., the interior surface facing the inner conduit and at least a portion of the exterior surface facing the outer conduit), the inner conduit having an inner conduit inlet (or supply) end and an inner conduit outlet end, and the inner conduit having an inner conduit diameter (e.g., defined by the average diameter of the interior surface of the inner walls); and

b. an outer conduit, the outer conduit being enclosed along the length of the conduit by an outer wall having an interior surface, the outer conduit having an outer conduit inlet (or supply) end and an outer conduit outlet end, and the outer conduit having an outer conduit diameter (e.g., defined by the average diameter of the interior surface of the outer walls);

the inner and outer conduit having a conduit overlap length, wherein the inner conduit is positioned inside the outer conduit (e.g., with optional additional inner conduits positioned inside the inner conduit), the exterior surface of the inner wall and the interior surface of the outer wall being separated by a conduit gap, the inner conduit outlet end protruding beyond the outer conduit outlet end by a protrusion length, and wherein:

i. the ratio of the conduit overlap length-to-outer conduit diameter is about 10 or more (e.g., about 13 or more, or about 18 or more),
ii. the ratio of the average conduit gap-to-outer conduit diameter about 0.2 or less (e.g., about 0.1 or less, or about 0.05 or less), and/or
iii. the ratio of the inner conduit protrusion length-to-outer conduit diameter is about 0.3 or less.

[0016] In certain embodiments, an electrospinning apparatus (or nozzle) provided herein comprises a nozzle having a first (or inner) conduit that is fluidly connected (e.g., via the inlet or supply end) to a first supply chamber, the first supply chamber configured to provide liquid polymer (e.g., polymer melt or polymer solution) to the first conduit. In some embodiments, an electrospinning apparatus provided herein comprises a nozzle having a second (or outer) conduit that is fluidly connected (e.g., via the inlet or supply end thereof) to a second supply chamber, the second supply chamber configured to provide pressurized (or high velocity) air to the second conduit. In some embodiments, the second supply chamber is a pressurized air tank, an air pump, a chamber containing a fan, or the like. In certain embodiments, an apparatus provided herein comprises a power source configured to provide a voltage to the nozzle component. In further embodiments, an apparatus provided herein comprises a grounded collector (e.g., for collecting nanofibers produced by the electrospinning apparatus).

[0017] In specific embodiments, the ratio of the conduit overlap length-to-outer conduit diameter is about 10 or more (e.g., about 13 or more, or about 18 or more). In further or alternative specific embodiments, the ratio of the average conduit gap-to-outer conduit diameter about 0.2 or less (e.g., about 0.1 or less, or about 0.05 or less). In further or alternative specific embodiments, the ratio of the inner conduit protrusion length-to-outer conduit diameter is about 0.3 or less. In specific embodiments, the ratio of the conduit overlap length-to-outer conduit diameter is about 10 or more (e.g., about 13 or more, or about 18 or more) and the ratio of the average conduit gap-to-outer conduit diameter about 0.2 or less (e.g., about 0.1 or less, or about 0.05 or less). In more specific embodiments, the ratio of the conduit overlap length-to-outer conduit diameter is about 10 or more (e.g., about 13 or more, or about 18 or more), the ratio of the average conduit gap-to-outer conduit diameter about 0.2 or less (e.g., about 0.1 or less, or about 0.05 or less), and the ratio of the inner conduit protrusion length-to-outer conduit diameter is about 0.3 or less.

[0018] In some embodiments, provided herein is a nozzle (e.g., multi-nozzle) system for producing nanofibers, the system comprising a manifold comprising a plurality of supply chambers and at least one (e.g., a plurality of) electrospinning nozzles (e.g., needle apparatuses). In some embodiments, provided herein is a system comprising a first manifold supply chamber, a second manifold supply chamber, a first conduit (e.g., needle) in fluid contact with the first manifold supply chamber, and a second conduit (e.g., needle) in fluid contact with the second supply chamber. In specific embodiments, the first conduit (e.g., needle) is arranged inside the second conduit (e.g., needle). In specific embodiments, the first conduit (e.g., needle) and the second conduit (e.g., needle) are arranged (e.g., concentrically arranged) about a common axis (e.g., within 5 degrees of the common axis). In some embodiments, the second conduit (e.g., needle) is arranged inside a third conduit (e.g., needle).

[0019] Generally, conduits provided herein are enclosed conduits comprising an inlet end and an outlet end and an enclosing wall that surrounds the conduit. Typically, the inlet end is opposite the outlet end. A needle and other “straw-like” structures are examples of enclosed conduits comprising an inlet end and an outlet end and an enclosing wall that surrounds the conduit. Embodiments described herein for “needle” structures are intended to also provide more general disclosure for enclosed conduits.

[0020] In some embodiments, a multi-nozzle system described herein comprises a manifold comprising (i) a first manifold inlet in fluid contact with a first manifold supply chamber, and (ii) a second manifold inlet in fluid contact with a second manifold supply chamber. In certain embodiments, provided herein is a multi-nozzle system comprising a plurality of nozzles described herein (e.g., coaxial nozzle (e.g., needle) apparatuses (e.g., wherein the coaxial nozzle apparatus comprises a plurality of coaxially aligned and concentrically arranged conduits)). In specific embodiments, each nozzle component (e.g., coaxial needle apparatus) comprises a first conduit (e.g., needle) comprising a first supply end and a first outlet end (e.g., the first supply end being in fluid contact with the first manifold supply chamber – either directly or via an intermediary structure). In further or alternative embodiments, each nozzle component (e.g., coaxial needle apparatus) comprises a second conduit (e.g., needle) comprising a second supply end and a second outlet end (e.g., the second supply end being in fluid contact with the second manifold supply manifold – either directly or via an intermediary structure). In specific embodiments, the first conduit (e.g., needle) and second conduit (e.g., needle) are aligned along a common axis (e.g., within 25% of the diameter of the outer needle and within 5 or 10 degrees of the common axis), and the first conduit (e.g., needle) is positioned inside the second conduit (e.g., needle) for at least a portion of the length of the first conduit (e.g., needle).

[0021] In some embodiments, the manifold further comprises a third inlet in fluid contact with a third supply chamber. In specific embodiments, each of the nozzle components (e.g., coaxial needle apparatuses) further comprises a third conduit (e.g., needle) comprising a third supply end and a third outlet end. In more specific embodiments, the third supply end is in fluid contact with the third manifold supply chamber. In some embodiments, the first, second, and third conduits (e.g., needles) are aligned along a common axis, the first conduit (e.g., needle) being positioned inside the second conduit (e.g., needle) for at least a portion of the length of the first conduit (e.g., needle), and the second conduit (e.g., needle) being positioned inside the third conduit (e.g., needle) for at least a portion of the length of the second conduit (e.g., needle).

[0022] In some embodiments, a system provided herein comprises a stock reservoir (e.g., a syringe) in fluid connection with at least one manifold inlet (e.g., an inlet in fluid contact with the supply chamber that is in fluid contact with the inlet of the first or inner conduit (e.g., needle)). In specific embodiments, the system comprises a pump, the pump configured to pump fluid from a stock reservoir through the at least one manifold inlet and into a manifold supply chamber (e.g., an inlet in fluid contact with the supply chamber that is in fluid contact with the inlet of the second, third, or outer (e.g., outermost) conduit (e.g., needle)).

[0023] In some embodiments, provided herein is a system configured to provide compressed / pressurized gas (e.g., air) to at least one manifold inlet (e.g., that leads to the outer conduit (e.g., needle) of a nozzle component (e.g., needle apparatus)). In certain embodiments, the system comprises (a) an air pump connected to a manifold inlet; and/or (b) a high-pressure gas (e.g., air) reservoir (e.g., a gas tank) connected to at least one manifold inlet.

[0024] In some embodiments, a system provided herein comprises a plurality of nozzle component (e.g., coaxial needle apparatuses), each nozzle component (e.g., coaxial needle apparatus) comprising at least two conduits (e.g., at least two needles), with one conduit arranged inside the other conduit (e.g., wherein the conduits are concentrically arranged). In certain embodiments, the conduits (e.g., coaxial needles) are suitably aligned with one another. In specific embodiments, the concentric conduits (e.g., needles of a coaxial needle apparatus) provided herein are aligned within 15 degrees of a common axis. In more specific embodiments, the concentric conduits (e.g., needles of a coaxial needle apparatus) provided herein are aligned within 10 degrees of a common axis. In still more specific embodiments, the concentric conduits (e.g., needles of a coaxial needle apparatus) provided herein are aligned within 5 degrees of a common axis. In yet more specific embodiments, the concentric conduits (e.g., needles of a coaxial needle apparatus) provided herein are aligned within 2 degrees of a common axis. In preferred embodiments, the concentric conduits (e.g., needles of a coaxial needle apparatus) provided herein are aligned within 1 degrees of a common axis.

[0025] In some embodiments, each conduit is arranged around a longitudinal axis. In certain embodiments, conduits (e.g., needles) of a nozzle component (e.g., coaxial needle) provided herein are aligned around a common (longitudinal) axis. In specific embodiments, axes of each of the conduits (e.g., needles) of a nozzle component (e.g., coaxial needle) are aligned within 500 microns of one another. In specific embodiments, axes of each of the conduits (e.g., needles) of a nozzle component (e.g., coaxial needle) are aligned within 250 microns of one another. In specific embodiments, axes of each of the conduits (e.g., needles) of a nozzle component (e.g., coaxial needle) are aligned within 100 microns of one another. In specific embodiments, axes of each of the conduits (e.g., needles) of a nozzle component (e.g., coaxial needle) are aligned within 50 microns of one another. In specific embodiments, axes of each of the conduits (e.g., needles) of a nozzle component (e.g., coaxial needle) are aligned within 20 microns of one another.

[0026] In some embodiments, the first (or inner) conduit (e.g., needle) has a smaller average diameter and a greater length than the second (or outer) conduit (e.g., needle). In specific embodiments, the first (e.g., innermost) conduit (e.g., needle) has a smaller average diameter and a greater length than or equal length to the second conduit (e.g., needle), and the second (e.g., intermediate inner) conduit (e.g., needle) has a smaller average diameter and a greater length than the third (e.g., outer or outermost) conduit (e.g., needle). More specifically, in some embodiments, the first conduit (e.g., needle) is arranged inside (for at least a portion of its length) inside the second conduit (e.g., needle), and the second conduit (e.g., needle) is arranged inside (for at least a portion of its length) inside the third conduit (e.g., needle) (if present).

[0027] In certain embodiments, the third conduit (e.g., needle) has a (inner) diameter of 1.5 mm to 4 mm. In more specific embodiments, the third conduit (e.g., needle) has a (inner) diameter of 2 mm to 3 mm (or about 9-12 gauge). In still more specific embodiments, the third conduit (e.g., needle) has a (inner) diameter of 2.3 mm to 2.7 mm (or about 10-11 gauge).

[0028] In some embodiments, the second conduit (e.g., needle) has a (inner) diameter of about 0.8 to about 4 mm (or about 7-18 gauge). In specific embodiments, the second conduit (e.g., needle) has a (inner) diameter of 0.8 mm to 2 mm (or about 13-18 gauge), such as when the third conduit (e.g., needle) is present. In specific embodiments, the second conduit (e.g., needle) has a (inner) diameter of 1.3 mm to 1.6 mm (or about 14-15 gauge). In some embodiments, the second conduit (e.g., needle) has an outer diameter (e.g., outer diameter of a wall enclosing the second conduit, such as the outer wall of a needle) of 1 mm to 2.4 mm (or about 13-18 gauge), such as when the third conduit (e.g., needle) is present. In specific embodiments, the second conduit (e.g., needle) has an outer diameter of 1.8 mm to 2.1 mm (or about 14-15 gauge).

