(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
21 August 2008 (21.08.2008)

PCT

(10) International Publication Number
WO 2008/100314 A1

(51) International Patent Classification:
H01L 21/00 (2006.01)

(21) International Application Number:
PCT/US2007/062204

(22) International Filing Date:
15 February 2007 (15.02.2007)

(25) Filing Language: English

(26) Publication Language: English

(71) Applicant *(for all designated States except US)*: **APPLIED MATERIALS, INC.** [US/US]; 3050 Bowers Avenue, Santa Clara, California 95054 (US).

(72) Inventor; and

(75) Inventor/Applicant *(for US only)*: **STOWELL, Michael, W.** [US/US]; 809 White Elm Drive, Loveland, Colorado 80538 (US).

(74) Agent: **STACY, Wayne, O.**; Cooley Godward Kronish LLP, Attn: Patent Group, 11951 Freedom Drive, Reston, VA 20190 (US).

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

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

Published:
— *with international search report*

(54) **Title:** SYSTEM AND METHOD FOR CHEMICAL VAPOR DEPOSITION PROCESS CONTROL

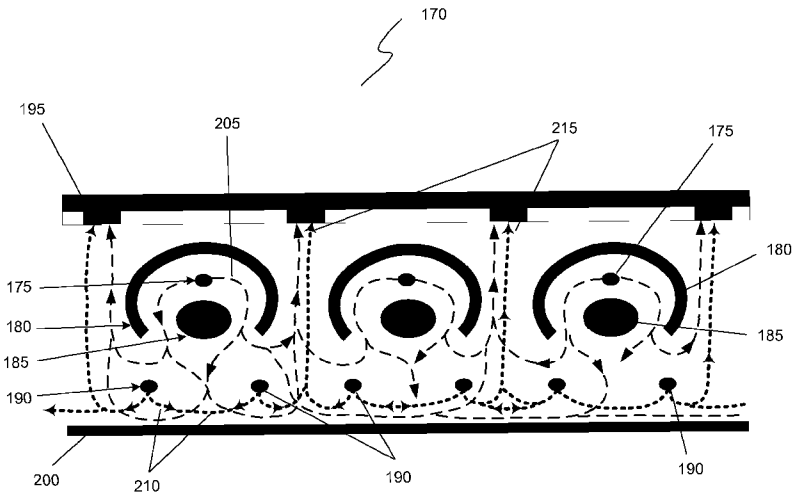


Fig. 3

(57) **Abstract:** A system and method for controlling deposition of thin films on substrates is disclosed. One embodiment includes providing the substrate; providing a plurality of sources configured to emit electromagnetic radiation; providing a first amount of power to a first of the plurality of sources; and providing a second amount of power to a second of the plurality of sources; wherein the first amount of power and the second amount of power are different to thereby control deposition of the film onto the substrate.

WO 2008/100314 A1

SYSTEM AND METHOD FOR CHEMICAL VAPOR DEPOSITION PROCESS CONTROL

RELATED APPLICATIONS

[0001] This application is related to commonly owned and assigned international application no. [not yet assigned], entitled "Localized Linear Microwave Source Array Pumping to Control Localized Partial Pressure in Flat and 3 Dimensional PECVD Coatings", filed simultaneously herewith and incorporated by reference.

COPYRIGHT

[0002] A portion of the disclosure of this patent document contains material that is subject to copyright protection. The copyright owner has no objection to the facsimile reproduction by anyone of the patent disclosure, as it appears in the Patent and Trademark Office patent files or records, but otherwise reserves all copyright rights whatsoever.

FIELD OF THE INVENTION

[0003] The present invention relates to systems and methods for managing vapor deposition processes and for depositing thin films on substrates.

BACKGROUND OF THE INVENTION

[0004] Chemical vapor deposition processes (CVD) are used to deposit non-conductive and conductive films on a variety of substrates. The chemical CVD process has been enhanced by the use of plasma. This process is referred to as plasma enhanced chemical vapor deposition (PECVD). This PECVD process is commonly used in industrial applications.

[0005] PECVD systems are typically driven by high power supplies including microwave, high frequency, very high frequency and radio frequency power supplies. The characteristics of thin films produced by a PECVD process vary substantially and can be controlled by varying the power supply type, the power supply output, carrier gas flow rates, precursor gas

flow rates, partial pressure of gases, and substrate pre-conditioning. By varying these parameters, films of different chemistries and thicknesses can be created.

[0006] Typical PECVD systems include a plurality of sources, also referred to as antennae, anode or cathode typically fixed in a plane. Each of these antennae are connected to a power supply and emit electromagnetic radiation or create electromagnetic fields producing electrons that are used to generate the plasma in a PECVD process. These antennae are typically arranged in a single plane and are used to deposit thin films on flat substrates. This planar array of antennas tends to result in a homogenous film and an even thickness for smaller substrates.

