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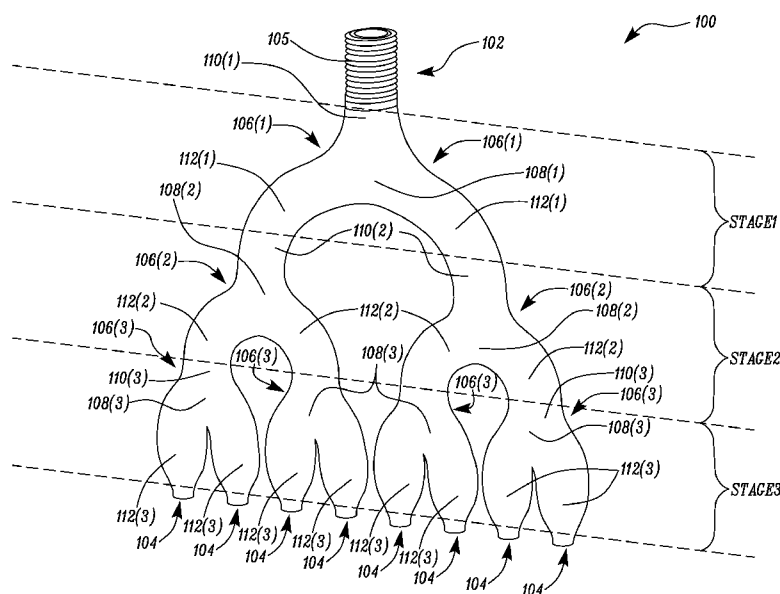
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(54) Title: MULTI-OUTLET NOZZLES AND METHODS**FIG. 1**

(57) **Abstract:** A multi-outlet nozzle includes an inlet defining an intake port for receiving a feed of a flowable material, 2^N outlets spaced apart from the inlet, and $2^N - 1$ flow splitters. Each outlet defines a discharge port for dispensing a $1/2^N$ portion of the feed of the flowable material. The intake port of the inlet is in fluid communication via divergent flow paths with the discharge ports of the outlets. The $2^N - 1$ flow splitters have flow paths through the multi-outlet nozzle from the inlet to the 2^N outlets. Each flow splitter includes an intake conduit and two discharge conduits. Each flow splitter splits an intake conduit flow into two symmetrical discharge conduit flows. The $2^N - 1$ flow splitters are arranged in N stages such that stage 1 has 1 flow splitter and at each successive stage the number of flow splitters doubles from the immediately prior stage.

MULTI-OUTLET NOZZLES AND METHODS

[001] Embodiments described herein relate generally to multi-outlet nozzles and methods for dispensing a flowable material onto a substrate using the multi-outlet nozzles.

5 **[002]** Photovoltaic (PV) cells are typically coated with an encapsulating material (e.g., a silicone) in order to protect the PV cells from harsh environments. PV cells are usually used in a PV cell module comprising a superstrate, backsheet, and the PV cells sandwiched between the superstrate and backsheet and encapsulated with the encapsulating material. In manufacturing the PV cell modules, material dispensing
10 systems are generally used for dispensing a curable flowable encapsulating material onto a suitable substrate such as the PV cells, superstrate, or backsheet. The dispensed curable flowable encapsulating material is spread over the PV cells and cured in situ to give the PV cell module.

[003] Prior material dispensing systems for dispensing a flowable material may
15 generally include a nozzle to dispense the flowable material onto a surface of a component to be coated (a "substrate," which may be, e.g., the superstrate, PV cells or backsheet of the PV cell module). The nozzle may dispense the flowable material in the form of a single bead or a plurality of beads, the beads being spaced apart from one another, such that no two beads touch each other during dispensing. When the nozzle
20 dispenses the flowable material in the form of single beads, multiple passes are required to dispense the beads over the entire substrate. Multiple passes over the component to be coated may increase coating process time and cost. Further when the flowable material is curable, prior nozzles may be prone to blockages due to their design allowing or facilitating premature curing of the curable flowable material within the nozzles. To
25 prevent blockages, a flushing material is periodically passed through the nozzle, thereby adding to both initial design costs and running costs and reducing production rates. Such material dispensing systems also require frequent cleaning and/or replacement of various components, including the nozzle. Such material dispensing systems also require expensive retooling for components of different sizes.

30 **[004]** Thus there is a need for material dispensing systems and methods to overcome these and other known drawbacks of prior material dispensing systems.

BRIEF SUMMARY OF THE INVENTION

[005] A multi-outlet nozzle is described, according to various embodiment of the present invention. The multi-outlet nozzle includes an inlet defining an intake port for

receiving a feed of a flowable material, 2^N outlets spaced apart from the inlet, and 2^N-1 flow splitters. Each outlet defines a discharge port for dispensing a $1/2^N$ portion of the feed of the flowable material. The intake port of the inlet is in fluid communication via divergent flow paths with the discharge ports of the outlets, wherein N is an integer of 2 or greater. Further, the 2^N-1 flow splitters have flow paths through the multi-outlet nozzle from the intake port to the 2^N outlets. Each flow splitter includes an intake conduit and two discharge conduits. Each flow splitter splits an intake conduit flow into two symmetrical discharge conduit flows. Moreover, the bore of the intake conduit and bore of the discharge conduits of each flow splitter are equal. The 2^N-1 flow splitters are arranged in N stages from stage 1 to stage N , such that stage 1 has 1 flow splitter and at each successive stage the number of flow splitters doubles from the immediately prior stage. Except for the stage N , each discharge conduit of a flow splitter in any particular stage is coupled to the intake conduit of a flow splitter in a subsequent stage. The intake conduit of the flow splitter in stage 1 is coupled to and in fluid communication with the intake port, and the discharge conduits of the flow splitters in stage N are coupled to and in fluid communication with the outlets.

[006] A method of dispensing a flowable material onto a substrate is described, according to various embodiments of the present invention. The method comprises dividing a feed of a flowable material ultimately into 2^N equal flows in N number of stages from stage 1 to stage N , wherein N is an integer of 2 or greater. The method receives the feed of the flowable material and divides the feed into two equal flows in stage 1. Further, the method, in each of the subsequent $(N - 1)$ number stages, receives flows from a previous stage, divides each of the flows from the previous stage into two equal flows to ultimately get the 2^N equal flows by flow splitters, and dispenses the 2^N equal flows of the material onto the substrate. Each of the flow splitters includes an inlet conduit configured to receive one of the flows, a junction configured to divide the flow into two equal flows, and two discharge conduits configured to receive the two equal flows from the junction. Further, a bore of the intake conduit and bore of the discharge conduits of each flow splitter are equal.

BRIEF DESCRIPTION OF THE DRAWINGS

[007] Various embodiments will now be described in conjunction with accompanying drawings, wherein:

[008] FIG. 1 illustrates a perspective view of an exemplary multi-outlet nozzle, according to an embodiment of the present invention;

[009] FIG. 2 is a front view of the multi-outlet nozzle, according to the embodiment of FIG. 2;

[010] FIG. 3 illustrates a cross-sectional view of the multi-outlet nozzle, according to the embodiment of FIG. 3;

5 **[011]** FIG. 4 is a perspective view of an exemplary first half of the multi-outlet nozzle, according to an embodiment of the present invention;

[012] FIG. 5 illustrates a perspective view of the multi-outlet nozzle, according to another embodiment of the present invention;

10 **[013]** FIGS. 6A-6C illustrate various operational states of an exemplary material dispenser, according to an embodiment of the present invention; and

[014] FIG. 7 is a flowchart of an exemplary method of dispensing a material onto a substrate, according to various embodiments of the present invention.

[015] FIG. 8 is a bottom-up perspective view of an embodiment of the multi-outlet nozzle.

15 **DETAILED DESCRIPTION OF THE INVENTION**

[016] The Summary and Abstract are incorporated here by reference. Various embodiments of the present invention presented herein describe multi-outlet nozzles and methods for dispensing a material onto a substrate.

20 **[017]** Referring to Figures, FIGS. 1, 2 and 3 are perspective, front and cross-sectional views, respectively, of an exemplary multi-outlet nozzle 100, according to an embodiment of the present invention. The multi-outlet nozzle 100 includes an inlet 102 and multiple outlets 104 spaced apart from the inlet 102. The inlet 102 includes a threaded portion 105 that may detachably engage with a corresponding threaded portion of a mixer (shown in FIGS. 6A-6C). In various alternate embodiments, the multi-outlet
25 nozzle 100 may include a quick coupler (not shown) for coupling with the mixer.

[018] Flow splitters 106(M) (M=1, 2, 3) are arranged in N = 3 stages between the inlet 102 and the outlets 104. An Mth stage includes 2^(M-1) of the flow splitters 106(M). Therefore, as shown in FIG. 1, stage 1 (M=1) includes one flow splitter 106(1). Similarly, stage 2 (M=2) includes two flow splitters 106(2) that is double the number of the flow splitter 106(1). Further, stage 3 (M=3) includes four flow splitters 106(3) that is double the number of the flow splitters 106(2). In other words, the number of the flow splitters 106(M) at each successive stage (an Mth stage) is double the number of the flow splitters 106(M-1) from the immediately prior stage (the (M-1)th stage). The total number
30 of the flow splitters 106(1), 106(2), 106(3) is seven. The number N of the stages is 3 in

an exemplary embodiment, and in various other embodiments, N may be any integer greater than 2. For example, in an embodiment, the number N may be 4 (shown in FIG. 5). In case the multi-outlet nozzle 100 includes N stages, the total number of the flow splitters 106(M) may be 2^{N-1} . Further, M may be any integer from 1 to N.

5 **[019]** As shown in FIG. 1, each of the flow splitters 106(M) includes a junction 108(M), an intake conduit 110(M) and two discharge conduits 112(M). Further, except for stage 3, discharge conduits 112(M) of the flow splitters 106(M) in any particular stage (an Mth stage) are coupled to the intake conduits 110(M) of the flow splitters 106(M+1) in the subsequent stage (the (M+1)th stage). As shown in FIG. 1, each of the discharge
10 conduits 112(1) of the flow splitter 106(1) in stage 1 are coupled to an intake conduit 110(2) of the flow splitters 106(2) in stage 2. Similarly, each of the discharge conduits 112(2) of the flow splitters 106(2) in stage 2 are coupled to an intake conduit 110(3) of the flow splitters 106(3) in stage 3. The intake conduit 110(1) of the flow splitter 106(1) in stage 1 is coupled to the inlet 102. Each of the discharge conduits 112(3) of the flow
15 splitters 106(3) in stage 3 are coupled to each of the outlets 104. Similar to the embodiment of FIG. 1 where N = 3, for any other N, each of the discharge conduits of the flow splitters in stage N may be coupled to the outlets.