[0029] In some embodiments, the first conduit (e.g., needle) has a (inner) diameter of about 0.3 to about 3 mm (or about 9-24 gauge). In specific embodiments, the first conduit (e.g., needle) has a (inner) diameter of about 0.5 mm to about 1.2 mm (or about 16-21 gauge). In specific embodiments, the first conduit (e.g., needle) has a (inner) diameter of 0.5 mm to 1 mm (or about 17-21 gauge). In specific embodiments, the first conduit (e.g., needle) has a (inner) diameter of 0.6 mm to 0.9 mm (or about 18-19 gauge). In some embodiments, the first conduit (e.g., needle) has an outer diameter (e.g., outer diameter of a wall enclosing the first conduit, such as the outer wall of a needle) of 0.5 mm to 3.8 mm (or about 9-24 gauge). In specific embodiments, the first conduit (e.g., needle) has an outer diameter of about 0.8 mm to about 1.7 mm (or about 16-21 gauge). In specific embodiments, the first conduit (e.g., needle) has an outer diameter of 0.8 mm to 1.5 mm (or about 17-21 gauge). In more specific embodiments, the first conduit (e.g., needle) has an outer diameter of 1 mm to 1.3 mm (or about 18-19 gauge).

[0030] In certain embodiments, nozzle component (e.g., coaxial needle apparatuses) provided herein have a terminal end, with the outlets of each of the needles within a nozzle component (e.g., coaxial needle apparatus) configured at the terminal end of the nozzle component (e.g., coaxial needle apparatus). In certain embodiments, each of the conduits (e.g., needles) of the nozzle component (e.g., coaxial needle apparatus) terminate within 5 mm of one another (e.g., **113** of **FIG. 1** or l^2 of **FIG. 3** is -5 mm to 5 mm). In specific embodiments, each of the conduits (e.g., needles) of the nozzle component (e.g., coaxial needle apparatus) terminate within 1 mm of one another. In more specific embodiments, each of the conduits (e.g., needles) of the nozzle apparatus (e.g., coaxial needle apparatus) terminate within 500 micron of one another. In still more specific embodiments, each of the conduits (e.g., needles) of the nozzle apparatus (e.g., coaxial needle apparatus) terminate within 100 micron of one another.

[0031] In some embodiments, a system provided herein comprises a heater. In specific embodiments, the heater is configured to heat one or more supply manifold, one or more nozzle component (e.g., coaxial needle apparatus), or a combination thereof. In some embodiments, the heater or an additional heater (furnace) is configured to thermally treat the spun nanofibers.

[0032] In certain embodiments, a system provided herein comprises a nanofiber collection surface (e.g., a grounded collection surface) in operable proximity to the terminal ends of the nozzle component(s) (e.g., coaxial needle apparatuses). In some embodiments, the nanofiber collection surface is a continuous conveyor collector.

[0033] In some embodiments, provided herein is a power supply configured to provide voltage to the nozzle component (e.g., to provide the electric force sufficient to electrospin nanofibers from a polymer liquid – e.g., polymer solution or melt). In some embodiments, the voltage supplied to the nozzle component is any suitable voltage, such as about 10 kV to about 50 kV. In more specific embodiments, the voltage supplied is about 20 kV to about 30 kV, e.g., about 25 kV.

[0034] In specific embodiments, a system provided herein comprises at least one manifold supply chamber containing therein a liquid polymer composition (i.e., a fluid stock for electrospinning). In specific embodiments, the liquid polymer composition is a composition comprising a polymer and a solvent (e.g., water, dimethylformamide (DMF), a hydrocarbon, or the like). In certain embodiments, the liquid polymer composition further comprises metal precursor (e.g., metal ions (e.g., from disassociated metal salt), metal salt, such as metal acetate, metal nitrate, metal halide, or the like), nanoparticles (e.g., metal, metalloid, metal oxide, ceramic, or the like nanoparticles), or the like. In other embodiments, the liquid polymer composition comprises a polymer melt (either alone or in combination with another agent). In some embodiments, the liquid polymer has any suitable viscosity, such as about 10 mPa.s to about 10,000 mPa.s (at 1/s, 20 ºC), or about 100 mPa.s to about 5000 mPa.s (at 1/s, 20 ºC), or about 1500 mPa.s (at 1/s, 20 ºC). In certain embodiments, liquid polymer is provided to the nozzle at any suitable flow rate. In specific embodiments, the flow rate is about 0.01 to about 0.5 mL/min. In more specific embodiments, the flow rate is about 0.05 to about 0.25 mL/min. In still more specific embodiments, the flow rate is about 0.075 mL/min to about 0.125 mL/min, e.g., about 0.1 mL/min. In some embodiments, at least one manifold supply chamber contains therein a fluid consisting essentially of gas (e.g., air). In certain embodiments, the nozzle velocity of the gas is any suitable velocity, e.g., about 0.1 m/s or more. In specific embodiments, the nozzle velocity of the gas is about 1 m/s to about 300 m/s. In certain embodiments, the pressure of the gas provided (e.g., to the manifold inlet or the nozzle) is any suitable pressure, such as about 2 psi to 20 psi. In specific embodiments, the pressure is about 5 psi to about 15 psi. In more specific embodiments, the pressure is about 8 to about 12 psi, e.g., about 10 psi.

[0035] Also provided herein are processes for electrospinning polymer (including polymer composite and polymer hybrid) nanofibers using any system described herein. In certain embodiments, provided herein is a process comprising (i) providing into at least one manifold inlet of a system described herein a liquid polymer composition; and (ii) providing into at least one other manifold inlet of a system described herein a high pressure gas (e.g., air). In some embodiments, also provided herein are processes for cleaning one or more needle apparatus described herein, the process comprising providing into at least one manifold inlet a compressed / high pressure gas (e.g., air). In some instances, this gas removes polymer build-up on the needle apparatus.

[0036] In some embodiments, provided herein is a process for producing nanofibers, the process comprising providing a nozzle component described herein, providing a liquid polymer (e.g., as described herein) to a first (or inner) conduit of said nozzle component, providing a pressurized and/or high speed gas to a second (or outer) conduit of said nozzle component, and providing a voltage to said nozzle component. Suitable nozzle systems include any nozzle system described herein. In further embodiments, a collector (e.g., grounded collector) is also provided, whereupon electrospun nanofiber is collected. In certain embodiments, the liquid polymer and gas are provided to the nozzle component via a manifold system described herein.

[0037] In certain embodiments, the nozzle component comprises:

a. a first (or inner) conduit, the first conduit being enclosed along the length of the conduit by a first wall having an interior and an exterior surface (e.g., the interior surface facing the first conduit and at least a portion of the exterior surface facing the second conduit), the first conduit having a first inlet (or supply) end and a first outlet end, and the first conduit having a first diameter defined by the diameter of the interior surface of the first walls; and

b. a second (or outer) conduit, the second conduit being enclosed along the length of the conduit by a second wall having an interior surface, the second conduit having a second inlet (or supply) end and a second outlet end, and the second conduit having a second diameter defined by the diameter of the interior surface of the second walls.

[0038] In some embodiments, the first and second conduit having a conduit overlap length. In some embodiments, the first conduit is positioned inside the second conduit, the exterior surface of the first wall and the interior surface of the second wall being separated by a conduit gap. In some embodiments, the first outlet end protruding beyond the second outlet end by a protrusion length. In certain embodiments, the second conduit has a second diameter (e.g., diameter of the interior surface of the second walls). In certain embodiments, nozzle components useful in such processes include those having any characteristic described herein, such as wherein (i) the ratio of the conduit overlap length-to-second diameter is about 10 or more (e.g., about 13 or more, or about 18 or more), (ii) the ratio of the average conduit gap-to-second diameter about 0.2 or less (e.g., about 0.1 or less, or about 0.05 or less), and/or (iii) the ratio of the protrusion length-to-second diameter is about 0.3 or less.

[0039] Any disclosure in this description of a specific value described herein includes a disclosure of a value "about" equal to that value (e.g., "1" includes a disclosure of "about 1"). Likewise, any disclosure of an approximate value in this description also includes disclosure of a value equal to that value (e.g., "about 1" includes a disclosure of "1").

BRIEF DESCRIPTION OF THE DRAWINGS

[0040] The novel features of the invention are set forth with particularity in the appended claims. A better understanding of the features and advantages of the present invention will be obtained by reference to the following detailed description that sets forth illustrative embodiments, in which the principles of the invention are utilized, and the accompanying drawings of which:

[0041] **FIG. 1** illustrates a two-needle electrospinning system provided herein.

[0042] **FIG. 2** illustrates a three-needle electrospinning system provided herein.

[0043] **FIG. 3** illustrates an alternate configuration of a two-needle electrospinning system provided herein.

[0044] **FIG. 4** illustrates a stacked bank electrospinning system provided herein.

[0045] **FIG. 5** illustrates exemplary polymer nanofibers prepared using a single needle apparatus (Panel A) and using needle apparatuses described herein with a liquid polymer composition through an inner needle and gas assistance through an outer needle (Panel B).

[0046] **FIG. 6** illustrates exemplary polymer composite nanofibers prepared using a single needle apparatus (Panel A) and using needle apparatuses described herein with a liquid polymer composition through an inner needle and gas assistance through an outer needle (Panel B).

[0047] **FIG. 7** illustrates a slightly offset coaxial needle apparatus provided herein.

[0048] **FIG. 8** illustrates exemplary electrospinning nozzle apparatuses provided herein, and cross-sections thereof.

[0049] **FIG. 9** illustrates an exemplary coaxial needle electrospinning apparatus provided herein.

DETAILED DESCRIPTION OF THE INVENTION

[0050] Provided herein are systems, apparatuses (e.g., nozzle apparatuses and components, such as needle apparatuses), and processes, such as for producing nanofibers.

[0051] In certain embodiments, provided herein are nozzle components (e.g., of an electrospinning system), such as for the production (e.g., mass production) of nanofibers. In some embodiments, provided herein is a stacked multi-nozzle system for the mass production of nanofibers. In some instances, the gas-assisted electrospinning (GAES) nozzle system has several nozzle components (e.g., coaxial needle apparatuses (e.g., two-needle apparatuses, three-needle apparatuses, four-needle apparatuses, or the like)), which are configured with a manifold system in a “stacked” format (e.g., as illustrated in an exemplary embodiments in **FIG. 4**).

[0052] In some embodiments, a liquid polymer composition (either pure polymer melt, or a combination of polymer and other agents, such as solvents, metal precursors, or the like) is supplied to the inner conduit (e.g., needle) of the stacked nozzles; and pressurized (e.g., compressed) or high velocity gas (e.g., air) is supplied to the outer conduit (e.g., needle). Also, in some instances, such systems can produce core/shell type nanofibers using this same configuration, supplying another polymer solution to the outer conduit (e.g., needle) instead of supplying gas. By adding a third conduit (e.g., needle) for compressed air around the second conduit, such systems provided herein can produce core/shell type nanofibers with GAES process. Furthermore, we can easily add more pieces for the various spinning process. In some instances, by supplying air to the inner conduit (e.g., needle) and liquid polymer to the outer conduit (e.g., needle), hollow fibers can be provided.

[0053] Further, if the nozzle components get clogged (e.g., by dried polymer or polymer/nanoparticles), they can be cleaned by applying compressed air to the polymer supply conduit (e.g., inner conduit (e.g., needle)), which offers a facile self-cleaning mechanism.

[0054] Electrospinning is a process for producing fine fibers with diameters ranging from micron scale to nano scale through the action of electrical forces. In some instances, the surface tension of polymer melt or solution is overcome by the electrical force applied to it, a charged jet is ejected from the surface. In certain instances, the jet initially extends in a straight line, then undergoes a whipping motion during the flight from nozzle to collector. In some instances, fibers are collected on a grounded mesh or plate in the form of a nonwoven web with high surface area. In general, fiber mats that prepared have a high surface area to mass ratio, and thus has great potential for filtration, biomedical, and sensing applications.