[0007] Unfortunately, this planar antennae array tends to be ineffective for curved substrates and large planar substrates. For example, current PECVD systems have difficulty in controlling gas pressure and gas flows around the edges of large substrates. This control difficulty results in uneven concentrations of carrier gas and precursor gas across the substrate surface—with lower concentrations near the edges. For example, typical PECVD systems pump excess gas and waste materials away from the substrate surface. Typically, this waste gas is pumped from behind the substrate—meaning that the flow of waste gas travels along the surface of the substrate and around the edges. For large substrates the gas concentrates at these edges and can dramatically change the film properties and deposition rates at the edges. Accordingly, a system and method are needed to better control PECVD processes and produce more uniform films.

SUMMARY OF THE INVENTION

[0008] Exemplary embodiments of the present invention that are shown in the drawings are summarized below. These and other embodiments are more fully described in the Detailed

Description section. It is to be understood, however, that there is no intention to limit the invention to the particular forms described in this Summary of the Invention or in the Detailed Description. One skilled in the art can recognize that there are numerous modifications, equivalents and alternative constructions that fall within the spirit and scope of the invention as expressed in the claims.

[0009] A system and method for controlling deposition of thin films on substrates is disclosed. One embodiment includes providing the substrate; providing a plurality of sources configured to emit electromagnetic radiation; providing a first amount of power to a first of the plurality of sources; and providing a second amount of power to a second of the plurality of sources; wherein the first amount of power and the second amount of power are different to thereby control deposition of the film onto the substrate.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Various objects and advantages and a more complete understanding of the present invention are apparent and more readily appreciated by reference to the following Detailed Description and to the appended claims when taken in conjunction with the accompanying Drawings wherein:

FIGURE 1 illustrates a cross section of a PECVD system;

FIGURE 2 is a block diagram of a PECVD system for coating a curved substrate;

FIGURE 3 illustrates a block diagram of a PECVD system designed to minimize edge effects and better control the deposition process;

FIGURE 4 illustrates a front view of the inside of the PECVD system shown in Figure 3;

FIGURE 5 illustrates another embodiment of a PECVD system;

FIGURE 6 illustrates a front view of the PECVD system of Figure 5;

FIGURE 7 illustrates one embodiment of a component of a drop tube;

FIGURE 8 illustrates a front view of a PECVD system that uses dual volume precursor drop tubes;

FIGURE 9 illustrates another embodiment of a PECVD system that can be used for dual-side coating of curved or flat substrates;

FIGURE 10 illustrates another embodiment of a PECVD system with power contouring; and

FIGURE 11 illustrates another embodiment of a PECVD system with power contouring.

DETAILED DESCRIPTION OF THE DRAWINGS

[0011] Referring now to the drawings, where like or similar elements are designated with identical reference numerals throughout the several views, and referring in particular to FIGURE 1, it illustrates a cross section of a PECVD system 100. This system includes a substrate 105, a carrier gas supply 110, a precursor gas supply 115, a pump 120, and three sources 125. Those skilled in the art understand that this system would also include a power source, a vacuum system, process chamber walls, a vacuum chamber and a substrate carrier. But for clarity, these elements are not illustrated in Figure 1.

[0012] In operation, the substrate 105 is placed inside the vacuum chamber. Power is supplied to the three sources 125. As previously mentioned, this power could be any type of high-energy power supply including RF, HF, VHF, etc. The sources 125, which are typically surrounded by dielectrics such as quartz, creates electrons that collide with carrier gas molecules introduced through the carrier gas supply. These collisions fractionalize the carrier gas molecules, thereby producing radicals and forming a plasma around the sources. The radicals cause a cascade reaction by colliding with other carrier gas molecules, forming even more radicals. These radicals then collide with the precursor gas molecules introduced

through the precursor gas supply, thereby causing the precursor gas molecules to fractionalize. Portions of the precursor gas molecules deposit upon the substrate 105. Waste portions of the precursor gas molecules are pumped away from the substrate 105 by the pump 120 located on the back side of the substrate 105. This pump 120 also pumps away excess carrier gas molecules.

[0013] The arrows in Figure 1 show the approximate flow path of the carrier gas, the precursor gas, and the waste gas. For example, flow path 130 illustrates the path that the carrier gas would follow, flow path 135 illustrates the flow path that the precursor gas would follow, and flow path 140 illustrates the path that the pumped off waste gas would follow from the substrate 105 to the pump 120. The concentration of gas, including precursor and carrier gas, is lower near the edges than it is in the center of the substrate.