[020] The multi-outlet nozzle 100 may be of a monolithic conduit structure and the flow splitters 106(M) (M = 1, 2, 3) are regions of the monolithic conduit structure. Thus, the
20 junctions 108(M), the intake conduits 110(M) and the discharge conduits 112(M) may not be separate components but different regions of the monolithic conduit structure. Each of the discharge conduits 112(M) and the coupled intake conduit 110(M+1) therefore form a continuous closed flow path (shown in FIG. 3) for the material.

[021] Referring now to FIG. 2, a length L(M) (M = 1, 2, 3) of an Mth stage may be
25 substantially equal for all the stages. The lengths L(1), L(2) and L(3) of stages 1, 2 and 3, respectively, may be substantially equal. In an embodiment a L/W₃ ratio of an overall length L of the multi-outlet nozzle 100 from the inlet 102 to each of the outlets 104 to a maximum width W₃ of the multi-outlet nozzle may be from 0.5 to 2, alternatively from 0.8 to 1.2, alternatively from 0.9 to 1.1, e.g., about 1.0. In an embodiment, an overall length
30 L of the multi-outlet nozzle 100 from the inlet 102 to each of the outlets 104 may lie in a range from about 10 mm to about 1,000 mm (e.g., from about 120 to 125 mm). The overall length L may be less than 10 mm or greater than 1,000 mm, however, for research or manufacturing uses. A maximum width W(M) of any particular stage (an Mth

stage) may be lower than a maximum width $W(M+1)$ of a subsequent stage (an $(M+1)^{\text{th}}$ stage). The maximum widths W_1 , W_2 and W_3 of stages 1, 2 and 3, respectively, may therefore progressively increase. The maximum width W_3 may be equal to a maximum width of the multi-outlet nozzle. In an embodiment, the maximum width W_3 may be from about 10 mm to about 1,000 mm (e.g., from about 120 mm to 125 mm). The maximum width W_3 may be less than 10 mm or greater than 1,000 mm, however, for research or manufacturing uses. In case of any number of stages N , a maximum width of the multi-outlet nozzle may therefore be equal to a maximum width of stage N . A maximum inner distance $E(M)$ between the two discharge conduits 112(M) of the flow splitter 106(M) in an M^{th} stage is greater than a maximum inner distance $E(M+1)$ between the two discharge conduits 112(M+1) of the flow splitter 106(M+1) in the subsequent stage (the $(M+1)^{\text{th}}$ stage). The maximum inner distances E_1 , E_2 and E_3 of stages 1, 2 and 3, respectively, may therefore progressively increase.

[022] As shown in FIG. 3, the inlet 102 defines an intake port 114 configured to receive a feed of the material from the material dispenser. Similarly, each of the outlets 104 defines a discharge port 116. Each of the flow splitters 106(M) ($M = 1, 2, 3$) have an axis of symmetry $A(M)$. For example, the flow splitter 106(1) has an axis of symmetry $A(1)$ that may divide the flow splitter 106(1) equally into two regions. The axis of symmetry $A(1)$ of the flow splitter 106(1) may coincide with a central axis X of the intake port 114. Further, each of the discharge ports 116 of the outlets 104 has a central axis Y . In an embodiment, the axes of symmetry $A(M)$, the central axis X of the intake port 114, and the central axis Y of the discharge ports 116 may be substantially parallel to each other. In a further embodiment, the axes of symmetry $A(M)$, the central axis X of the intake port 114, and the central axis Y of the discharge ports 116 may be in the same plane. A distance $D(M)$ ($M > 1$) between two adjacent axes of symmetry $A(M)$ in an M^{th} stage may be greater than a distance $D(M+1)$ between two adjacent axes of symmetry $A(M)$ in the subsequent stage (the $(M+1)^{\text{th}}$ stage). For example, the distance $D(2)$ between the two adjacent axes of symmetry $A(2)$ in stage 2 may be greater than the distance $D(3)$ between the two adjacent axes of symmetry $A(3)$ in stage 3. Further, a distance D_T between the central axes Y of adjacent discharge ports 116 may be from about 2 mm to about 25 mm, alternatively from about 7 mm to about 20 mm, e.g., about 15 mm.

[023] As illustrated in FIG. 3, a flow path F_0 of the material in the intake port 114 continues in the intake conduit 110(1) of the flow splitter 106(1). The junction 108(1) of

the flow splitter 106(1) in stage 1 may divide the flow path F0 into two symmetric flow paths F1 through the discharge conduits 112(1). Thus, the junction 108(1) may divide the flow of the material, represented by the flow path F0 through the intake conduit 110(1), into two substantially equal halves represented by the flow paths F1 through the discharge conduits 112(1). Subsequently, each of the flow paths F1 may continue into each of the intake conduits 110(2) of the flow splitters 106(2) in stage 2. Each of the junctions 108(2) in stage 2 may divide each of the flow paths F1 into two substantially symmetric flow paths F2 through each pair of the discharge conduits 112(2). Thus, each of the junctions 108(2) may divide the flow of the material, represented by each of the flow paths F1 through each of the intake conduits 110(2), into two substantially equal halves represented by the flow paths F2 through each pair of the discharge conduits 112(2). Subsequently, each of the flow paths F2 may continue into each of the intake conduits 110(3) of the flow splitters 106(3) in stage 3. Each of the junctions 108(3) in stage 3 may divide each of the flow paths F2 into two substantially symmetric flow paths F3 through each pair of the discharge conduits 112(3). Thus, each of the junctions 108(3) may divide the flow of the material, represented by each of the flow paths F2 through each of the intake conduits 110(3), into two substantially equal halves represented by the flow paths F3 through each pair of the discharge conduits 112(3). Finally, each of the flow paths F3 may continue into each of the discharge ports 116. It may be apparent that the junctions 106(M) in any stage any stage M, may divide a flow path F(M-1) of the previous stage (M-1) into two substantially symmetric flow paths F(M). Therefore, the multi-outlet nozzle 100 may divide a single flow of the material represented by the flow path F0 into 2^N ($N = 3$), i.e., 8 equal flows of the material represented by the flow paths F3. In an embodiment, a flow path from the intake conduit 110(M) to the discharge conduit 112(M) of the flow splitter 106(M) in an Mth stage F(M) may be greater than a flow path from the intake conduit 110(M+1) to the discharge conduit 112(M+1) of the flow splitter 106(M+1) in the subsequent stage (the (M+1)th stage). For example, the part of the flow path F0 in the intake conduit 110(1) and the part of the flow path F1 in the discharge conduit 112(1) of the flow splitter 106(1) in stage 1 may be greater than the part of the flow path F1 in the intake conduit 110(2) and the part of the flow path F2 in the discharge conduit 112(2) of the flow splitter 106(2) in stage 2. The multi-outlet nozzle 100 therefore defines divergent flow paths from the flow path F0 to the flow paths F3. Further, a single continuous flow path including the flow path F0, and one of the flow paths F1, F2 and F3 from the intake port 114 to the outlet port 116

may be substantially equal to the other seven continuous flow paths. In general if an embodiment of the multi-outlet nozzle includes N stages, the N continuous flow paths may be substantially equal to each other.

[024] Further, in FIG. 3, an interior surface 120 of the multi-outlet nozzle 100 enclosing the flow paths F0, F1 and F3 may include smooth curves between any two points. In other words, the interior surface 120 of the multi-outlet nozzle 100 may not include any sharp edges. Further, the interior surface 120 of the multi-outlet nozzle 100 may be smooth with low average surface roughness (R_a). In an embodiment, an interior surface 120 of the multi-outlet nozzle 100 enclosing the flow paths F0, F1 and F3 may have an average surface roughness (R_a) in a range from 2 to 300 microns, alternatively 5 to 150 microns, alternatively 10 to 70 microns. The flow paths F0, F1, F2 and F3, as illustrated in FIG. 3, are purely exemplary in nature to represent flows of the material. The flow paths may be represented in any alternative manner without deviating from the scope of the present invention.

[025] As illustrated in FIG. 3, each of the junctions 108(1), 108(2) and 108(3) may be configured as a Y-junction to facilitate substantially symmetric division of the flow paths F0, F1 and F2, respectively. Further, an intake conduit 110(M) ($M = 1, 2, \text{ and } 3$) and the two discharge conduits 112(M) of each of the flow splitters 106(M) may have a substantially equal bore B1. Therefore, the material flows through the substantially equal bore B1 through the intake port 114, the intake conduits 110(M) and the discharge conduits 112(M). The bore B1 of the discharge conduits 112(3) of the last stage (stage $N = 3$) may reduce in the outlets 104 to a minimum bore B2 of the discharge ports 116. The discharge ports 116 may be configured with the minimum bore B2. In an embodiment, the bore B1 may be in a range from about 5 mm to about 25 mm, alternatively from about 7 mm to about 20 mm, e.g., about 15 mm. In an embodiment, the minimum bore B2 may be from about 2 mm to about 4 mm. Further, a wall thickness of the outlets 104 defining discharge ports 116 may be from about 0.5 mm to about 1 mm.

[026] Referring again to FIG. 3, two flow splitters 106(M+1) in an $(M+1)^{\text{th}}$ stage are formed by a self-similar transformation from one of the flow splitters 106(M) in the preceding stage (the M^{th} stage). The self-similar transformation involves a scale variance, i.e., each of the flow splitters 106(M+1) has smaller dimensions than the flow splitter 106(M). However, even though there is a scale variance, the bore of the flow

splitters 106(M+1) is the same as the bore of the flow splitters 106(M). For example, the flow splitters 106(2) in stage 2 are formed by a self-similar transformation of the flow splitter 106(1) in stage 1. Further, each of the flow splitters 106(2) has smaller dimensions than the flow splitter 106(1). The multi-outlet nozzle 100 is therefore a self-similar, multi-outlet nozzle having divergent flow paths for evenly splitting a feed of a material into 2^N streams of the material, wherein N is an integer of 2 or greater.