[0055] However, there is a shortcoming in electrospinning technology, which is a relative low production rate of quality nanofibers. Because of the low flow rate of polymer melt or solution the production rate is very low and does not scale profitably to mass production. Systems, apparatuses, and processes described herein overcome such shortcomings. In some instances, with the help of compressed gas (e.g., air argon, nitrogen, or any other suitable gas), the flow rate of the polymer compositions is much (e.g., 10 to 100 times) higher than that of an electrospinning system not using compressed gas (e.g., air). In certain embodiments, nanofibers provided using the systems, apparatuses, components, or processes described herein have any desired diameter, such as less than 2 micron, 50 nm to 1500 nm, 200 nm to 1000 nm, or the like.

[0056] **FIG. 1** illustrates a non-limiting exemplary system provided herein. In some instances, the (manifold) system **100** comprises a manifold housing **117**. In specific instances, the system or manifold **100** comprises (i) a first manifold inlet **101** in fluid contact with a first manifold supply chamber **102**, and (ii) a second manifold inlet **103** in fluid contact with a second manifold supply chamber **104**. In some embodiments, the system comprises a plurality of nozzle components (e.g., coaxial needle apparatuses) **105**. Panel 1B illustrates a nozzle component (e.g., needle apparatus) proved herein separate from the manifold of a system described herein. In specific instances, nozzle component (e.g., coaxial needle apparatuses) provided herein each comprise a first conduit (e.g., needle) **106** comprising a first supply end **107** and a first outlet end **108**, the first supply end being in fluid contact with the first manifold supply chamber **102**; and a second conduit (e.g., needle) **109** comprising a second supply end **110** and a second outlet end **111**, the second supply end being in fluid contact with the second manifold supply chamber **104**. In some instances, the first conduit supply end is fluidly connected to the first supply chamber via a first supply component **119** (as illustrated in FIG. 1, such supply chamber has two components 119 and 119a). In further or alternative embodiments, the second conduit supply end is fluidly connected to the second supply chamber via a second supply component **120**. In specific instances, the first conduit (e.g., needle) and second conduit (e.g., needle) are aligned or arranged along or around a common axis **112**. Panel 1C illustrates a cutout **116** of a portion of the nozzle component (e.g., needle apparatus), illustrating a common axis along and around which the first and second conduits (e.g., needles) may be aligned or arranged (the common axis may constitute the central longitudinal axis of either or both of the first and second conduits or needles). **115** illustrates a cross-sectional view of an exemplary bi-conduit nozzle component (e.g., two-needle coaxial needle apparatus). Generally, the first conduit (e.g., needle) **106** is positioned inside the second conduit (e.g., needle) **109** for at least a portion of the length of the first conduit (e.g., needle) **118** (l^1). In some embodiments, the first conduit comprises a first wall **121** (e.g., that encloses the conduit longitudinally) and the second conduit comprises a second wall **122** (e.g., that encloses the conduit longitudinally). In certain instances, the first conduit (e.g., needle) protrudes **106b** a certain distance **113** (l^2) beyond the second conduit outlet. In some instances, a voltage is supplied to the needle component **105** (e.g., voltage sufficient to overcome the surface tension of a liquid polymer composition – such as 5 kV to 100 kV, e.g., 8 kV to 40 kV, or 20 kV to 30 kV) to produce a jet **114**, which is collected on a collection surface (not shown) as a nanofiber. In some instances, a polymer composition (fluid stock) is optionally provided to one or more manifold inlet by any suitable device, e.g., by a syringe or a pump. Similarly, a (pressurized / compressed) gas is optionally provided to one or more manifold inlet by any suitable device, e.g., a gas canister, pump, or the like.

[0057] **FIG. 2** illustrates another non-limiting exemplary system provided herein. In some instances, the system comprises a manifold. In specific instances, the system or manifold comprises (i) a first manifold inlet in fluid contact with a first manifold supply chamber **201**, (ii) a second manifold inlet in fluid contact with a second manifold supply chamber **202**, and (iii) a third manifold inlet in fluid contact with a third manifold supply chamber **203**. In specific embodiments, the system is configured to receive a fluid polymer composition into any manifold supply chamber (e.g., as shown in **FIG. 2** – in the first manifold supply chamber **201** and the second manifold supply chamber **202**) via any suitable device, such as a pump (not shown) or syringe **205**. In further specific embodiments, the system is configured to receive a gas into any manifold supply chamber (e.g., as shown in **FIG. 2** – in the third manifold supply chamber **203**) via any suitable device **206** (e.g., via gas tank or pump). In some embodiments, the system comprises a plurality of nozzle components (e.g., coaxial needle apparatuses) **204**. In specific instances, nozzle components (e.g., coaxial needle apparatuses) provided herein each comprise a first conduit (e.g., needle) comprising a first supply end and a first outlet end, the first supply end being in fluid contact with the first manifold supply chamber; a second conduit (e.g., needle) comprising a second supply end and a second outlet end, the second supply end being in fluid contact with the second manifold supply chamber; and a third conduit (e.g., needle) comprising a third supply end and a third outlet end, the third supply end being in fluid contact with the third manifold supply chamber. In specific instances, the first conduit (e.g., needle) and second conduit (e.g., needle) are aligned along a common axis **112**. **207** illustrates a cross-sectional view of an exemplary tri-conduit nozzle component (e.g., three-needle coaxial needle apparatus), with the third conduit (e.g., needle) **208** surrounding the second conduit (e.g., needle) **209**, which in turn surrounds the first conduit (e.g., needle) **210**. Generally, the first conduit (e.g., needle) **210**

is positioned inside the second conduit (e.g., needle) **209** for at least a portion of the length of the first conduit (e.g., needle), and the second conduit (e.g., needle) **209** is positioned inside the third conduit (e.g., needle) **208** for at least a portion of the length of the second conduit (e.g., needle). In some instances, a voltage is supplied **211** to the nozzle component (e.g., needle apparatus) **204** (e.g., voltage sufficient to overcome the surface tension of a liquid polymer or polymer solution) to produce a jet, which is collected on a collection surface **212** as a nanofiber. Systems described herein optionally comprise a single manifold housing that contains the first, second, and any additional supply chambers (e.g., as illustrated in FIG. 1 and FIG. 2). In other embodiments, systems described herein comprise separate manifold systems, e.g., wherein a system comprises a first manifold housing a first supply chamber, with a first manifold inlet in fluid contact with a first manifold supply chamber and a second manifold housing a second supply chamber, with a second manifold inlet in fluid contact with a second manifold supply chamber.

[0058] **FIG. 3** illustrates a section of a non-limiting exemplary system provided herein. In some instances, the system comprises a manifold **100**. In specific instances, the manifold **100** comprises (i) a first manifold supply chamber **102**, and (ii) a second manifold supply chamber **104**. In some embodiments, the system comprises a plurality of multi-conduit nozzle components (e.g., coaxial needle apparatuses) **105**. In specific instances, multi-conduit nozzle components (e.g., coaxial needle apparatuses) provided herein each comprise a first conduit (e.g., needle) **106** comprising a first supply end and a first outlet end **108**, the first supply end being in fluid contact with the first manifold supply chamber **102**; and a second conduit (e.g., needle) **109** comprising a second supply end and a second outlet end **111**, the second supply end being in fluid contact with the second manifold supply chamber **104**. For illustrative purposes, a portion of the second conduit is removed **312** to provide display of the first conduit position inside the second conduit. Generally, the first conduit is positioned inside the second conduit. Typically, the first and second conduits are enclosed, with the exception of the supply and outlet ends. In specific instances, the first conduit (e.g., needle) and second conduit (e.g., needle) are aligned along a common axis **112**, such as illustrated in **FIG. 3** (or, e.g., wherein the axes of the conduits is within 0.5 mm, 0.25 mm, 0.1 mm or the like of one another). In some instances, the system is configured to allow a voltage to be supplied to the needle apparatus **105** (e.g., voltage sufficient to overcome the surface tension of a liquid polymer or polymer solution) to produce a jet, which is collected on a collection surface (not shown) as a nanofiber.

[0059] In some embodiments, the first conduit (e.g., needle) has any suitable diameter **309** (e.g., inner wall diameter ($\mathbf{d}^1$) and/or outer wall diameter ($d^{1'}$)), such as a diameter described herein. In certain embodiments, the second conduit (e.g., needle) has any suitable diameter **310** (e.g., inner diameter ($\mathbf{d}^2$)), such as a diameter described herein.

[0060] In certain embodiments, provided herein is a nozzle apparatus comprising a first conduit and a second conduit, the first conduit arranged inside the second conduit. In some embodiments, the nozzle apparatus comprises (i) a nozzle component comprising the first conduit and the second conduit, and (ii) an optional supply component (e.g., that is operably and fluidly connected to the nozzle component and a supply source, such as a manifold system described herein). In some embodiments, a nozzle apparatus provided herein comprises (i) a first conduit (e.g., needle) **106** comprising a portion that has substantially parallel (e.g., parallel, or within 15 degrees, within 10 degrees, or within 5 degrees of parallel) walls **303** and (ii) an optional first supply component **307** that has non-parallel walls **308** (e.g., substantially non-parallel walls, or greater than 15 degrees, greater than 10 degrees, or greater than 5 degree from parallel). Similarly, in certain embodiments, the nozzle apparatus comprises (i) a second conduit (e.g., needle) comprising a portion that has substantially parallel walls **302** (e.g., parallel – as shown, or within 15 degrees, within 10 degrees, or within 5 degrees of parallel), and (ii) an optional second supply component **304** that has non-parallel walls **301** (e.g., substantially non-parallel walls, or greater than 15 degrees, greater than 10 degrees, or greater than 5 degree from parallel – e.g., as illustrated by the angle **305**). In some embodiments, the walls of the outer conduit of the nozzle component (e.g., needle, such as the second needle **109** as illustrated in FIG. 3) of the nozzle apparatus are aligned (e.g., parallel – as shown, or within 15 degrees, within 10 degrees, or within 5 degrees of parallel) (e.g., and are aligned (e.g., parallel – as shown, or within 15 degrees, within 10 degrees, or within 5 degrees of parallel) with the walls of the inner conduit(s) (e.g., needle(s), such as the first needle **106**)) for at least a portion of the length of the nozzle (e.g., needle) **306** (**l^1**) apparatus. In certain embodiments, the length of **l^1** is long enough to provide high performance and/or highly uniform nanofibers. In some embodiments, the length of **l^1** is long enough to provide a system suitable for high throughput production of nanofibers. In some embodiments, the first or inner conduit extends beyond (or protrudes beyond) the end of the second or outer conduit **311** (**l^2**). In certain instances, the outer surface of the wall enclosing the first (inner) conduit and the inner surface of the wall enclosing the second (outer) conduit are set off by a certain distance **313**. In some embodiments, the average of this distance is the conduit gap (d^4).

[0061] In specific embodiments, the ratio of the length **l^1** to the diameter of the inner conduit (e.g., outer diameter of the inner conduit, such as a needle) (e.g., the first needle **106** in **FIG. 3** having a diameter **d^1**) is at least 20. In more specific embodiments, ratio is at least 25, at least 30, at least 40, at least 50, or the like. In further or additional specific embodiments, the ratio of **l^1** to the diameter of the outer conduit (e.g., needle) (e.g., the second conduit **109** in **FIG. 3** having a diameter **d^2**) is at least 10, at least 20, at least 25, at least 30, at least 40, at least 50, or the like.