[0014] Referring now to Figure 2 it is a block diagram of a PECVD system 145 for coating a curved substrate 150. This system includes a curved substrate 150, a carrier gas supply 155, a precursor gas supply 160, and a pump 165 located on the back side of the curved substrate 150.

[0015] Curved substrates present particular difficulty for the thin film industry because of the difficulty in depositing a uniform film. This embodiment attempts to compensate for the curved substrate by providing different length precursor gas supplies 160. The goal of the different length supplies is to release precursor gas at a fixed distance from the surface of the substrate. This fixed distance helps promote even film thickness across the substrate. Even with variable length precursor gas supply tubes, this system still suffers from the edge effect caused by backside pumping. That is, the gas flow rate and the gas concentration are lower at the edges of the curved substrate than they are in the center of the substrate. Accordingly, film thickness and chemistry varies at the edges of the substrate.

[0016] Referring now to Figure 3, it illustrates a block diagram of a PECVD system 170 designed to minimize edge effects and better control the deposition process. This system includes a carrier gas source 175, a shield 180, three sources 185, a precursor gas source 190, a pump 195, and a substrate 200.

[0017] In this embodiment of the PECVD system, the back side pump is replaced with a pump 195 (and corresponding duct work) that is opposite the substrate surface. For the purpose of this document, this general style of pumping will be referred to as back-side pumping. It can be used independently or in conjunction with front-side pumping.

[0018] By using back-side pumping rather than only front-side pumping, the substrate 200 is effectively divided into localized areas that can be more finely controlled. In this example, edge effects are greatly reduced because pumping is performed relatively near to where the precursor gas is released and where the waste particles are formed.

[0019] In this embodiment, the carrier gas supply 175 is located inside the shield 180 that partially surrounds the source 185. By locating the carrier gas supply 175 inside this shield 180, carrier gas concentrations and pressures can be more finely controlled. Moreover, the shield 180 helps to increase the fractionalization percentage of the carrier gas over a system that does not include a shield 180. This component composed of or coated with dielectric materials reduces the recombination of the radicalized species further increasing the available radical for the process.

[0020] The flow arrows in Figure 3 help illustrate the flow paths of the carrier gas, the precursor gas, and the waste gas. Flow arrow 265 illustrates the path that the carrier gas follows from the carrier gas supply to the substrate and then back to the pump. Flow arrow 210 illustrates the path that the precursor gas follows from the precursor gas supply toward

the substrate 200 and back toward the pump 195. And finally, flow arrow 215 illustrates the combined waste gas that is being pumped away from the substrate 200 and out of the PECVD chamber.

[0021] Figure 4 illustrates a front view of the inside of the PECVD system 170 shown in Figure 3. This illustration shows that the precursor gas supply 190 runs parallel to the substrate 200 and is roughly the length of the source 185. Only three sources 185 are illustrated, but those skilled in the art will understand that any number of sources and gas supplies can be used.

[0022] Referring now to Figure 5, it illustrates another embodiment of a PECVD system 220. This system includes three sources 225, three shields 230, carrier gas supplies 235, precursor gas supplies 240, a top-side pump 245, and a substrate 250. In this embodiment, the precursor gas supplies 240 are a series of drop tubes rather than a series of linear tubes. These drop tubes can provide even more precision in delivering the precursor gas to an area near the substrate surface. This embodiment also includes a different configuration for front-side pumping that is included in the embodiment of Figure 4.

[0023] Referring now to Figure 6, it illustrates a front view of the PECVD system of Figure 5, in particular, this front view diagram shows that multiple precursor drop tubes 240 would be utilized along the width of the substrate. These tubes are perpendicular to the substrate. In certain embodiments, these drop tubes are coated with a dielectric to minimize recombination, prevent etching by the plasma and to minimize deposition upon the tubes.

[0024] Referring now to Figure 7, it illustrates one embodiment of a component of a drop tube. In particular, Figure 7 illustrates a dual-volume drop tube 260 that can be used to deliver precursor gas. This embodiment includes a first volume 265 that delivers the

precursor gas to the substrate surface and a second volume 270 that provides pumping to remove waste gas from near the substrate surface. This embodiment also includes a flow regulator 275 that could be manually or computer controlled to vary the flow of precursor gas through the first volume 265. This embodiment further includes a discharge volume 280 to which many tubes can be connected so that the waste gas could be pumped away. The use of this dual-volume drop tube 260 provides highly localized precursor delivery and pumping. By providing such highly localized delivery and pumping, film chemistry and thickness can be precisely controlled for large substrates and curved substrates.