[027] FIG. 4 illustrates a perspective view of a first half 200 of the multi-outlet nozzle 100, according to an embodiment of the present invention. The first half 200 of the multi-outlet nozzle 100 includes protruding members 202A, 202B, 202C and 202D disposed on edges 204A, 204B, 204C and 204D, respectively. The edge 204A may be an overall outer edge of all the three stages of the first half 200. The edge 204B may be an overall inner edge of all the three stages of the first half 200. The edge 204C may be inner edges of stages 2 and 3. The edge 204D may be inner edges of stage 3. In an embodiment, the protruding members 202A, 202B, 202C and 202D may be O-rings, which would then be sealed against a flat surface on a corresponding second half (not shown). The protruding members 202A-D may be joined to the corresponding edges 204A-D by adhesives, mechanical couplings, or the like. The second half (not shown) includes edges corresponding to the edges 204A, 204B, 204C and 204D of the first half 200. The first half 200 and the second half may be mated together such that the corresponding edges match with each other. Further, the protruding members 202A, 202B, 202C and 202D may in contact against the corresponding edges of the second half. The edges 204A-D of the first half 200 and the edges of the second half may be then joined to each other by various methods, for example, but not limited to, ultrasonic welding, adhesives, or the like. The protruding members 202A-D may seal the joined edges and prevent any leakage of the material. The first half 200 and the two-piece construction of the multi-outlet nozzle 100, as described above, is an exemplary embodiment, and various alternative two-piece constructions may be envisioned without deviating from scope of the present invention. For example, in an embodiment, the first half 200 may include male members (E.g., lips) on the edges and the second half may include complementary female members (E.g., grooves). In another embodiment, the first half 200 may include a lip portion, forming a “male portion” per se, while the second half may not have any corresponding grooves for the lip portion of the first half 200. In yet another embodiment, neither the first half 200 nor a second half have an interlocking portion, instead, may include flat interfaces. The male and the complementary female

members may be engaged with each other and then joined by various methods. The first half 200 may be of a monolithic construction, formed by, for example, extrusion or extrusion molding.

[028] The multi-outlet nozzle 100 may be monolithically fabricated using any of various methods, for example, rapid prototyping, 3D printing, or the like. In various embodiments, the multi-outlet nozzle 100 may be made of polymeric material, for example, vinyl-functional polymer, amino-functional polymer, ABS, PET, or the like. The vinyl-functional polymer may be UV cured acrylate. UV cured acrylate may be used in a one-piece (or monolithic) construction of the multi-outlet nozzle 100 in conjunction with rapid prototyping or 3D printing.

[029] FIG. 5 illustrates a perspective view of a multi-outlet nozzle 300, according to another embodiment of the present invention. The multi-outlet nozzle 300 includes an inlet 302 and multiple outlets 304 spaced apart from the inlet 302. The inlet 302 includes a threaded portion 305 that may detachably engage with a corresponding threaded portion of a material dispenser (shown in FIGS. 6A-6C). Flow splitters 306(M) (M=1, 2, 3, 4) are arranged in $N = 4$ stages between the inlet 302 and the outlets 304. Each of the flow splitters 306(M) includes a junction 308(M), an intake conduit 310(M) and two discharge conduits 312(M). The total number of the flow splitters 306(M), 306(2), 306(3) is (2^4-1) , i.e., 15. Stage 4 includes $2^{(4-1)}$, i.e., 8 flow splitters 306(4). Each of the discharge conduits 312(4) of the flow splitters 106(4) in stage 4, are coupled to each of the outlets 304. The total number of outlets 304 is 2^4 , i.e., 16. It is apparent that various other features, construction, material and embodiments of the multi-outlet nozzle 300 may be substantially similar to those of the multi-outlet nozzle 100 except that the multi-outlet nozzle 300 has 4 stages.

[030] FIG. 6A illustrate a schematic view of a material dispenser 400. The material dispenser 400 includes two storage containers 402A and 402B, a mixer 404, and the multi-outlet nozzle 100 detachably connected to the mixer 404. The multi-outlet nozzle 100 is shown by way of example, and the multi-outlet nozzle 300 or any other multi-outlet nozzle with N stages ($N \geq 2$) may be used with the material dispenser 400 in other alternate embodiments. Further, the mixer 404 may be a static mixer or a powered mixer. The storage containers 402A and 402B are in fluid communication with the mixer 404 via supply lines 406A and 406B, respectively. The storage containers 402A and 402B contain two components A and B, respectively, of the two-component material that is dispensed by the multi-outlet nozzle 100. Pumps (not shown) may be provided to

transport the materials A and B to the mixer 404 via the supply lines 406A and 406B. Alternatively, the materials A and B may be gravity fed to the mixer 404. Materials A and B mix together in mixer 404 to form curable material C, which comprises a mixture of materials A and B.

5 **[031]** In an embodiment, the material A may be an olefin-functional organosiloxane, whereas the material B may be an SiH-functional organosiloxane, alternatively an SiH-functional silane. In various other embodiments, the materials A and B may be olefin-functional materials, such as olefin monomers that may undergo polymerization or copolymerization when mixed, or an olefin oligomer and polyolefin that may undergo
10 olefin metathesis reactions when mixed. Additional catalysts and/or inhibitors may be mixed with the material A and/or the material B. In an embodiment, the catalyst may be a transition metal catalyst, for example, platinum. The materials A and B may be mixed in the mixer 404 to undergo a hydrosilylation reaction to form a curable material C. The material C is therefore a two-component curable material. In particular, the material C
15 may be an addition-cure silicone. The material C then enters the multi-outlet nozzle 100 through the inlet 102. In an embodiment, a valve may be provided to regulate flow of the material C from the mixer 404 to the multi-outlet nozzle 100. The amount of the catalyst and inhibitor may be balanced to ensure that the material C stays in liquid form for dispensing but cures within a reasonable duration once dispensed. In an embodiment,
20 the multi-outlet nozzle 100 may be made of a substance, for example, an UV cured acrylate, such that the substance inhibits curing of the material C. In particular, UV cured acrylate may inhibit curing of the material C having platinum as a catalyst. Thus, the material C may not get prematurely cured within the multi-outlet nozzle 100 due to use of a specific material of construction for the multi-outlet nozzle, and therefore the multi-outlet nozzle 100 of such material may reduce likelihood of any blockage, while still
25 maintaining the cure profile of the final dispensed material C.

[032] FIG. 6B illustrates a substrate 408 on which the material C is dispensed. The substrate 408 may be may include a suitable transparent material, such as soda-lime glass (vitreous silica). In an embodiment, the substrate 408 may be used as a
30 photovoltaic (PV) panel and the material C dispensed on the substrate 408 may cure to act as an encapsulant for the PV panel. In an embodiment, the multi-outlet nozzle 100 and/or the mixer 404 may be moved relative to the substrate 408 by one or more actuators (not shown), for example, mechanical, electrical, hydraulic, pneumatic, or a combination thereof. The one or more actuators may be part of an automated system,

such as, a robot. The multi-outlet nozzle 100 may be located at an initial position over the substrate 408 before commencement of coating of the substrate 408 with the material C. The multi-outlet nozzle 100 may then move relative to the substrate 408 to perform coating. In an alternate embodiment, the multi-outlet nozzle 100 may be stationary and the substrate 408 moved relative to the multi-outlet nozzle 100. The substrate 408 may be manually placed beneath the multi-outlet nozzle 100 or automatically, for example, by a conveyor system.

[033] FIG. 6C illustrates the multi-outlet nozzle 100 dispensing the material C on the substrate 408. Each of the eight outlets 104 may dispense the material C on the substrate 408 in the form of beads 410. The multi-outlet nozzle 100 may perform a lateral pass along a lateral direction, in and out of the plane of the drawing, to dispense the beads 410. Flow of the material C into the multi-outlet nozzle 100 may be controlled to provide a pulsed flow, such that, the material C is dispensed only while the substrate 408 is stationary. In other words, after dispensing one line of beads 410, the flow of material C is stopped, and the substrate 408 is moved to a next position (in or out of the plane of the drawing) for dispensing another line of beads 410. This procedure may be continued until the required number of beads 410 of material C have been dispensed on the substrate 408. In an embodiment, each of the beads 410 may have a width and spacing such that when compressed may spread outward over the substrate 408 to form a uniform coating on the substrate 408. The substrate 408 may have a length such that the multi-outlet nozzle 100 requires 8 lateral passes to completely coat the substrate 408. Thus, the multi-outlet nozzle 100 may complete the coating of the substrate 408 with a lower number of passes as compared to a non-invention nozzle with only one outlet. In particular, the number of passes may be reduced by a factor equal to the number of the outlets 104, which is eight, as compared to a non-invention nozzle with a single outlet. In case, the multi-outlet nozzle 300 (shown in FIG. 5) is used, the number of lateral passes will be reduced by a factor of sixteen as the multi-outlet nozzle 300 includes sixteen outlets 304. Therefore, a total time for coating is substantially reduced. A multi-outlet nozzle with a greater number of outlets may be used to coat the substrate 408 in a single lateral pass. The multi-outlet nozzle 100 may also be easily replaced by other multi-outlet nozzles (E.g., the multi-outlet nozzle 300) to cater to various sizes of the substrates 408.

[034] The multi-outlet nozzle 100 also ensures equal flows/flow rates through each of the outlets 104 such that each of the beads 410 is similar and the coating of the

substrate 408 is uniform across the whole surface. In an embodiment, each of the beads 410 may have a thickness of from about 0.1mm to about 4 mm from the surface of the substrate 408. The beads may be spaced between about 0.5 mm and about 30 mm apart. Referring to FIGS. 1-4, the bore B1 of the intake conduits 110(M) (M = 1, 2, 3) and the discharge conduits 112(M) may be substantially similar to facilitate equal flows to the outlets 104. Further, each of the junctions 108(M) may be configured as a Y-junction to result in equal divisions of flow. The minimum bore B2 of the discharge ports 116 may create a restriction in flow of the material C, thereby creating a back pressure. The back pressure may ensure an equal flow of the material C to each of the outlets 104. Further, the minimum bore B2 may also reduce a surface area of each of the discharge ports 116. This may enhance a pulling effect of the valve (that controls flow into the multi-outlet nozzle 100) on the material C when the valve is closed, thereby reducing snuff back or dripping from the multi-outlet nozzle 100 during idle periods. The flow of the material through the interior surface 120 of the multi-outlet nozzle 100 may be uniform and smooth without any blockages as the interior surface 120 includes smooth curves between any two points. Further, the interior surface 120 of the multi-outlet nozzle 100 may be smooth with low average surface roughness (R_a). Therefore, the material C may not get prematurely cured inside the multi-outlet nozzle 100. Consequently, the multi-outlet nozzle 100 may not require frequent cleaning to remove any cured material C. Further, there is no necessity of passing an additional flushing material to clean the multi-outlet nozzle 100. The multi-outlet nozzle 100 may therefore be easily cleaned and reused due to reduced curing inside the multi-outlet nozzle 100. The multi-outlet nozzle 100 may also be easily retrofitted with existing material dispensers.