[0062] **FIG. 8** illustrates exemplary electrospinning nozzle apparatuses **800** and **830** provided herein. Illustrated by both nozzle components **800** and **830** some embodiments, the nozzle apparatus comprises a nozzle component comprising a first conduit, the first conduit being enclosed along the length of the conduit by a first wall **801** and **831** having an interior and an exterior surface, and the first conduit having a first inlet (or supply) end **802** and **832** (e.g., fluidly connected to a first supply chamber and configured to receive a liquid polymer – such as a liquid polymer composition) and a first outlet end **803** and **833**. Generally, the first conduit has a first diameter **804** and **834** (e.g., the average diameter as measured to the inner surface of the wall enclosing the conduit (d^1) or the average diameter as measured to the outer surface of the wall enclosing the conduit ($d^{1'}$)). In further instances, the nozzle component comprising a second conduit, the second conduit being enclosed along the length of the conduit by a second wall **805** and **835** having an interior and an exterior surface, and the second conduit having a second inlet (or supply) end **806** and **836** (e.g., fluidly connected to a second supply chamber and configured to receive a gas – such as a high velocity or pressurized gas (e.g., air)) and a second outlet end **807** and **837**. In some instances, the second inlet (supply) end **806** and **836** are connected to a supply chamber (e.g., in a manifold described herein – e.g., comprising the second supply chamber and, optionally, the first supply chamber). In certain instances, the second inlet (supply) end **806** and **836** are connected to the second supply chamber via a supply component. **FIG. 8** illustrates an exemplary supply component comprising a connection supply component (e.g., tube) **813** and **843** that fluidly connects **814** and **844** the supply chamber (not shown) to an inlet supply component **815** and **845**, which is fluidly connected to the inlet end of the conduit. The figure illustrates such a configuration for the outer conduit, but such a configuration is also contemplated for the inner and any intermediate conduits as well. Generally, the first conduit has a first diameter **808** and **838** (e.g., the average diameter as measured to the inner surface of the wall enclosing the conduit (d^2)). The first and second conduits have any suitable shape. In some embodiments, the conduits are cylindrical (e.g., circular or elliptical), prismatic (e.g., a octagonal prism), conical (e.g., a truncated cone – e.g., as illustrated by the outer conduit **835**) (e.g., circular or elliptical), pyramidal (e.g., a truncated pyramid, such as a truncated octagonal pyramid), or the like. In specific embodiments, the conduits are cylindrical (e.g., wherein the conduits and walls enclosing said conduits form needles). In some instances, the walls of a conduit are parallel, or within about 1 or 2 degrees of parallel (e.g., wherein the conduit forms a cylinder or prism). For example, the nozzle apparatus **800** comprise a first and second conduit having parallel walls **801** and **805** (e.g., parallel to the wall on the opposite side of the conduit, e.g., as illustrated by **801a** / **801b** and **805a** / **805b**, or to a central longitudinal axis **809**). In other embodiments, the walls of a conduit are not parallel (e.g., wherein the diameter is wider at the inlet end than the outlet end, such as when the conduit forms a cone (e.g., truncated cone) or pyramid (e.g., truncated pyramid)). For example, the nozzle apparatus **830** comprise a first conduit having parallel walls **831** (e.g., parallel to the wall on the opposite side of the conduit, e.g., as illustrated by **831a / 831b**, or to a central longitudinal axis **839**) and a second conduit having non-parallel walls **835** (e.g., not parallel or angled to the wall on the opposite side of the conduit, e.g., as illustrated by **835a** / **835b**, or to a central longitudinal axis **839**). In certain embodiments, the walls of a conduit are within about 15 degrees of parallel (e.g., as measured against the central longitudinal axis, or half of the angle between opposite sides of the wall), or within about 10 degrees of parallel. In specific embodiments, the walls of a conduit are within about 5 degrees of parallel (e.g., within about 3 degrees or 2 degrees of parallel). In some instances, conical or pyramidal conduits are utilized. In such embodiments, the diameters for conduits not having parallel walls refer to the average width or diameter of said conduit. In certain embodiments, the angle of the cone or pyramid is about 15 degrees or less (e.g., the average angle of the conduit sides/walls as measured against a central longitudinal axis or against the conduit side/wall opposite), or about 10 degrees or less. In specific embodiments, the angle of the cone or pyramid is about 5 degrees or less (e.g., about 3 degrees or less). Generally, the first conduit **801** and **831** and second conduit **805** and **835** having a conduit overlap length **810** and **840** (l^1), wherein the first conduit is positioned inside the second conduit (for at least a portion of the length of the first and/or second conduit).

In some instances, the exterior surface of the first wall and the interior surface of the second wall are separated by a conduit gap **811** and **841** (d^4). In certain instances, the first outlet end protrudes beyond the second outlet end by a protrusion length **812** and **842** (l^2). In certain instances, the ratio of the conduit overlap length-to-second diameter is any suitable amount, such as an amount described herein, e.g., about 10 or more (e.g., about 13 or more, or about 18 or more). In further or alternative instances, the ratio of the average conduit gap-to-second diameter is any suitable amount, such as an amount described herein, e.g., about 0.2 or less (e.g., about 0.1 or less, or about 0.05 or less). In further or alternative instances, the ratio of the protrusion length-to-second diameter is any suitable amount, such as an amount described herein, e.g., about 0.3 or less.

[0063] **FIG. 8** also illustrates cross-sections of various nozzle components provided herein **850**, **860** and **870**. Each comprises a first conduit **851**, **861** and **871** and second conduit **854**, **864**, and **874**. As discussed herein, in some instances, the first conduit is enclosed along the length of the conduit by a first wall **852, 862** and **872** having an interior and an exterior surface and the second conduit is enclosed along the length of the conduit by a second wall **855, 865** and **875** having an interior and an exterior surface. Generally, the first conduit has any suitable first diameter **853, 863** and **864** (d^1) and any suitable second diameter **856**, **866**, and **876** (d^2). The cross-dimensional shape of the conduit is any suitable shape, and is optionally different at different points along the conduit. In some instances, the cross-sectional shape of the conduit is circular **851 / 854** and **871 / 874**, elliptical, polygonal **861 / 864**, or the like.

[0064] In some instances, coaxially configured nozzles provided herein and coaxial gas assisted electrospinning provided herein comprises providing a first conduit or fluid stock along a first longitudinal axis, and providing a second conduit or gas (e.g., pressurized or high velocity gas) around a second longitudinal axis (e.g., and electrospinning the fluid stock in a process thereof). In specific embodiments, the first and second longitudinal axes are the same. In other embodiments, the first and second longitudinal axes are different. In certain embodiments, the first and second longitudinal axes are within 500 microns, within 100 microns, within 50 microns, or the like of each other. In some embodiments, the first and second longitudinal axes are aligned within 15 degrees, within 10 degrees, within 5 degrees, within 3 degrees, within 1 degree, or the like of each other. For example, **FIG. 8** illustrates a cross section of a nozzle component **870** having an inner conduit **871** that is off-center (or does not share a central longitudinal axis) with an outer conduit **874**. In some instances, the conduit gap (e.g., measurement between the outer surface of the inner wall and inner surface of the outer wall) is optionally averaged – e.g., determined by halving the difference between the diameter of the inner surface of the outer wall **876** and the diameter of the outer surface of the inner wall **872**. In some instances, the smallest distance between the inner surface of the outer wall **876** and the diameter of the outer surface of the inner wall **872** is at least 10% (e.g., at least 25%, at least 50%, or any suitable percentage) of the largest distance between the inner surface of the outer wall **876** and the diameter of the outer surface of the inner wall **872**.

[0065] For further illustration, **FIG. 9** provides a non-limiting three dimensional illustration (with illustrative cut outs **901** and **902**) of a nozzle component (e.g., coaxial needle nozzle component) **900**

provided herein. In specific instances, the needle apparatus (or nozzle component) comprises a first (inner) needle **904** comprising a first (inner) conduit **904** enclosed by a first wall **905**, the first wall comprising a first wall inner surface **906**, a first wall outer surface **907**, a first (inner) outlet end **908**, a first (inner) inlet (supply) end (e.g., configured to be in fluid contact with a first supply chamber, and/or to receive a liquid polymer), a first inner diameter **918** (d^1) and a first outer diameter **919** ($d^{1'}$). In further instances, the needle apparatus (or nozzle component) comprises a second (outer) needle **909** comprising a second (outer) conduit **910** enclosed by a second wall **911**, the first wall comprising a second wall inner surface **912**, a (optional) second wall outer surface **913**, a second (outer) outlet end **914**, a second (outer) inlet (supply) end (e.g., configured to be in fluid contact with a second supply chamber, and/or to receive a liquid polymer or high velocity or high pressure gas (e.g., air)) a second inner diameter **920** (d^2) and (optionally) a second outer diameter.

[0066] Generally, the first (inner) needle **903** is positioned inside the second needle **909** for at least a portion of the length of the first needle **915** (l^1)**.** In certain instances, the first needle **903** (outlet end **908**) protrudes a certain distance **916** (l^2) beyond the second needle **909** (outlet end **914**). As discussed for other embodiments described herein, in some instances, the exterior surface of the first (inner) wall **907** and the interior surface of the second (outer) wall **912** are separated by a conduit gap **917** (d^4). In certain instances, the ratio of the conduit overlap length **915** -to- second inner diameter **920** is any suitable amount, such as an amount described herein, e.g., about 10 or more (e.g., about 13 or more, or about 18 or more). In further or alternative instances, the ratio of the average conduit gap **917** -to- second inner diameter **920** is any suitable amount, such as an amount described herein, e.g., about 0.2 or less (e.g., about 0.1 or less, or about 0.05 or less). In further or alternative instances, the ratio of the protrusion length **916** -to- second inner diameter **920** is any suitable amount, such as an amount described herein, e.g., about 0.3 or less.

[0067] In some embodiments, a system provided herein comprises an apparatus comprising a plurality of rows of nozzle components (e.g., coaxial needle apparatuses) (nozzles in the rows and columns may be aligned or offset – both are aligned in the examples illustrated in **FIG. 4**). **FIG. 4** illustrates two examples of such systems. In some instances, a (e.g., single) first manifold supply chamber (e.g., having a single inlet **101** – e.g., as illustrated in the upper panel of **FIG. 4**) optionally feeds the first conduits (e.g., needles) of each row of nozzles (e.g., needle apparatuses). In certain instances, a (e.g., single) second manifold supply chamber (e.g., having a single inlet **103** – e.g., as illustrated in the upper panel of **FIG. 4**) optionally feeds the second conduits (e.g., needles) of each row of nozzles (e.g., needle apparatuses). In some instances, e.g., wherein multiple rows and of nozzles (e.g., needle apparatuses) are utilized, a plurality of first manifold supply chambers, a plurality of second manifold supply chambers, or the like are optionally utilized. In addition, in some instances, multiple first inlets **101** may feed the first manifold supply chamber(s), and/or multiple second inlets **103** may feed the second manifold supply chamber(s) (e.g., as illustrated in the lower panel of **FIG. 4**).

[0068] In certain embodiments, conduits (e.g., needles) of a nozzle component (e.g., coaxial needle apparatus) provided herein are aligned around a common (longitudinal) axis. In some embodiments, the (longitudinal) axes of the conduits (e.g., needles) of a nozzle component (e.g., coaxial needle apparatus) provided herein are slightly offset. In specific instances, such offset is small enough that high performance and throughput characteristics of the system are retained. **FIG. 7** illustrates that the central logitindual axis of an inner conduit (e.g., needle) **702** may be slightly offset from the central longitudinal axis of an outer conduit (e.g., needle) **701**, such as by an amount **703** ($\mathbf{d^3}$). In specific embodiments, axes of each of the conduits (e.g., needles) of a nozzle component (e.g., coaxial needle) are aligned within any suitable distance, e.g., within about 0.5 mm, within about 200 microns, or within 100 microns of one another (e.g., 100 microns $\geq \mathbf{d^3}$). In specific embodiments, axes of each of the conduits (e.g., needles) of a nozzle component (e.g., coaxial needle) are aligned within 50 microns of one another. In specific embodiments, axes of each of the conduits (e.g., needles) of a nozzle component (e.g., coaxial needle) are aligned within 20 microns of one another. In some embodiments, the offset is less than 0.1 of the diameter of the inner conduit (e.g., needle) (e.g., $\mathbf{d^3/d^1} \leq 0.1$). In some embodiments, the offset is less than 0.05, less than 0.03, or less than 0.01 of the diameter of the inner conduit (e.g., needle).

[0069] Any suitable polymer is optionally utilized in systems, apparatuses, or processed described herein e.g., any electrospinnable polymer (e.g., electrospinnable as a melt or in solution). Exemplary polymers suitable for use in systems, apparatuses, or processed described herein include but are not limited to polyvinyl alcohol ("PVA"), polyvinyl acetate ("PVAc"), polyethylene oxide ("PEO"), polyvinyl ether, polyvinyl pyrrolidone, polyglycolic acid, polyvinylidene difluoride (PVDF), hydroxyethylcellulose ("HEC"), ethylcellulose, cellulose ethers, polyacrylic acid, polyisocyanate, and the like. In some embodiments, the polymer is isolated from biological material. In some embodiments, the polymer is starch, chitosan, xanthan, agar, guar gum, and the like. In other instances, other polymers, such as polyacrylonitrile ("PAN") are optionally utilized (e.g., with DMF as a solvent). In other instances, a polyacrylate (e.g., polyalkacrylate, polyacrylic acid, polyalkylalkacrylate, or the like) is optionally utilized.

[0070] Any suitable polymer concentrations may be utilized in the systems, apparatuses, components, or processes described herein. In some instances, a liquid polymer (e.g., polymer composition) provided herein is neat polymer (meaning about 100% polymer). In other instances, a polymer composition comprises solvent and/or an additional component (such as metal precursor, metal ion, nanoparticle, or the like). In some instances, the polymer concentration in a polymer composition provided herein is, e.g., 5-50 wt. %. In specific embodiments, the polymer concentration is below 20 wt %. In more specific embodiments, the polymer concentration is 2-20 wt %. In still more specific embodiments, the polymer concentration is 8-12 wt %. Specific polymers, metal precursors, nanoparticles, and process parameters set forth in U.S. Patent Application Publication No. 2011/0148005, U.S. Patent Application Publication No. 2007/0259655, U.S. Patent No. 7,083,854, International Patent Application Publication No. WO 2011/100743, International Patent Application Publication No. WO 2013/0033367, and International Patent Application No. PCT/US13/28132 are contemplated herein, e.g., for use with the system described herein, and all of which are incorporated herein for such disclosure.

[0071] In some embodiments, compressed gas is provided to a system here at any suitable pressure. In specific instances, the gas pressure is about 0.1 to 10 kgf/cm^2. In more specific embodiments, the gas is provided at a pressure of about 0.5~3kgf/cm^2.

[0072] Any suitable distance may be utilized between the nozzle and collection plate. In some instances, the distance is about 3-100 cm. In more specific instances, the distance is about 5-50 cm, or more specifically about 10~25cm.

[0073] In some embodiments, the flow rate of the fluid stock (e.g., to each needle apparatus) is about 0.05 mL/min to 3 mL/min, or more specifically about 0.1~0.5.ml/min.

[0074] In various embodiments, the supply components, manifold components, and nozzle components comprise any suitable material. In some embodiments, such materials are resistant to corrosion, such as plastics (e.g., polyethylene, polypropylene, etc.) or inert or semi-inert metals. In some embodiments, nozzle components (e.g., the conduit walls) provided herein comprise stainless steel, brass, bronze, or the like. In some embodiments, nozzle components (e.g., the conduit walls) provided herein comprise plastic (e.g., polyethylene), stainless steel, brass, bronze, or the like.

[0075] In some embodiments, the multi-nozzle system allows for high throughput nanofiber processing. In certain embodiments, the multi-nozzle system also provides for the preparation of high performance nanofibers – e.g., nanofibers having uniform structures and components. In certain embodiments, such nanofibers allow for the production of nanofibers that have narrow, uniform diameters. For example, in some instances, the standard deviation of nanofibers provided, or prepared according to systems and processes described, herein is less than 100% of the average diameter, less than 50% of the average diameter, less than 25% of the average diameter, or the like.

EXAMPLES

Example 1 – Polymer Nanofibers

[0076] Polyvinyl alcohol (PVA) (M_w 78,000) is charged in DI water with concentration of 8~12 wt%. The prepared polymer composition is pumped into the inner channel of spinneret and compressed air gas is provided through the outer channel with the pressure of 0.5~3kgf/cm^2. The distance between the nozzle and collection plate is kept to 10~25cm, and the flow rate of 0.1~0.5.ml/min is maintained. A charge of +20 to +30 kV is maintained at the needle. **FIG. 5** (Panel A) illustrates an SEM of PVA nanofibers prepared without gas assistance, and (Panel B) illustrates an SEM of PVA nanofibers prepared with gas assistance. Nanofibers prepared with gas assistance showed significantly fewer bead structures in the nanofibers, as well as much higher production rates.

Example 2 – Polymer Composite/Hybrid Nanofibers

[0077] Polyvinyl alcohol (PVA) (M_w 78,000) is provided and nanoparticles with the size of 20~30 nm are supplied. PVA is dissolved in DI water with concentration of 8~12wt%. And nanoparticles are added in the PVA solution to prepare PVA/NP composition. The weight ratio of PVA to nanoparticles is 0.5~5, and to prevent the aggregation of nanoparticles the composition is sonicated for 3~5hrs.

[0078] The prepared polymer composition is pumped into the inner channel of spinneret and compressed air gas is provided through the outer channel with the pressure of 0.5~3kgf/cm^2. The distance between the nozzle and collection plate is kept to 10~25cm, and the flow rate of 0.1~0.5.ml/min is maintained. A charge of +20 to +30 kV is maintained at the needle. **FIG. 6** (Panel A) illustrates an SEM of PVA nanofibers prepared without gas assistance, and (Panel B) illustrates an SEM of PVA nanofibers prepared with gas assistance.

Example 3 – Nozzle Configuration

[0079] Polyvinyl alcohol (PVA) is provided and metal precursor are supplied. PVA is dissolved in DI water with concentration of 8~12wt%. And metal precursor is added in the PVA solution to prepare PVA/precursor aqueous composition. The weight ratio of PVA to precursor is about 2:3.

[0080] The prepared polymer composition is pumped into the inner channel of the nozzle at a flow rate of about 0.1 mL/min (e.g., about 0.075 to about 0.12 mL/min) and compressed air gas is provided through the outer channel with the pressure of about 10 psi (e.g., about 8 psi to about 12 psi). The distance between the nozzle and collection plate is kept to 20~30 cm (e.g., about 25 cm). A charge of +20 to +30 kV (e.g., about +25 kV) is maintained at the needle.

[0081] A manifold system comprising a plurality of nozzles described was utilized to prepare polymer composite nanofibers. Various nozzle configurations were utilized, such as set forth in Table 1. The term d1' refers to the diameter (in mm) of the outer walls of the first (inner) conduit; d2 refers to the diameter (in mm) of the second (outer) conduit; d4 refers to the conduit gap (in mm) (the average distance between the outer surface of the wall enclosing the first (inner) conduit and the inner surface of the wall enclosing the second (outer) conduit); l1 refers to the conduit overlap length (in mm) (the length over which the first conduit runs within the second conduit); and l2 refers to the protrusion length (in mm) of the first inner conduit (e.g., the distance that the first (inner conduit) outlet extends beyond the second (outer conduit) outlet). The spinnability is measured qualitatively, with 1 being extremely poor electrospinnability (nanofiber formation) and 5 being extremely good electrospinnability.

Table 1: Nozzle Parameters

	d1'	d2	d4	l1	l2	d4/d2	l1/d2	l2/d2	Spinnability
1	0.90	1.4	0.24	30	0.27	0.17	22	0.20	4
2	1.27	1.6	0.17	5	0.77	0.10	3.1	0.48	1
3	1.27	1.6	0.17	5	0.32	0.10	3.1	0.20	2
4	1.27	1.6	0.17	15	0.37	0.10	9.4	0.23	2
5	1.27	1.6	0.17	30	0.4	0.10	18.8	0.25	4
6	1.47	1.6	0.06	30	0.48	0.04	18.8	0.30	4
7	1.47	1.6	0.06	30	0.61	0.04	18.8	0.38	4
8	1.47	1.6	0.06	30	0.44	0.04	18.8	0.28	5

9	1.47	1.6	0.06	30	1.2	0.04	18.8	0.75	1
10	1.47	1.8	0.165	30	0.4	0.09	16.6	0.22	3
11	1.65	2.2	0.25	30	0.33	0.12	13.9	0.15	4

[0082] Table 1 illustrates that superior electrospinnability is achieved at lower values of d4/d2 (e.g., compare 5 and 8), at higher values of l1/d2 (e.g., compare 2 and 3, 4 and 5), and at lower values of l2/d2 (e.g., compare 8 and 9).

CLAIMS

What is Claimed is:

1. A system for producing nanofibers, the system comprising
   a. one or more manifold comprising (i) a first manifold inlet in fluid contact with a first manifold supply chamber, and (ii) a second manifold inlet in fluid contact with a second manifold supply chamber;
   b. a plurality of nozzle components (e.g., coaxial needle apparatuses), each comprising:
      i. a first conduit (e.g., needle) comprising a first supply end and a first outlet end, the first supply end being in fluid contact with the first manifold supply chamber; and
      ii. a second conduit (e.g., needle) comprising a second supply end and a second outlet end, the second supply end being in fluid contact with the second manifold supply manifold,

      the first conduit (e.g., needle) being positioned inside the second conduit (e.g., needle) for at least a portion of the length of the first conduit (e.g., needle).

2. The system of claim 1, wherein
   a. the one or more manifold further comprises a third inlet in fluid contact with a third supply chamber; and
   b. each of the nozzle components (e.g., coaxial needle apparatuses) further comprises a third conduit (e.g., needle) comprising a third supply end and a third outlet end, the third supply end being in fluid contact with the third manifold supply chamber,

   the first conduit (e.g., needle) being positioned inside the second conduit (e.g., needle) for at least a portion of the length of the first conduit (e.g., needle), and the second conduit (e.g., needle) being positioned inside the third conduit (e.g., needle) for at least a portion of the length of the second conduit (e.g., needle).

3. The system of any one of the preceding claims, further comprising a stock reservoir (e.g., a syringe) in fluid connection with at least one manifold inlet.

4. The system of claim 3, further comprising a fluid stock pump, the fluid stock pump configured to pump fluid from the stock reservoir through the at least one manifold inlet and into the connected manifold supply chamber.

5. The system of any one of the preceding claims configured to provide pressurized or high velocity gas (e.g., air) to at least one manifold inlet.

6. The system of any one of the preceding claims, wherein the system comprises (a) an air pump connected to at least one manifold inlet; and/or (b) a high-pressure or high-velocity gas (e.g., air) reservoir connected to at least one manifold inlet.

7. The system of any one of the preceding claims, wherein all conduits (e.g., needles) of each of the plurality of nozzle components (e.g., coaxial needle apparatuses) are aligned longitudinally within 5 degrees of a common axis.

8. The system of any one of the preceding claims, wherein the first conduit (e.g., needle) has a smaller average diameter and a greater length than the second conduit (e.g., needle).

9. The system of any one of the preceding claims, wherein the second conduit (e.g., needle) has a smaller average diameter and a greater length than the third conduit (e.g., needle).

10. The system of any one of the preceding claims, wherein each of the plurality of nozzle components (e.g., coaxial needle apparatuses) has a terminal end and wherein the outlets of each of the conduits (e.g., needles) within the nozzle components (e.g., coaxial needle apparatuses) are configured at the terminal end of the respective nozzle component (e.g., coaxial needle apparatus), and terminate within 100 micron of one another.

11. The system of any one of the preceding claims, wherein the first conduit (e.g., needle) has a first wall and the second conduit (e.g., needle) has a second wall, at least a portion of the second wall being within 10 degrees (e.g., within 5 degrees or within 3 degrees) of parallel of the first wall.

12. The system of claim 11, wherein the first conduit (e.g., needle) has a first diameter and the portion of the second wall being within 10 degrees (e.g., within 5 degrees or within 3 degrees) of parallel with the first wall is at least twenty times the first diameter.