[035] FIG. 7 is a flowchart of an exemplary method 500 of dispensing a material onto a substrate using the multi-outlet nozzle (e.g., multi-outlet nozzle 100 of FIG. 1). As shown in FIG. 7, the method 500 comprises steps 502, 504, 506, 508, 510 and 512. Step 502 comprises receiving a feed of a material. Step 504 comprises dividing the feed of the material into two equal flows in stage 1 of the multi-outlet nozzle. Step 506 comprises receiving flows from a previous stage of the multi-outlet nozzle in a next stage. Step 508 comprises dividing each of the flows from a previous stage the multi-outlet nozzle into two equal flows by flow splitters (not shown) including an intake conduit (not shown) configured to receive one of the flows, a junction (not shown) configured to divide the flow into two equal flows, and two discharge conduit configured to receive the two equal flows from the junction. Further, a bore (not shown) of the intake conduit and a bore of

the discharge conduits of each of the flow splitters are substantially equal. Step 510 comprises repeating steps 506 and 508 ($N-1$) times to ultimately get 2^N equal flows of the material. Step 512 comprises dispensing the 2^N equal flows of the material onto a substrate.

5 **[036]** An embodiment of the method 500 of FIG. 7 will now be described in conjunction with the multi-outlet nozzle 100, and the material dispenser 400, as illustrated in FIGS. 1-4, and 6A-6C, respectively.

10 **[037]** In step 502 of the embodiment of the method 500 of FIG. 7, the intake port (114 of FIG. 3) of the multi-outlet nozzle (100 of FIG. 3) receives the feed of the material (e.g., C of FIG. 6C) from the mixer (e.g., 404 of FIG. 6A). The material (C) is a multi-component curable material formed by mixing together the materials (e.g., A of FIG. 6C) and (e.g., B of FIG. 6C) in the mixer (404). Further, the multi-outlet nozzle (100) is made of a polymeric material that inhibits curing of the curable material (C).

15 **[038]** In step 504 of the embodiment of the method 500 of FIG. 7, the feed is divided into two equal flows by the flow splitter (e.g., 106(1) in stage 1 of FIG. 2). The feed of the material (e.g., C in FIG. 6C) flows from the intake port (e.g., 114 in FIG. 3) into the intake conduit (e.g., 110(1) of FIG. 2). The junction (e.g., 108(1) of FIG. 2) symmetrically divides the feed of the material (C) into two equal flows. The two discharge conduits (e.g., 112(1) of FIG. 2) receive the two equal flows.

20 **[039]** In step 506 of the embodiment of the method 500 of FIG. 7, each of the flows from a previous stage M ($M = 1$ to N) are received by an intake conduit of one of the flow splitters in stage. In step 508 of the embodiment of the method 500 of FIG. 7, each of the flows is divided by the junction of one of the flow splitters into two equal flows. Subsequently, the two discharge conduits of one of the flow splitters receive the two
25 equal flows from the junction. Further, the intake conduit and each of the discharge conduits have the same bore (B_1). Specifically, for $M = 1$, the intake conduit (e.g., 110(2) of FIG. 3) of one of the flow splitters (e.g., 106(2) of FIG. 3) in stage 2 (FIG. 3) receives the flow from one of the discharge conduit (e.g., 112(2) of FIG. 3) of stage 1 (FIG. 3). The flow is divided into two equal flows by the junction (e.g., 108(2) of FIG. 3) if one of
30 the flow splitters (e.g., 106(2) of FIG. 3). Subsequently, the two discharge conduits (e.g., 112(2) of FIG. 3) of one of the flow splitters (e.g., 106(2) of FIG. 3) receive the two equal flows from the junction (e.g., 108(2) of FIG. 3). For $M = 2$, the intake conduit (e.g., 110(3) of FIG. 3) of one of the flow splitters (e.g., 106(3) of FIG. 3) in stage 3 (FIG. 3) receives the flow from one of the discharge conduit (e.g., 112(3) of FIG. 3) of stage 2 (FIG. 3).

The flow is divided into two equal flows by the junction (e.g., 108(3) of FIG. 3) if one of the flow splitters (e.g., 106(3) of FIG. 3). Subsequently, the two discharge conduits (e.g., 112(3) of FIG. 3) of one of the flow splitters (e.g., 106(3) of FIG. 3) receive the two equal flows from the junction (e.g., 108(3) of FIG. 3).

5 **[040]** In step 510 of the embodiment of the method 500 of FIG. 7, steps 506 and 508 are repeated (N-1) times to get 2^N equal flows of the material (e.g., C in FIG. 6C). Thus, the feed of the material (C) is divided into 2^N equal flows in N stages from stage 1 to stage N.

10 **[041]** In step 512 of the embodiment of the method 500 of FIG. 7, the 2^N equal flows are dispensed onto the substrate (e.g., 408 of FIG. 6C) in the form of 2^N beads (e.g., 410 of FIG. 6C) via the discharge ports (e.g., 116 of FIG. 3) of the outlets (e.g., 104 of FIG. 3). The discharge ports (e.g., 116 of FIG. 3) receive the 2^3 (N = 3) equal flows from the discharge conduits (e.g., 112(3) of FIG. 3). The beads (410) may be uniform in terms of thickness and width. Further if material (e.g., C of FIG. 6C) is of sufficiently low dynamic
15 viscosity such that material (C) spreads under influence of gravity over substrate (408), the beads (410) may ultimately flatten and merge together and cover the whole surface of the substrate (408) after the coating may be completed in one or more lateral passes of the multi-outlet nozzle (e.g., 100 of FIG. 3).

20 **[042]** The discharge ports (116) may be an aperture of any profile such as a geometric or irregular profile. The geometric profile may be circular (116), ovoid, star, regular polygon, rectangular, or trapezoidal. For example, the discharge ports 116 are circular having a maximum bore equal to its diameter.

25 **[043]** Alternatively the discharge ports may be slots as shown in the embodiment of the multi-outlet nozzle in FIG. 8. Each slot independently may be rectangular, rectangular with rounded corners, or ovoid. The slot may be from 2.5 mm to 10 mm long and from 0.4 mm to 2 mm wide, alternatively from 3 mm to 8 mm long and from 0.5 mm to 1.5 mm wide, alternatively from 4 mm to 6 mm long and from 0.8 mm to 1.2 mm wide. Each slot may have a maximum bore equal to its length. The slots may be oriented parallel to an x-axis spanning the width W3 of the multi-outlet nozzle. In the multi-outlet nozzle, the
30 slots may be spaced apart from each other, as measured at their midpoints (Y), by from about 5 mm to about 25 mm, alternatively from about 7 mm to about 20 mm, e.g., 15 mm.

[044] As used herein, “may” confers a choice, not an imperative. “Contacting” means bringing into physical contact. “Contact” comprises operative touching. The contact may

be direct physical touching, alternatively indirect touching. All U.S. patent application publications and patents referenced herein, or a portion thereof if only the portion is referenced, are hereby incorporated herein by reference to the extent that incorporated subject matter does not conflict with the present description, which would control in any such conflict. The x-direction and y-direction respectively refer to horizontal and vertical axes of a Cartesian coordinate system. Average surface roughness (R_a) is an arithmetical mean height and if desired may be measured using a profilometer instrument.

[045] The below claims are incorporated by reference here as correspondingly numbered aspects except where “claim and “claims” are rewritten as “aspect” and “aspects.” Embodiments of the invention include such resulting numbered aspects.

[046] The various embodiments of systems and methods described herein have been presented by way of example, and not limitation. Various changes in form and detail can be made therein without departing from the spirit and scope of the present invention.

Thus, the present disclosure should not be limited by any of the above described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

What is claimed is:

1. A multi-outlet nozzle comprising:
an inlet defining an intake port for receiving a feed of a flowable material;
5 2^N outlets spaced apart from the inlet, wherein each outlet defines a discharge
port for dispensing a $1/2^N$ portion of the feed of the flowable material, wherein the intake
port of the inlet is in fluid communication via divergent flow paths with the discharge
ports of the outlets, wherein N is an integer of 2 or greater; and
 2^N-1 flow splitters, wherein the 2^N-1 flow splitters halve flow paths through the
10 multi-outlet nozzle from the inlet to the 2^N outlets, wherein each flow splitter comprises
an intake conduit and two discharge conduits, wherein each flow splitter splits an intake
conduit flow into two symmetrical discharge conduit flows, wherein the bore of the intake
conduit and bore of the discharge conduits of each flow splitter are equal;
wherein the 2^N-1 flow splitters are arranged in N stages from stage 1 to stage N,
15 wherein stage 1 has 1 flow splitter and at each successive stage the number of flow
splitters doubles from the immediately prior stage, wherein except for the stage N, each
discharge conduit of a flow splitter in any particular stage is coupled to and in fluid
communication with the intake conduit of a different flow splitter in a subsequent stage;
and
20 wherein the intake conduit of the flow splitter in stage 1 is coupled to and in fluid
communication with the intake port, and the discharge conduits of the flow splitters in
stage N are coupled to and in fluid communication with the outlets.
2. The multi-outlet nozzle of claim 2 being of one-piece or two-piece construction.
- 25 3. The multi-outlet nozzle of claim 1 or 2, wherein the flowable material is a curable
liquid composition and the multi-outlet nozzle is made of a substance that inhibits curing
of the curable liquid composition.
- 30 4. The multi-outlet nozzle of claim 3, wherein the flowable material comprises an
olefin-functional material and a transition metal catalyst for catalyzing reaction of the
olefin-functional material and the multi-outlet nozzle is made of a vinyl-functional polymer
or an amino-functional polymer.