13. The system of any one of the preceding claims, further comprising a heater.

14. The system of claim 13, wherein the heater is configured to heat one or more supply manifold, one or more nozzle components (e.g., coaxial needle apparatus), or a combination thereof.

15. The system of any one of the preceding claims, further comprising a nanofiber collection surface (e.g., a grounded surface) in operable proximity to the terminal ends of the nozzle components (e.g., coaxial needle apparatuses).

16. The system of claim 15, wherein the nanofiber collection surface is a continuous conveyor collector.

17. The system of any one of the preceding claims, further comprising a furnace for thermally treating collected nanofibers.

18. The system of any one of the preceding claims, wherein at least one manifold supply chamber contains therein a liquid polymer composition.

19. The system of claim 18, wherein the liquid polymer composition is (i) a composition comprising a melted polymer, or (ii) an aqueous composition comprising a polymer.

20. The system of any one of the preceding claims, wherein at least one manifold supply chamber contains therein a fluid consisting essentially of gas (e.g., air).

21. A nozzle component of any one of claims 1-20.

22. An electrospinning nozzle component comprising:

    a. a first conduit, the first conduit being enclosed along the length of the conduit by a first wall having an interior and an exterior surface, the first conduit having a first inlet end and a first outlet end, and the first conduit having a first diameter; and
    b. a second conduit, the second conduit being enclosed along the length of the conduit by a second wall having an interior surface, the second conduit having a second inlet end and a second outlet end, and the second conduit having a second diameter;

    the first and second conduit having a conduit overlap length, wherein the first conduit is positioned inside the second conduit, the exterior surface of the first wall and the interior surface of the second wall being separated by a conduit gap, the first outlet end protruding beyond the second outlet end by a protrusion length, and wherein:

    i. the ratio of the conduit overlap length-to-second diameter is about 10 or more (e.g., about 13 or more, or about 18 or more), and/or
    ii. the ratio of the average conduit gap-to-second diameter about 0.2 or less (e.g., about 0.1 or less, or about 0.05 or less), and/or
    iii. the ratio of the protrusion length-to-second diameter is about 0.3 or less.

23. The nozzle of either one of claims 21 or 22, wherein the first conduit is configured to receive liquid polymer.

24. The nozzle of claim 23, wherein the first conduit is configured to receive a liquid polymer at a rate of about 0.05 mL/min to about 3 mL/min.

25. The nozzle of any one of claims 21-24, wherein the second conduit is configured to receive a gas (e.g., a pressurized gas).

26. The nozzle of claim 25, wherein the second conduit is configured to receive a gas having a pressure of about 15 to about 30 psi, e.g., about 25 psi.

27. The nozzle of any one of claims 21-26, wherein the ratio of the conduit overlap length-to-second diameter is about 13 or more (e.g., about 18 or more).

28. The nozzle of any one of claims 21-27, wherein the ratio of the average conduit gap-to-second diameter about 0.1 or less (e.g., or about 0.05 or less).

29. The nozzle of any one of claims 21-28, wherein the ratio of the conduit overlap length-to-second diameter is about 18 or more, the ratio of the average conduit gap-to-second diameter about 0.05 or less, and the ratio of the protrusion length-to-second diameter is about 0.3 or less.

30. The nozzle of any one of claims 21-29, wherein the first and second conduits are cylindrical.

31. The nozzle of any one of claims 21-29, wherein the first conduit and the first wall, taken together, form a first needle, and the second conduit and the second wall, taken together, form a second needle.

32. The nozzle of any one of claims 21-31, wherein the first diameter being about 0.05 mm to about 3 mm.

33. The nozzle of any one of claims 21-32, wherein the second diameter is about 0.1 mm to about 5 mm.

34. The nozzle of any one of claims 21-33, wherein the conduit gap is on average 0.5 mm or less.

35. The nozzle of any one of claims 21-34, wherein the first and second walls comprise stainless steel.

36. The nozzle of any one of claims 21-35, further comprising a third conduit, the third conduit being enclosed along the length of the conduit by a third wall having an interior and exterior surface, and having a third inlet end and a third outlet end.

37. The nozzle of claim 36, wherein inside the first conduit, the exterior surface of the third wall and the interior surface of the first wall being separated by a second conduit gap (e.g., on average 0.5 mm or less).

38. The nozzle of either one of claims 36 or 37, wherein the third conduit is configured to receive liquid polymer.

39. The nozzle of any one of claims 21-38, wherein the nozzle is configured to receive a voltage (e.g., 10 kV to about 50 kV).

40. A process for cleaning a system of any one of claims 1-20 comprising providing into at least one manifold inlet a high pressure gas (e.g., air).

41. A process for mass production of nanofibers, the process comprising (i) providing into at least one manifold inlet of a system described in any one of claims 1-20 a liquid polymer composition; and (ii) providing into at least one other manifold inlet of the system a gas (e.g., pressurized or pumped air).

42. A process for cleaning a nozzle of any one of claims 21-39 comprising providing into at least one conduit inlet (e.g., the first inlet) a high pressure gas (e.g., air).

43. A process for mass production of nanofibers, the process comprising (i) providing into at least one conduit inlet of a nozzle described in any one of claims 21-39 a liquid polymer composition; (ii) providing into at least one other conduit inlet of the nozzle a gas (e.g., pressurized or pumped air); and (iii) applying a voltage to the nozzle.

44. The process of claim 43, wherein the liquid polymer composition is provided to the first inlet and the gas is provided to the second inlet.

45. The process of either one of claims 43 or 44, wherein the liquid polymer is provided at a rate of about 0.05 mL/min to about 3 mL/min.

46. The process of any one of claims 43-45, wherein the gas is provided at a pressure of about 15 psi to about 30 psi (e.g., about 25 psi).

47. A system of claim 1, wherein the plurality of nozzles components comprise a plurality of nozzles of any one of claims 21-39.

48. The system of claim 47, wherein a ratio of the distance between adjacent nozzles-to-second diameter is about 1 to about 5.

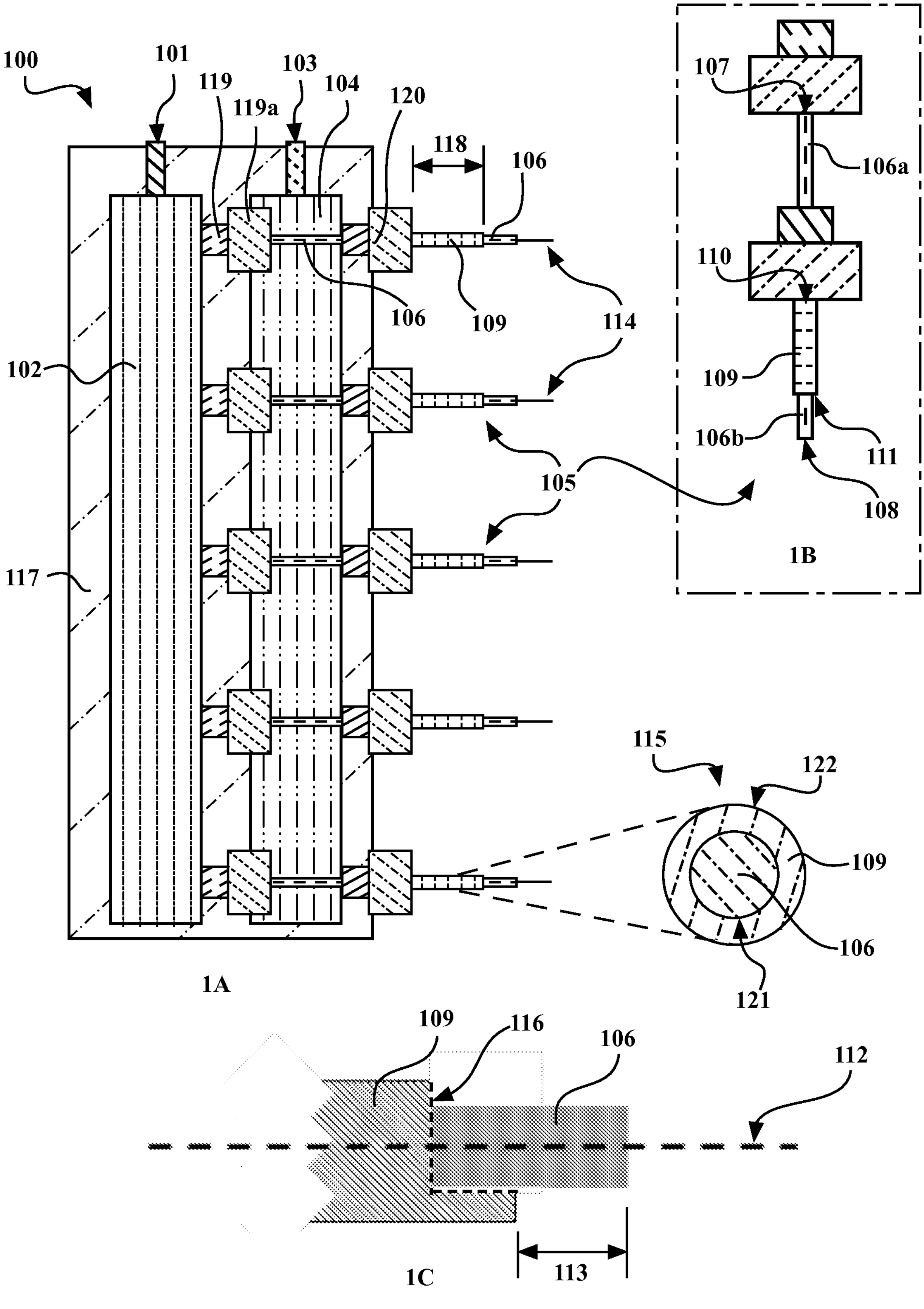
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FIG. 1

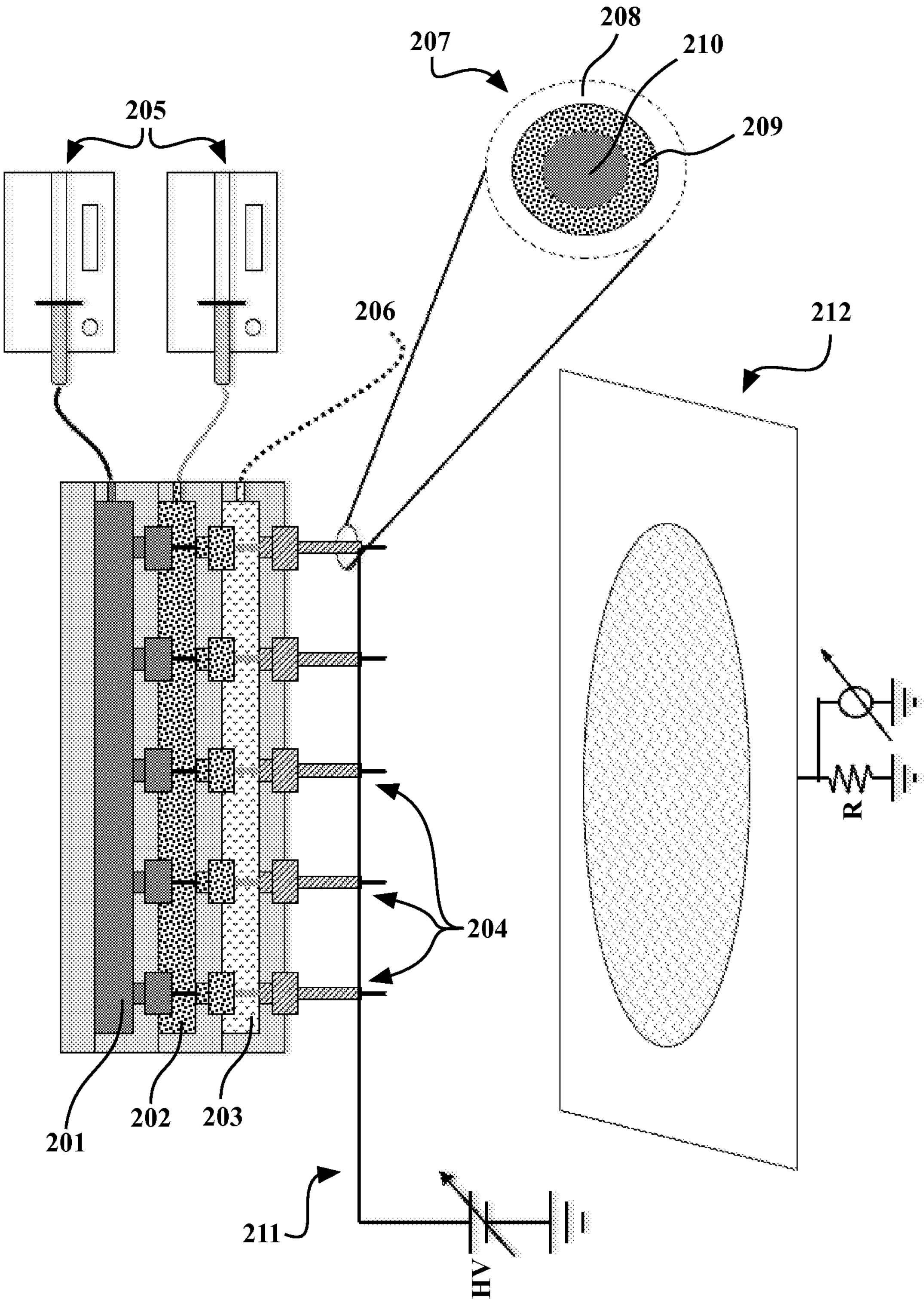

FIG. 2

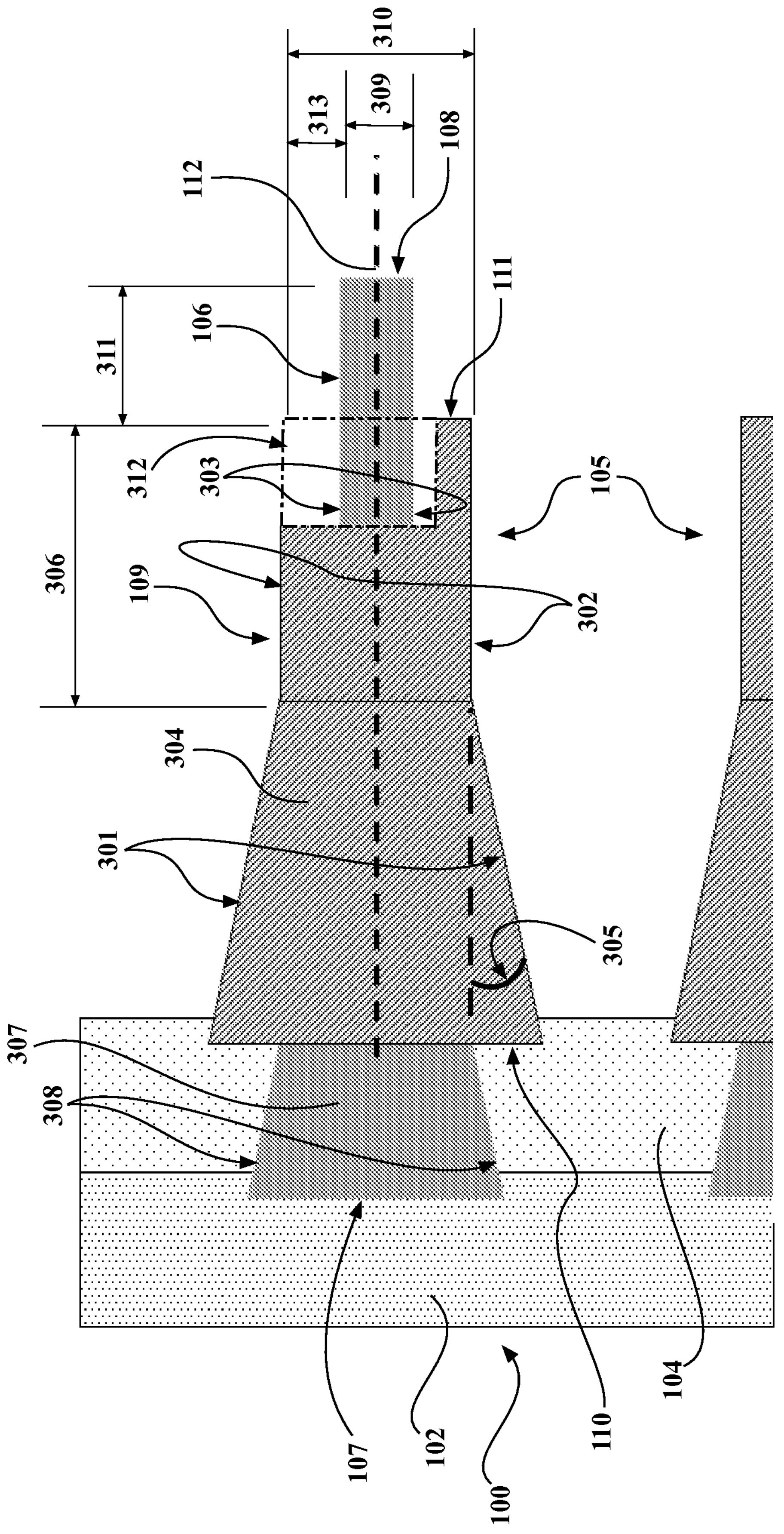
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FIG. 3