5. The multi-outlet nozzle of claim 4, wherein the flowable material comprises a multi-component organosiloxane composition comprising olefin-functional organosiloxane, a Si-H functional organosiloxane, and a transition metal catalyst for catalyzing a hydrosilylation reaction of the olefin-functional organosiloxane with the SiH-functional organosiloxane and wherein the multi-outlet nozzle is made of the vinyl-functional polymer, and the vinyl-functional polymer is a UV cured acrylate that inhibits curing of the multi-component organosiloxane composition.

6. The multi-outlet nozzle of any one of claims 1 to 5, wherein the inlet of the multi-outlet nozzle is configured to detachably engage a material dispenser, wherein the material dispenser is for introducing the flowable material into the intake port of the inlet.

7. The multi-outlet nozzle of any one of claims 1 to 6, wherein the bore of the intake conduit and bore of the two discharge conduits of each flow splitter are equal.

8. The multi-outlet nozzle of any one of claims 1 to 7, wherein the intake conduit and the two discharge conduits of each of the flow splitters are coupled to and in fluid communication with each other through a Y-junction.

9. The multi-outlet nozzle of any one of claims 1 to 8 wherein lengths of the flow paths from the intake port of the inlet to each of the discharge ports of the outlets are equal.

10. The multi-outlet nozzle of any one of claims 1 to 9, wherein an axis of the intake port, axes of symmetry of the flow splitters and axes of the discharge ports of the outlets are parallel to each other.

11. The multi-outlet nozzle of claims 1-10, wherein the axis of the intake port, the axes of the flow splitters, and the axes of the 2^N outlets are in the same plane as each other.

12. The multi-outlet nozzle of any one of claims 1 to 11, wherein a distance between the discharge conduits of a flow splitter in a particular stage is greater than a distance between the discharge conduits of a flow splitter in the immediately subsequent stage.

13. The multi-outlet nozzle of any one of claims 1 to 12, wherein a length of a flow path from the intake conduit to a discharge conduit of a flow splitter in a particular stage is greater than a length of the flow path from the intake conduit to a discharge conduit of a flow splitter in the subsequent stage.

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14. The multi-outlet nozzle of any of claims 1 to 13, wherein an interior surface of the multi-outlet nozzle defining the flow paths has an average surface roughness (R_a) from 2 microns to 300 microns.

10

15. The multi-outlet nozzle of any of claims 1 to 14, wherein the multi-outlet nozzle is configured in such a way that during use thereof, the multi-outlet nozzle discharges a flowable material at equal flow rates from each of 2^N outlets.

15

16. A method of dispensing a flowable material onto a substrate, the method comprising:

dividing a feed of a flowable material ultimately into 2^N equal flows in N number of stages from stage 1 to stage N, wherein N is an integer of 2 or greater, the stage 1 receiving the feed, dividing the feed into two equal flows in the stage 1, each of the subsequent (N - 1) number stages comprising:

20

receiving flows from a previous stage;

dividing each of the flows from the previous stage into two equal flows to ultimately get the 2^N equal flows by flow splitters, each of the flow splitters comprising an inlet conduit configured to receive one of the flows, a junction configured to divide the flow into two equal flows and two discharge conduits configured to receive the two equal flows from the junction, wherein a bore of the intake conduit and bore of the discharge conduits of each flow splitter are equal; and

25

dispensing the 2^N equal flows of the flowable material onto the substrate.

30

17. The method of claim 16, wherein the flowable material is a multi-component flowable material wherein the method further comprises a preliminary step of mixing the components of the multi-component flowable material together so as to produce a curable liquid composition as the feed.

18. The method of claim 17, wherein the multi-outlet nozzle is made of a polymeric material that inhibits curing of the curable liquid composition.

19. The method of claim 16, 17, or 18 wherein the feed of the flowable material is pulsed.

20. A multi-outlet nozzle comprising:

a monolithic conduit structure defining an intake port, 2^N outlets spaced apart from the intake port, and flow paths from the intake port to the 2^N outlets;

the monolithic conduit structure comprising $2^N - 1$ junctions arranged in N stages, wherein an M^{th} stage comprises $2^{(M-1)}$ junctions, and wherein each of the $2^N - 1$ junctions splits a flow into two symmetrical flows; and

wherein the monolithic conduit structure splits a source flow received at the intake port into 2^N equal flows to be discharged at the 2^N outlets.

21. A multi-outlet nozzle comprising:

a conduit structure comprising two symmetrical open channel structures fused together by ultrasonic welding;

wherein the conduit structure defines an intake port, 2^N outlets spaced apart from the intake port, and flow paths from the intake port to the 2^N outlets;

the conduit structure comprising $2^N - 1$ junctions arranged in N stages, wherein an M^{th} stage comprises $2^{(M-1)}$ junctions, wherein each of the $2^N - 1$ junctions splits a flow into two symmetrical flows; and

wherein the conduit structure splits a source flow received at the intake port into 2^N equal flow paths to be discharged at the 2^N outlets.

22. A self-similar, multi-outlet nozzle having divergent flow paths for evenly splitting a feed of a flowable material into 2^N equal streams of the flowable material, wherein N is an integer of 2 or greater.

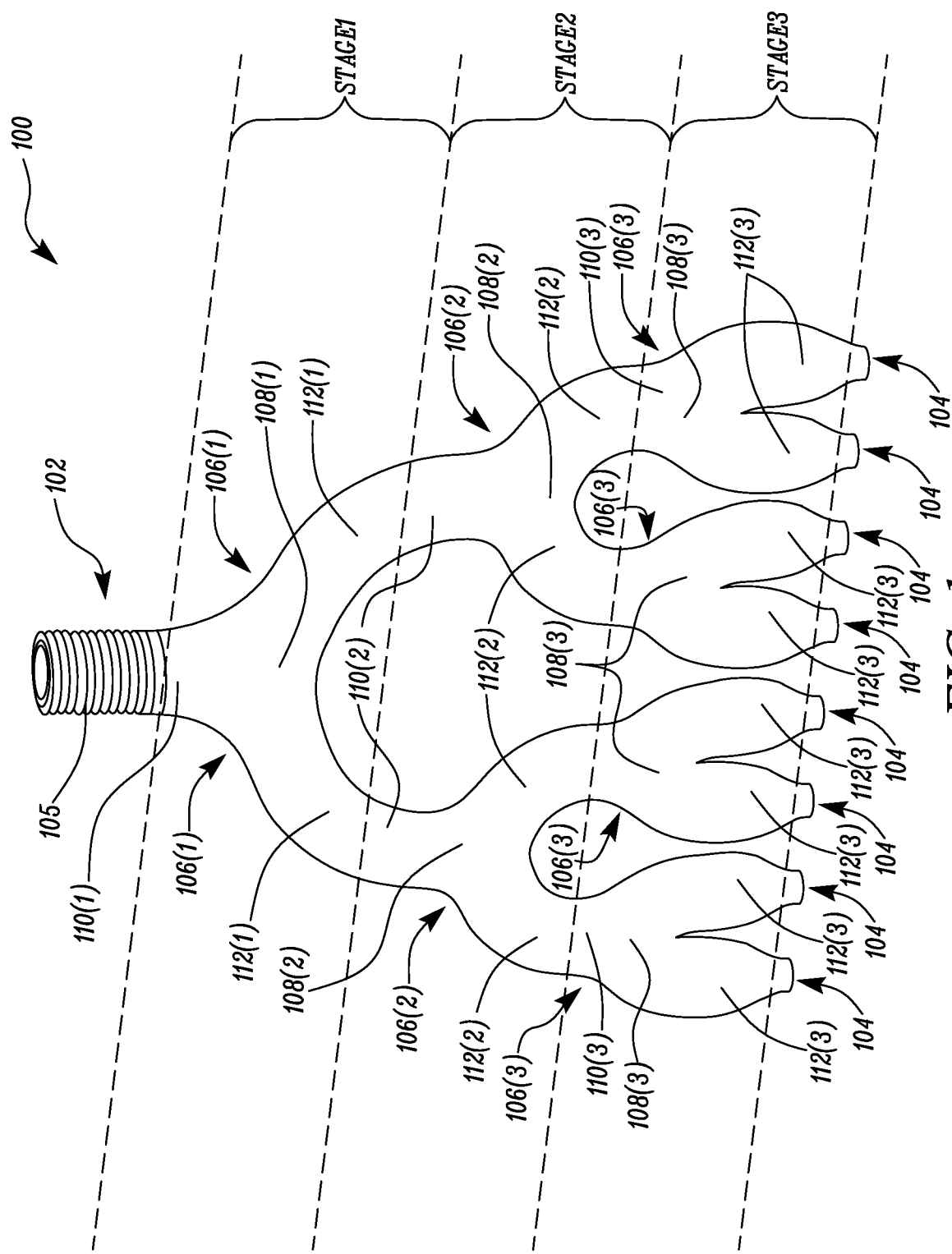


FIG. 1

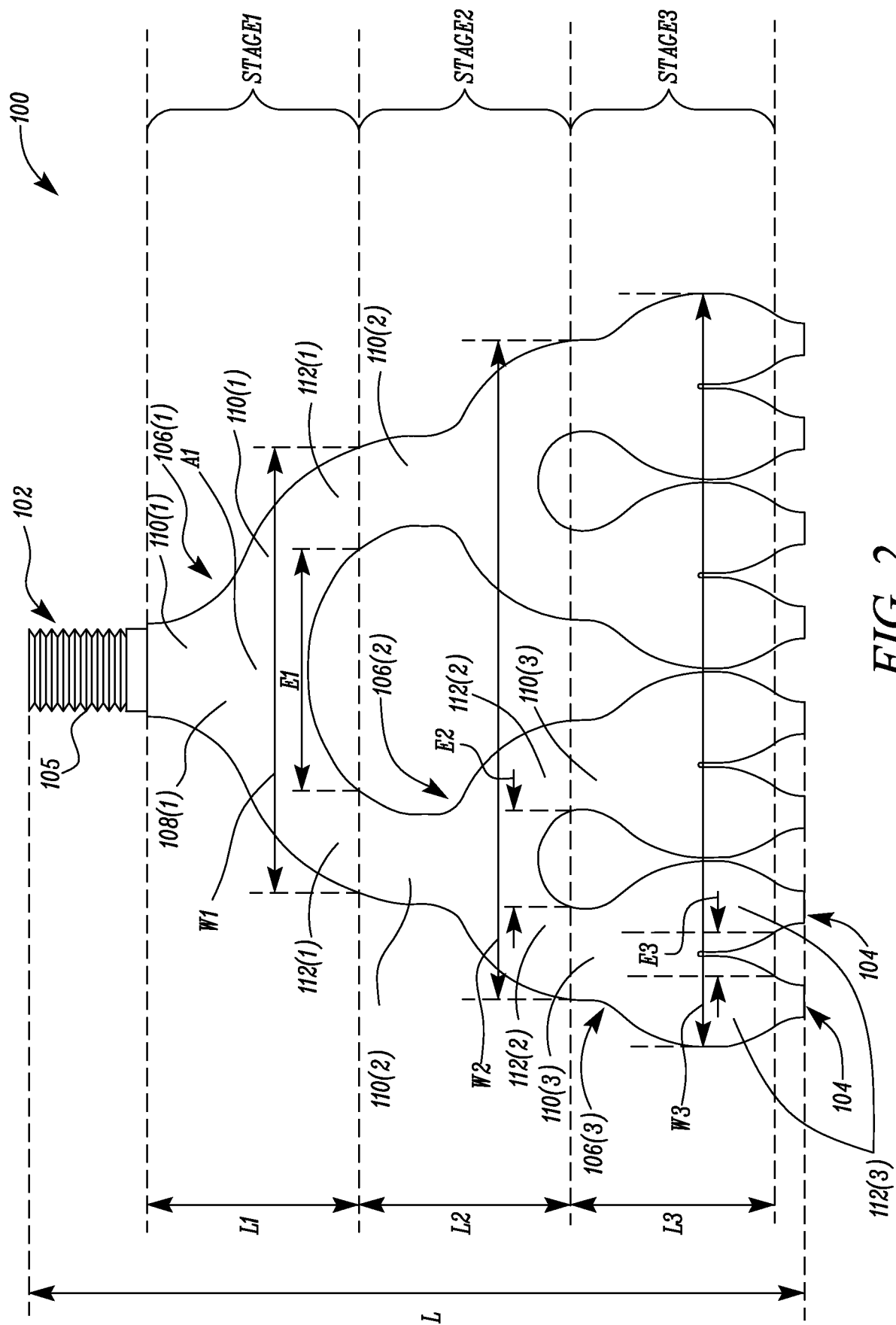
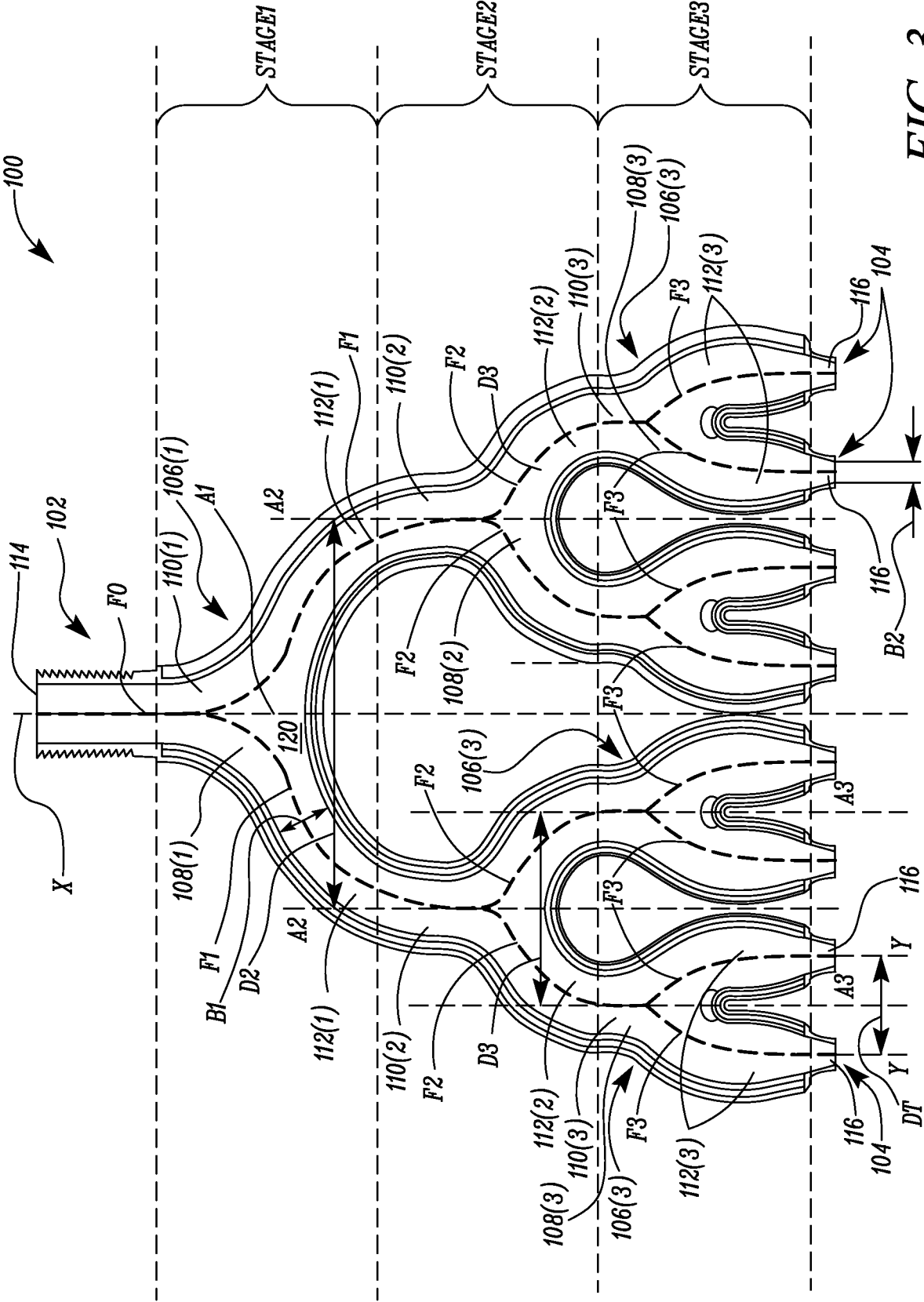