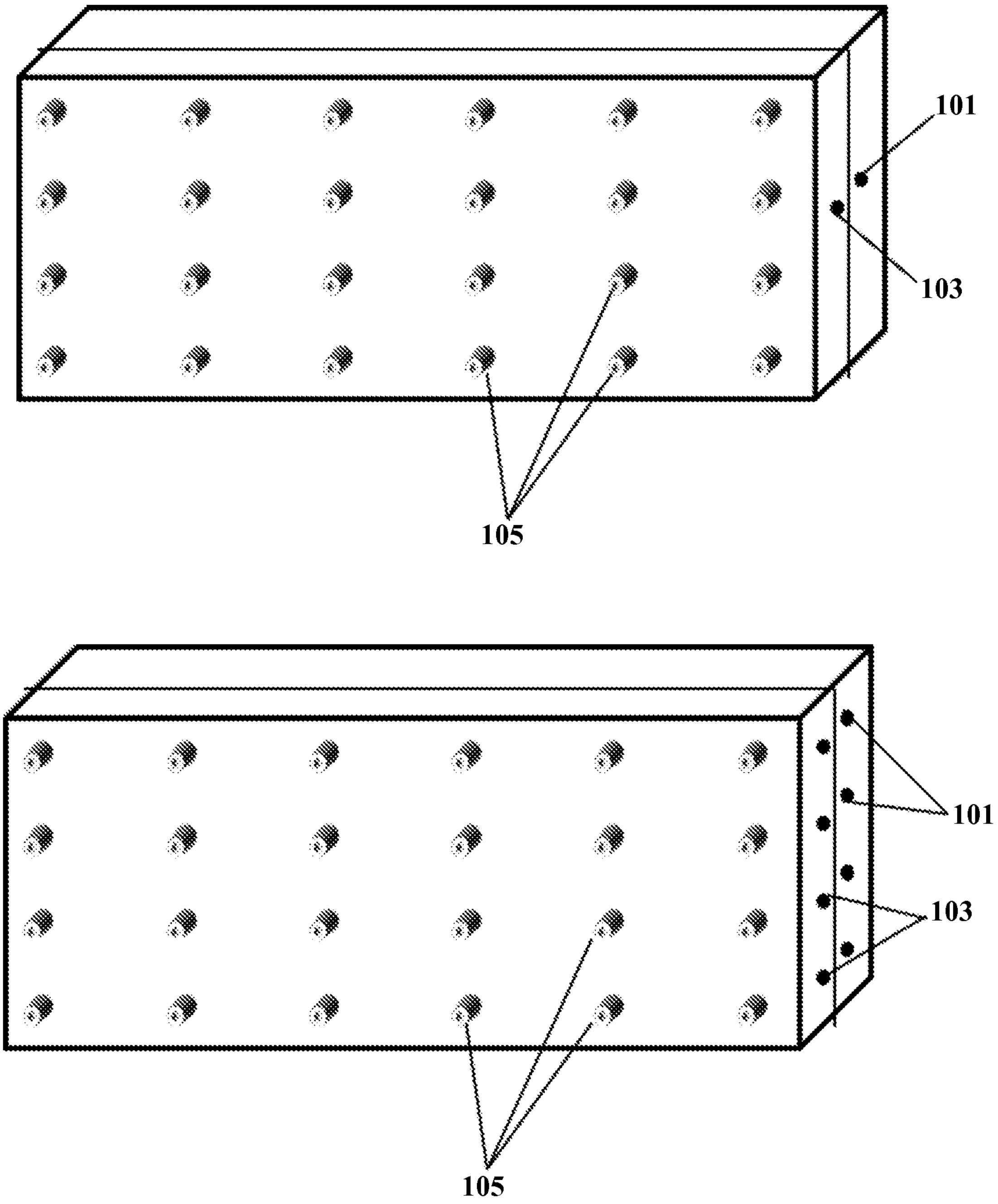

FIG. 4

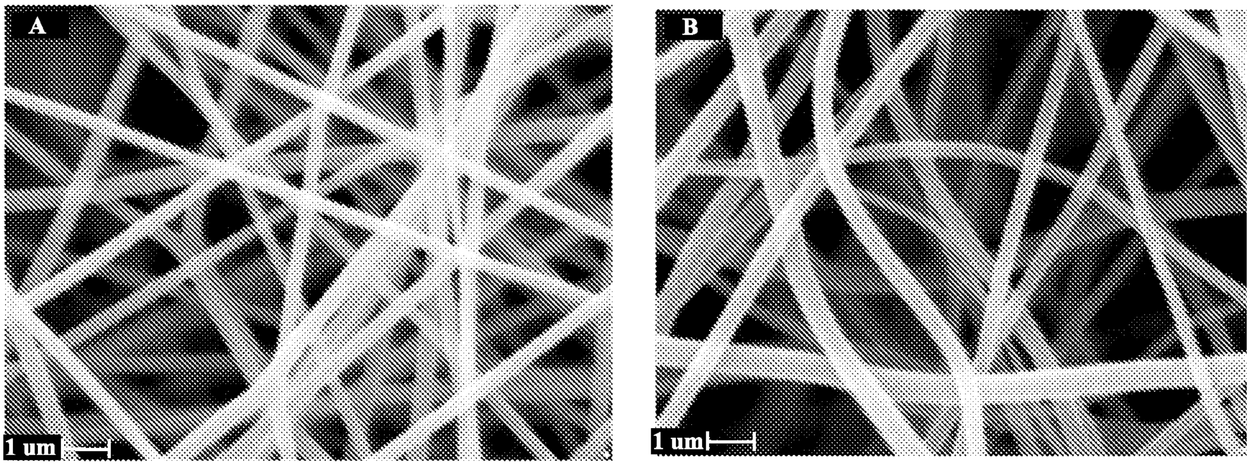

FIG. 5

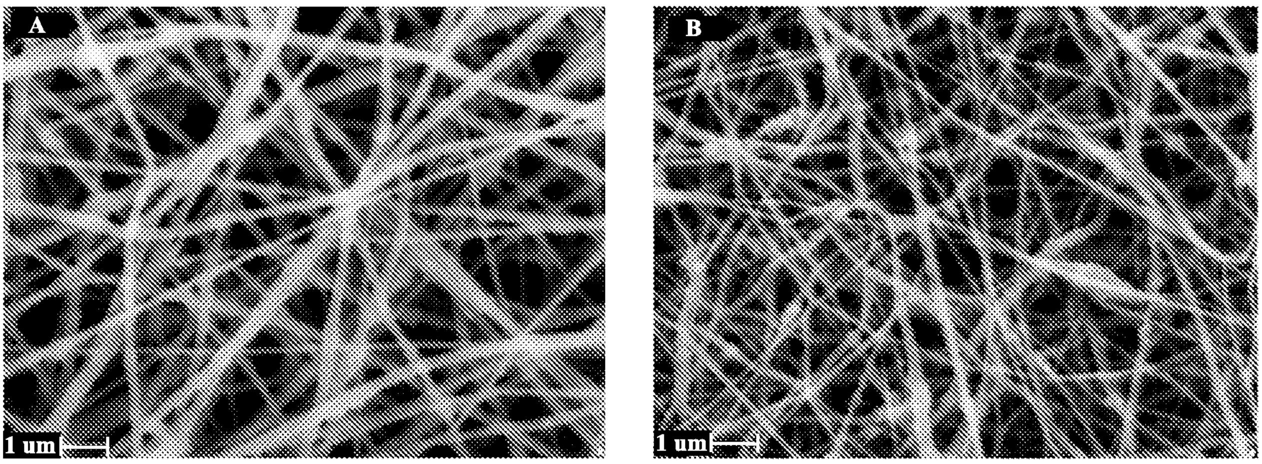

FIG. 6

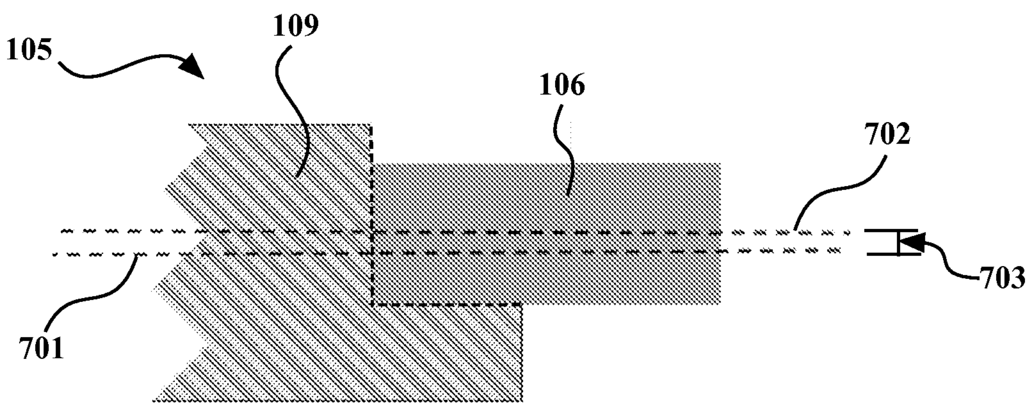

FIG. 7

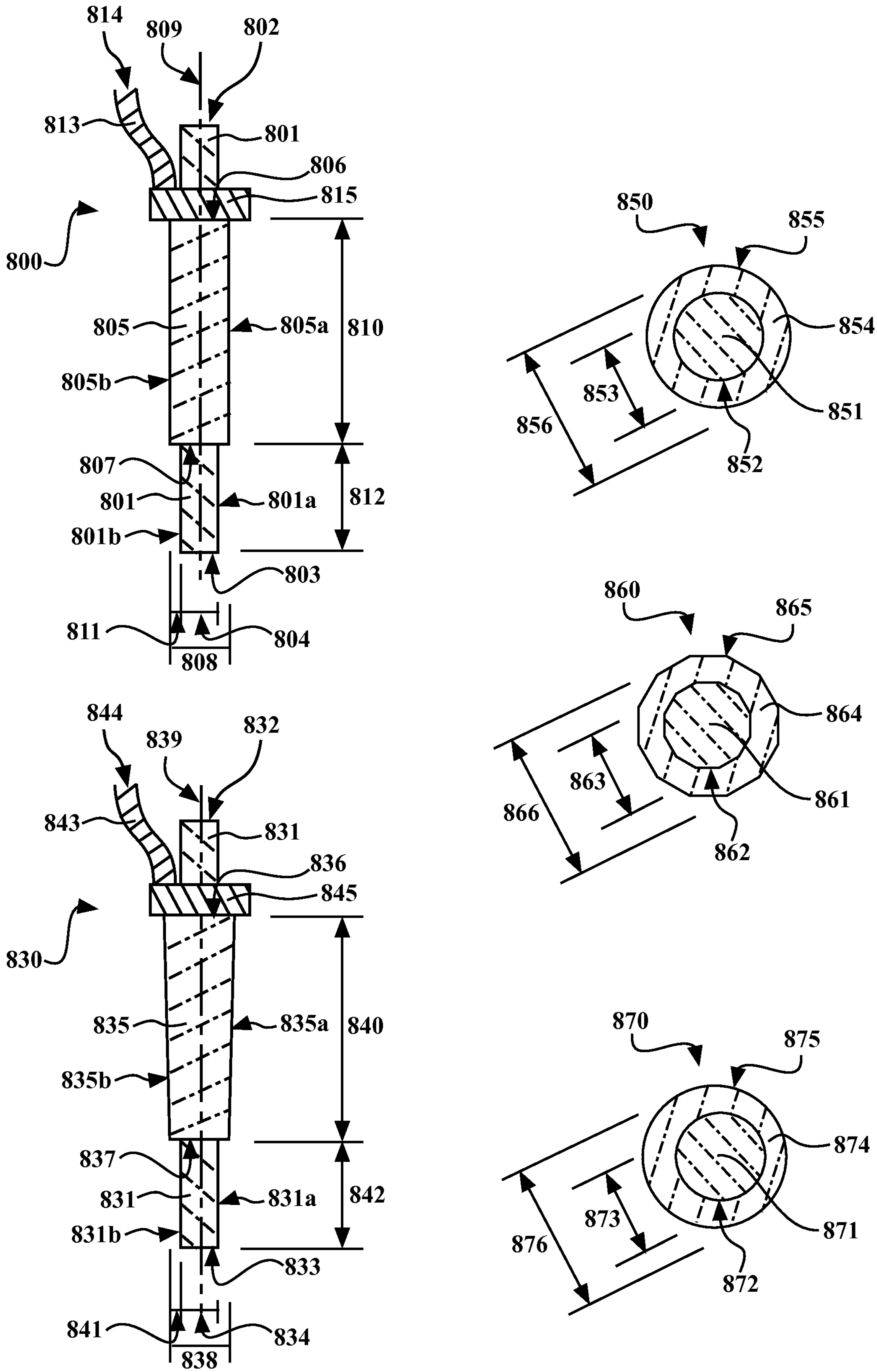

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FIG. 8

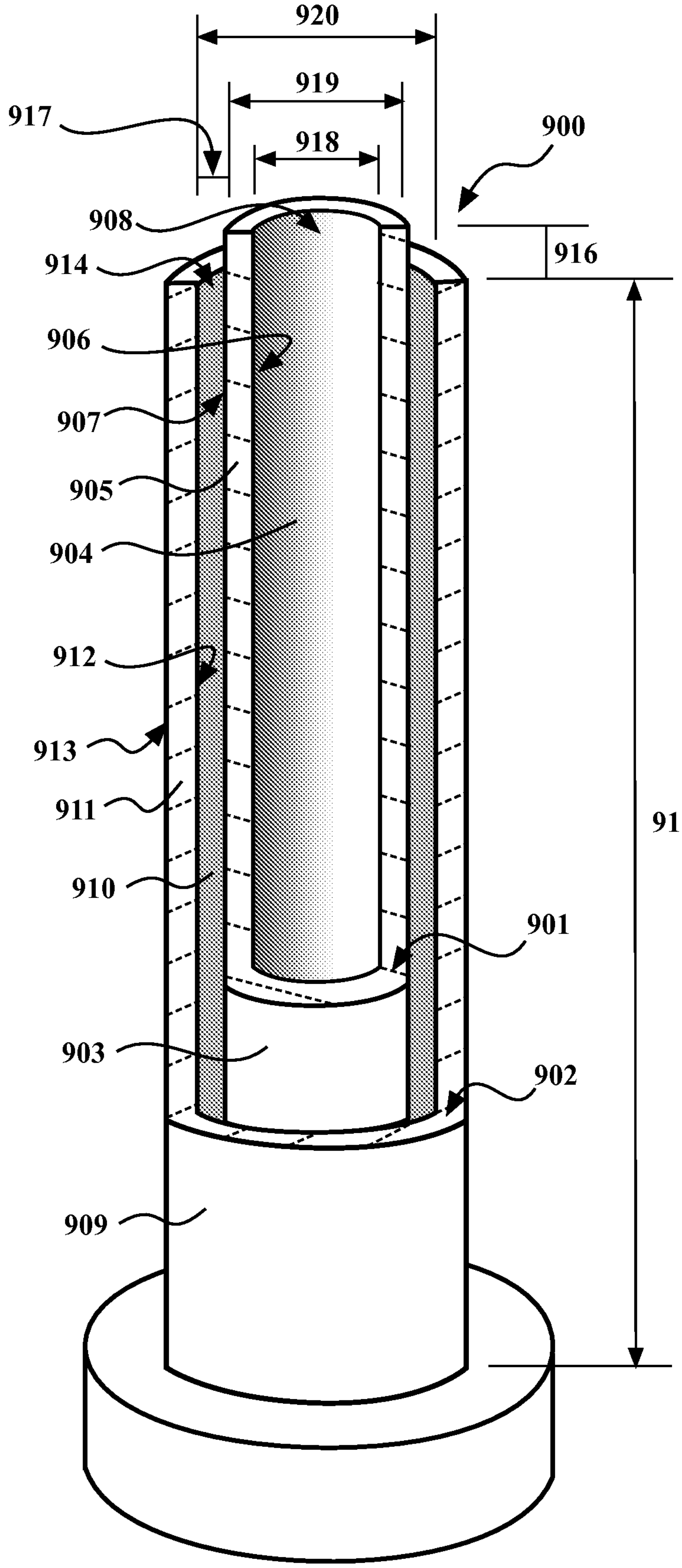
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FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2014/025699

A. CLASSIFICATION OF SUBJECT MATTER

D01D 5/34(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
D01D 5/34; B29C 47/60; B05B 5/00; D02G 3/36; D02G 3/00; B29C 47/06; B05B 5/025; D01D 5/06

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: electrospinning, nanofiber, multi-nozzle, conduit, needle, manifold supply chamber

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012-0034461 A1 (STEVENS, R.) 9 February 2012 See abstract, claims 1-41, paragraphs [0001], [0043]-[0049], figs. 3a-3b, 10a-12.	22
A		1-4
A	US 2006-0049542 A1 (CHU, B. et al.) 9 March 2006 See abstract, claims 1-13, paragraphs [0074], [0081], figs. 1-2, 4, 7.	1-4,22
A	US 2006-0081178 A1 (WILLEY, A. D. et al.) 20 April 2006 See abstract, claims 1-10, paragraphs [0031], [0047]-[0051], figs. 1, 4-6.	1-4,22
A	US 2012-0128978 A1 (BALLWEG, T. et al.) 24 May 2012 See abstract, paragraphs [0014]-[0017], fig. 1.	1-4,22
A	US 2013-0011508 A1 (KIM, H. C.) 10 January 2013 See abstract, claims 1-9, paragraphs [0033]-[0035], fig. 1.	1-4,22
A	SRIVASTAVA, Y. et al., "Electrospinning of hollow and core/sheath nanofibers using a microfluidic manifold", Microfluidics and Nanofluidics, 2008, Vol. 4, Pages 245-250 See abstract.	1-4,22

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 July 2014 (24.07.2014)	**24 July 2014 (24.07.2014)**

Name and mailing address of the ISA/KR
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Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.: 12, 14, 16, 19, 24, 26, 37, 44, 48
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
Claims 12, 14, 16, 19, 24, 26, 37, 44, 48 are regarded to be unclear since they refer to multiple dependent claims which are not drafted in accordance with PCT Rule 6.4(a).

3. ☒ Claims Nos.: 5-11, 13, 15, 17-18, 20-21, 23, 25, 27-36, 38-43, 45-47
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required addtional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of any additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2014/025699

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