FIG. 2



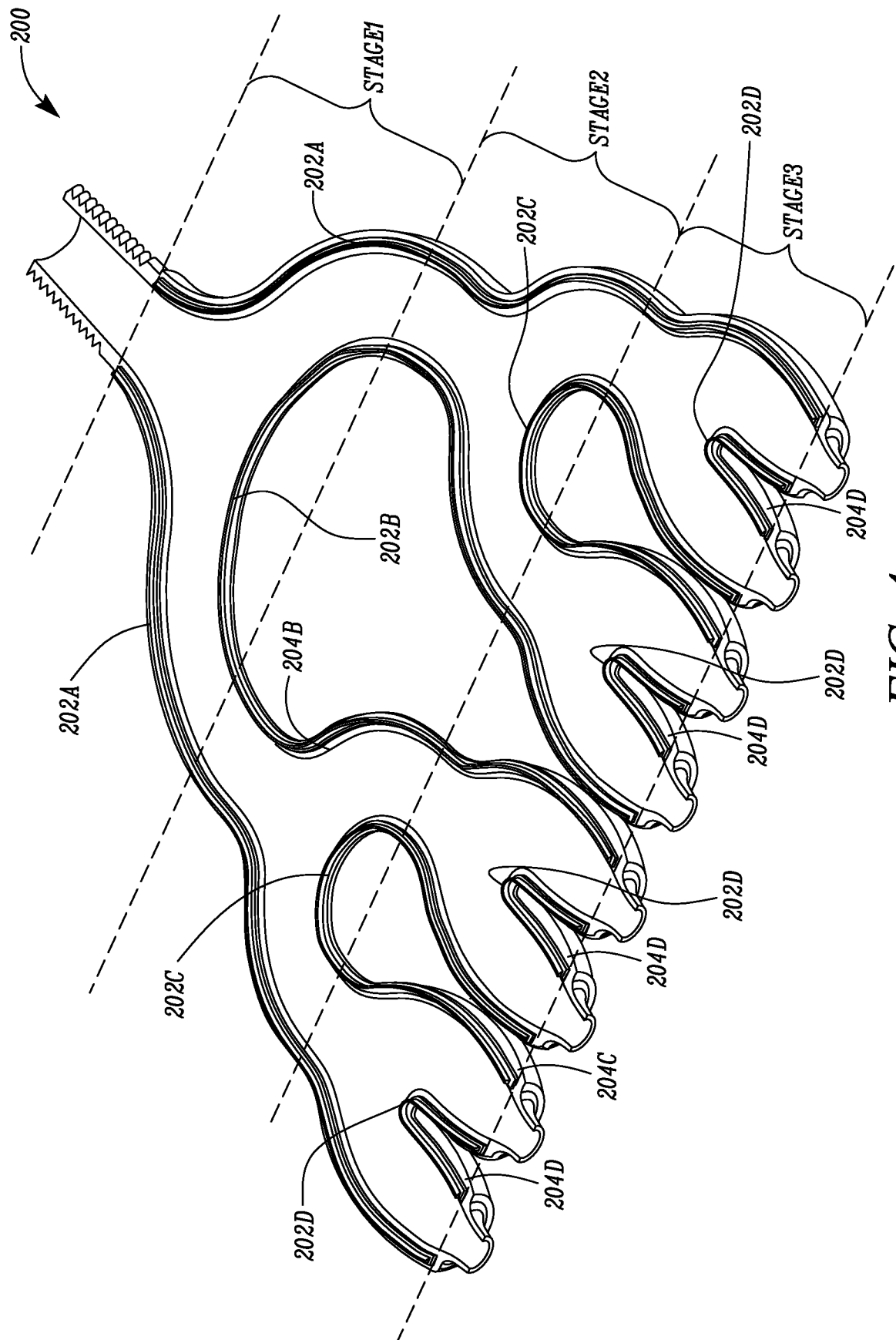


FIG. 4

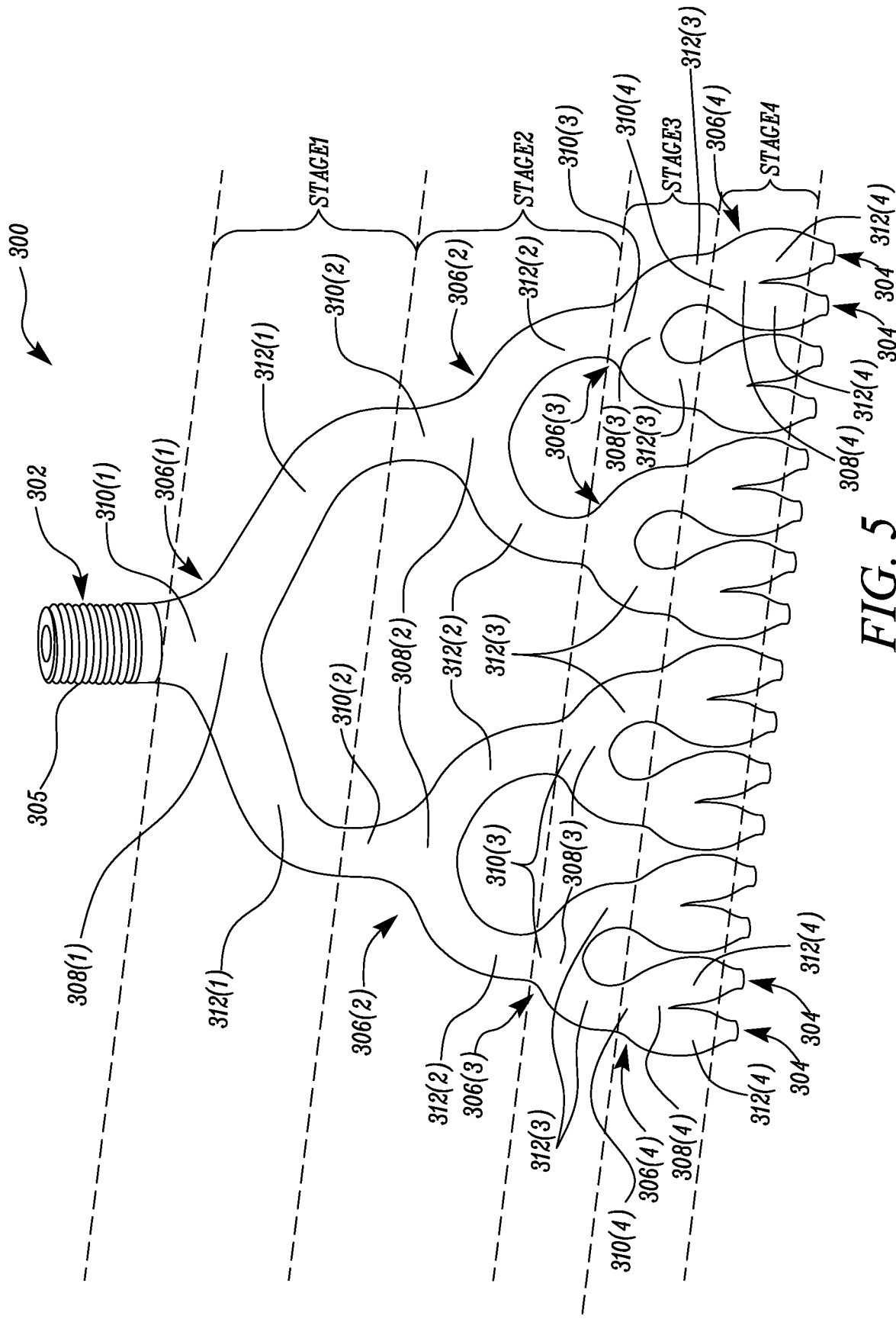
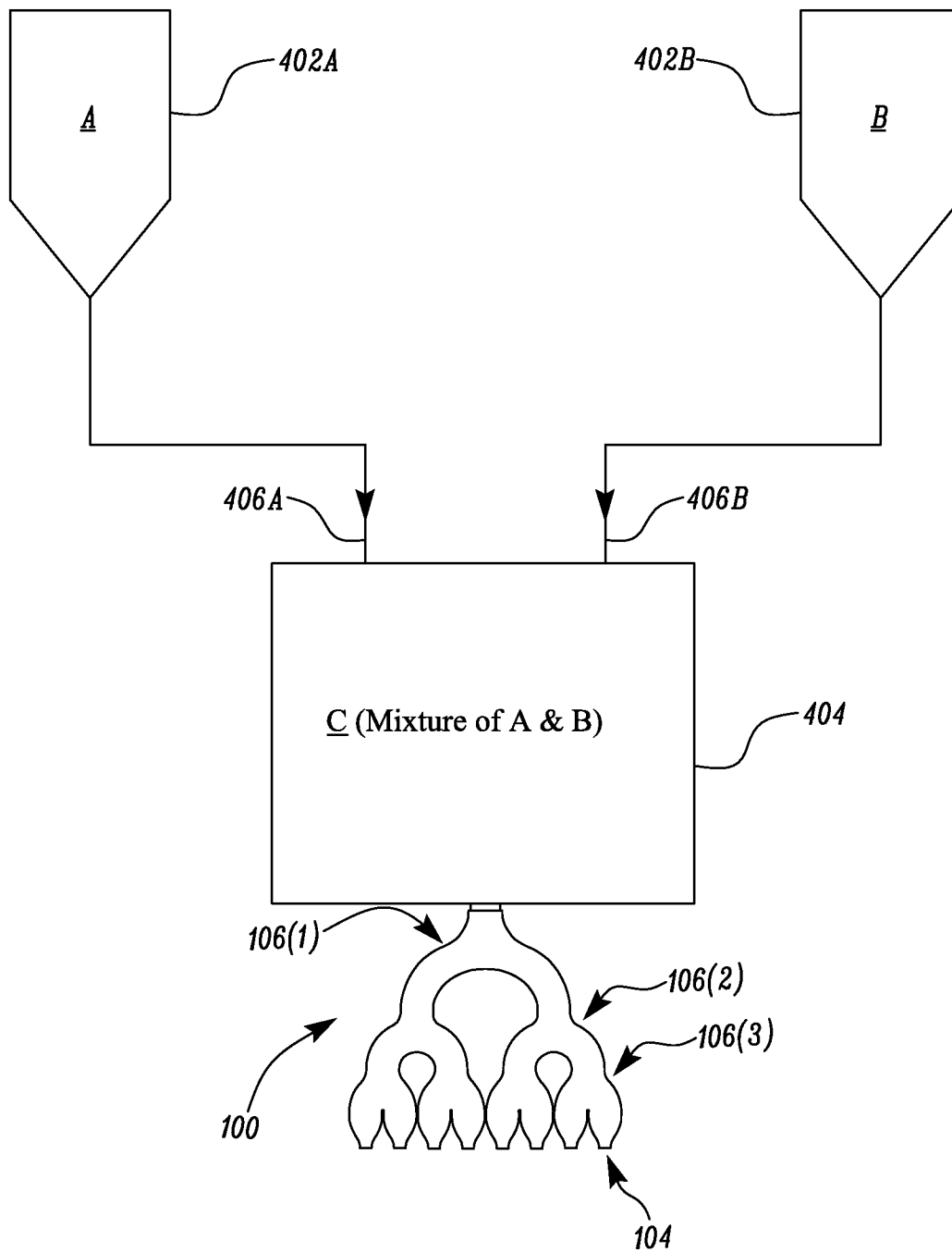
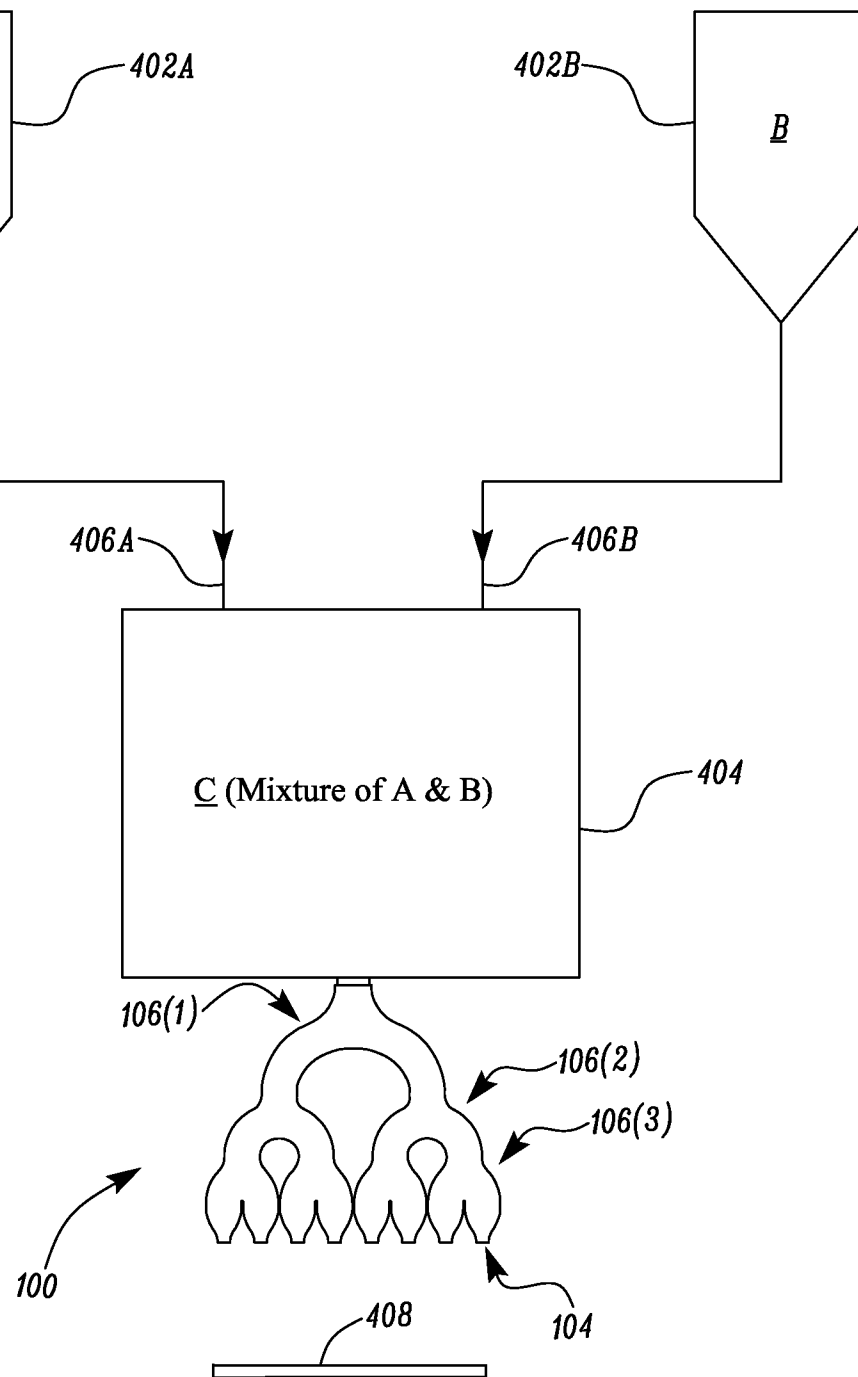
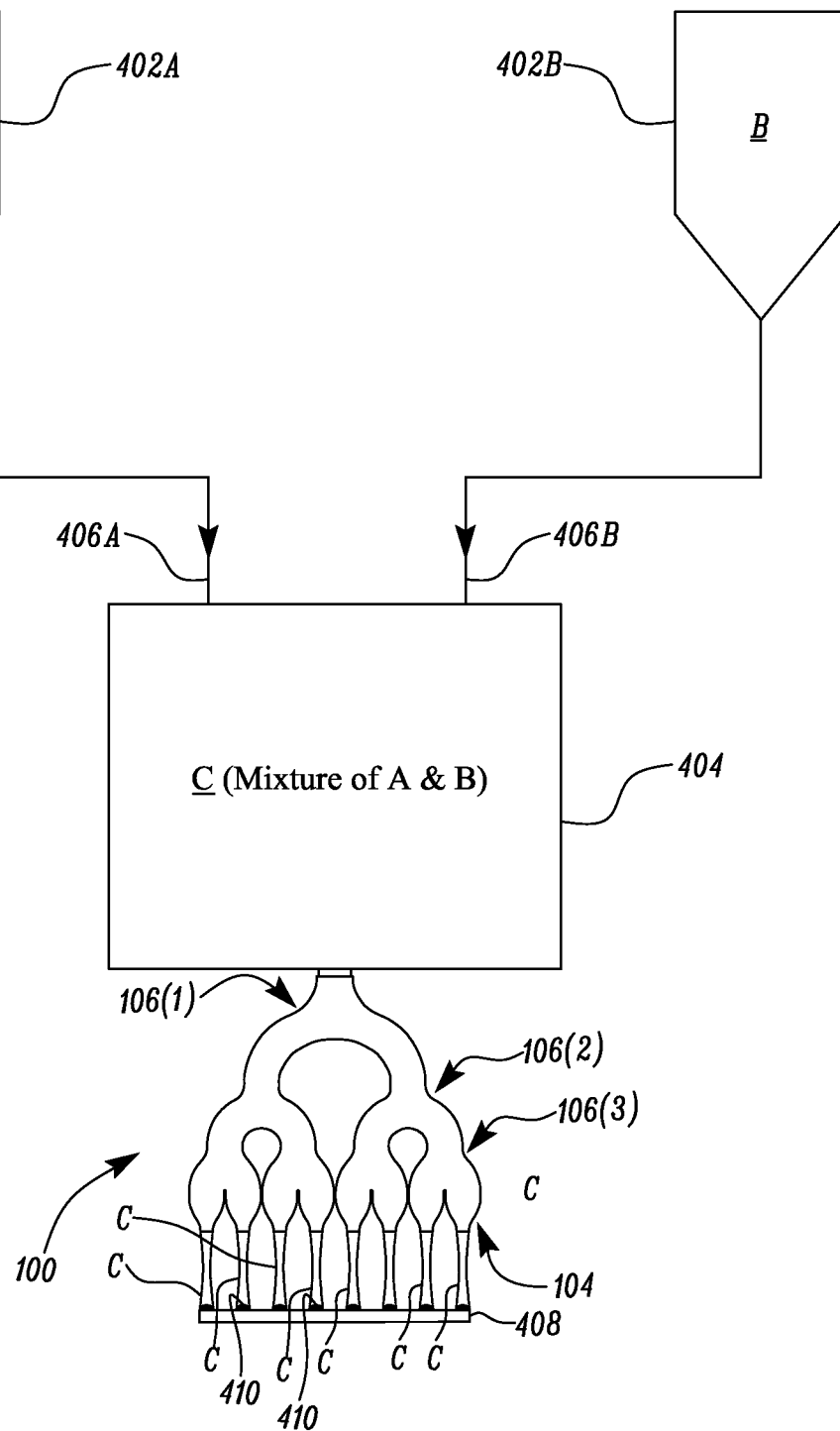
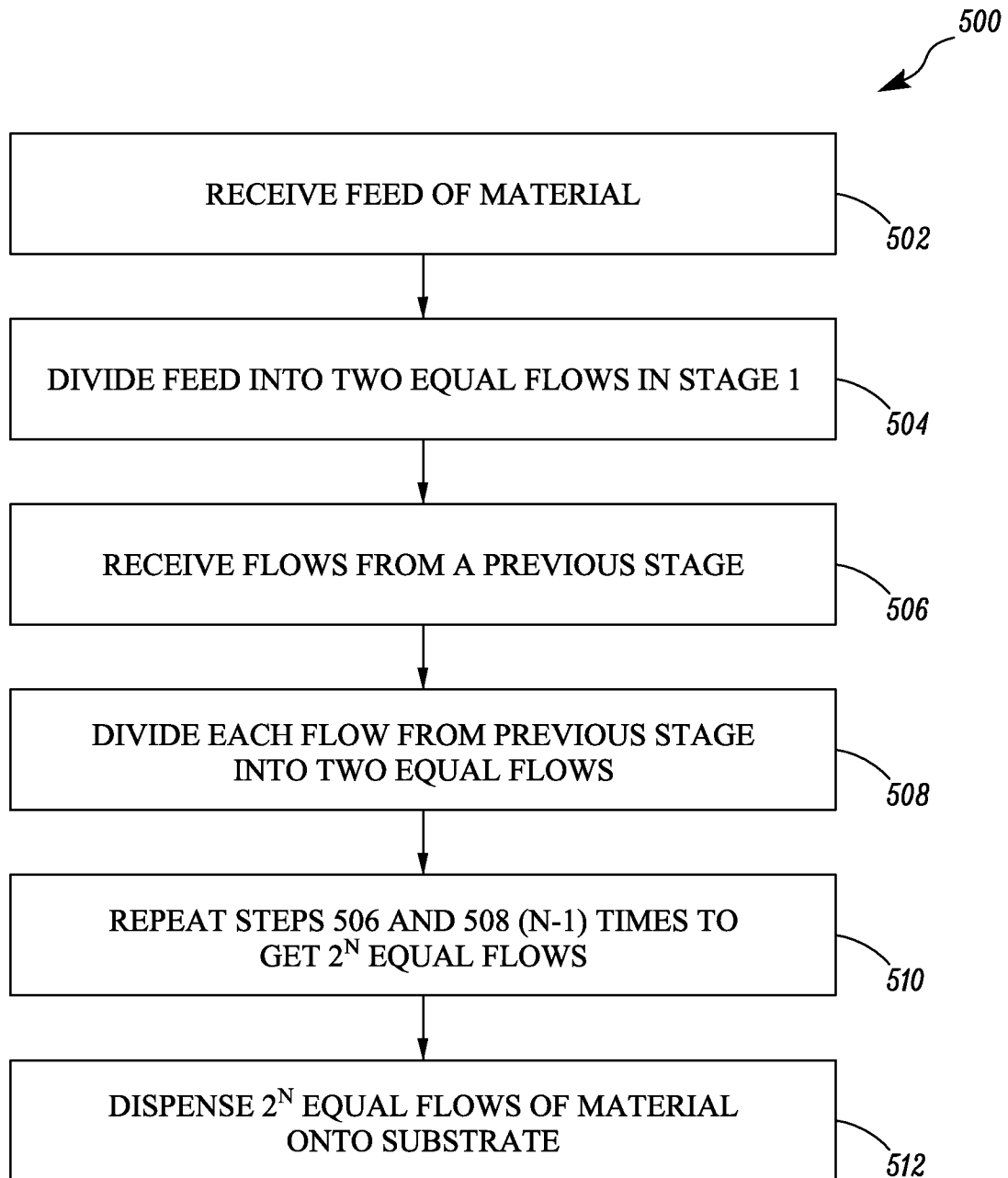


FIG. 5

*FIG. 6A*

**FIG. 6B**

*FIG. 6C*

*FIG. 7*

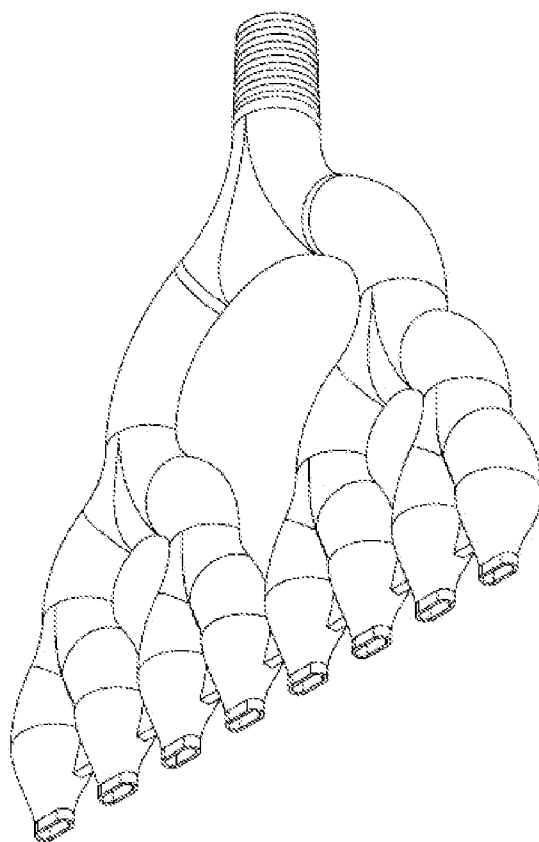


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2014/036729

A. CLASSIFICATION OF SUBJECT MATTER
 INV. H01L21/67 B29C45/27
 ADD.

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)
 H01L B29C

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	WO 2004/103670 A2 (KORTEC INC [US]; SABIN DOUG [US]; SWENSON PAUL [US]) 2 December 2004 (2004-12-02) page 17, line 27 - page 18, line 20; figure 9 -----	1-22



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

14 August 2014

Date of mailing of the international search report

26/08/2014

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/US2014/036729

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