[0025] Figure 8 illustrates a front view of a PECVD system 285 that uses dual volume precursor drop tubes. This embodiment includes power generators 290 connected to a series of split sources 295 and an array of dual volume drop tubes 300. In one embodiment each of these drop tubes can be individually controlled by an attached flow regulator. Alternatively groups of the drop tubes could be separately controllable by the flow regulator. Independent control permits localized control of film properties and greatly reduces edge effects.

[0026] Figure 9 illustrates another embodiment of a PECVD system 305 that can be used for dual-side coating of curved or flat substrates. This system includes a plurality of dual-volume drop tubes on both sides of the substrate 335. In this embodiment the dual volume drop tubes 310 have a staggered length. That is, one portion of the drop tube is a different length of the other portion of the drop tube. This variable length can be used to change pumping effects.

[0027] This PECVD system 305 includes a plurality of drop tubes 310, an exhaust pump 315, an exhaust 320 connected to the drop tubes 310 and exhaust pump 315, a series of flow regulators 322, a precursor gas supply 325, and a computer system 330 connected to the flow regulators.

[0028] Referring now to Figures 10 and 11, they illustrate other embodiments of a PECVD system. In these embodiments, the gas supplies and pump are not shown, but those skilled in the art understand that the elements are present. The embodiment of Figure 10 illustrates the process chamber 340, the power supply 345, a curved substrate 350, and an array of sources 355.

[0029] Referring to Figure 11, the sources 360 are driven with different amounts of power. As previously discussed, the deposition rate and film chemistry can be altered by altering the power applied to a source. In typical systems, power is applied evenly across all sources in the array of sources. In this system however, the power is varied at each source based, for example, upon the source's distance from the surface of the substrate 365. For example, in this embodiment, sources 360A are operated at a higher power than are sources 360B because sources 360A are further from the substrate than are sources 360B.

[0030] This system also includes a power regulator 370 configured to vary the power applied at each source according to configurations set by the user. Accordingly, such a system could be rapidly reconfigurable to evenly coat any type of curved substrate. Similarly, this variable source power arrangement could be used to coat flat substrates and compensate for edge effects by applying, for example, less power to sources near the edges than is applied to sources in the center of the substrate.

[0031] The exact amount of power applied to individual sources will vary according to precursor-gas type, supporting-gas type, substrate type, desired film properties, vacuum chamber pressures, characteristics of particular coating machines, etc. Those of skill in the art can easily select power amounts to produce the desired type of film. Some experimentation will likely be necessary due the variances in coating machines and other characteristics.

[0032] This variable power embodiment could be utilized by itself or could be utilized in combination with the previously described precursor gas delivery system and excess gas pumping systems.

[0033] In conclusion, the present invention provides, among other things, a system and method for controlling a chemical vapor deposition process. Those skilled in the art can readily recognize that numerous variations and substitutions may be made in the invention, its use and its configuration to achieve substantially the same results as achieved by the embodiments described herein. Accordingly, there is no intention to limit the invention to the disclosed exemplary forms. Many variations, modifications and alternative constructions fall within the scope and spirit of the disclosed invention as expressed in the claims.

WHAT IS CLAIMED IS:

1. A method for depositing a film on a substrate, the system comprising:

providing the substrate;

providing a plurality of sources configured to emit electromagnetic radiation or create electromagnetic fields;

providing a first amount of power to a first of the plurality of sources; and

providing a second amount of power to a second of the plurality of sources;

wherein the first amount of power and the second amount of power are different to thereby control deposition of the film onto the substrate.

2. The method of claim 1, further comprising:

selecting the first amount of power based at least upon the distance from the first source to the substrate.

3. The method of claim 2, further comprising:

selecting the second amount of power based at least upon the distance from the second source to the substrate.

4. The method of claim 1, wherein the plurality of sources is a first plurality of sources and wherein the first plurality of sources is positioned on a first side of the substrate, the method further comprising:

providing a second plurality of sources configured to emit electromagnetic radiation, the second plurality of sources positioned on a second side of the substrate.

5. The method of claim 4, wherein the second plurality of sources comprises a third source and a fourth source, the method further comprising:

providing a third amount of power to the third source; and

providing a fourth amount of power to a fourth source;

wherein the third amount of power and the fourth amount of power are different to thereby control deposition of the film onto the second side of the substrate.

6. The method of claim 1, further comprising:

selecting the first amount of power and the second amount of power to create a film on the substrate of near even thickness.

7. The method of claim 6, further comprising:

selecting the first amount of power and the second amount of power to create a film on the substrate of near homogenous chemical composition.

8. The method of claim 1, further comprising:

providing a power source configured to provide power to the plurality of sources;

providing a power regulator configured to operate with the power source;

wherein the power regulator controls the amount of power provided by the power source.

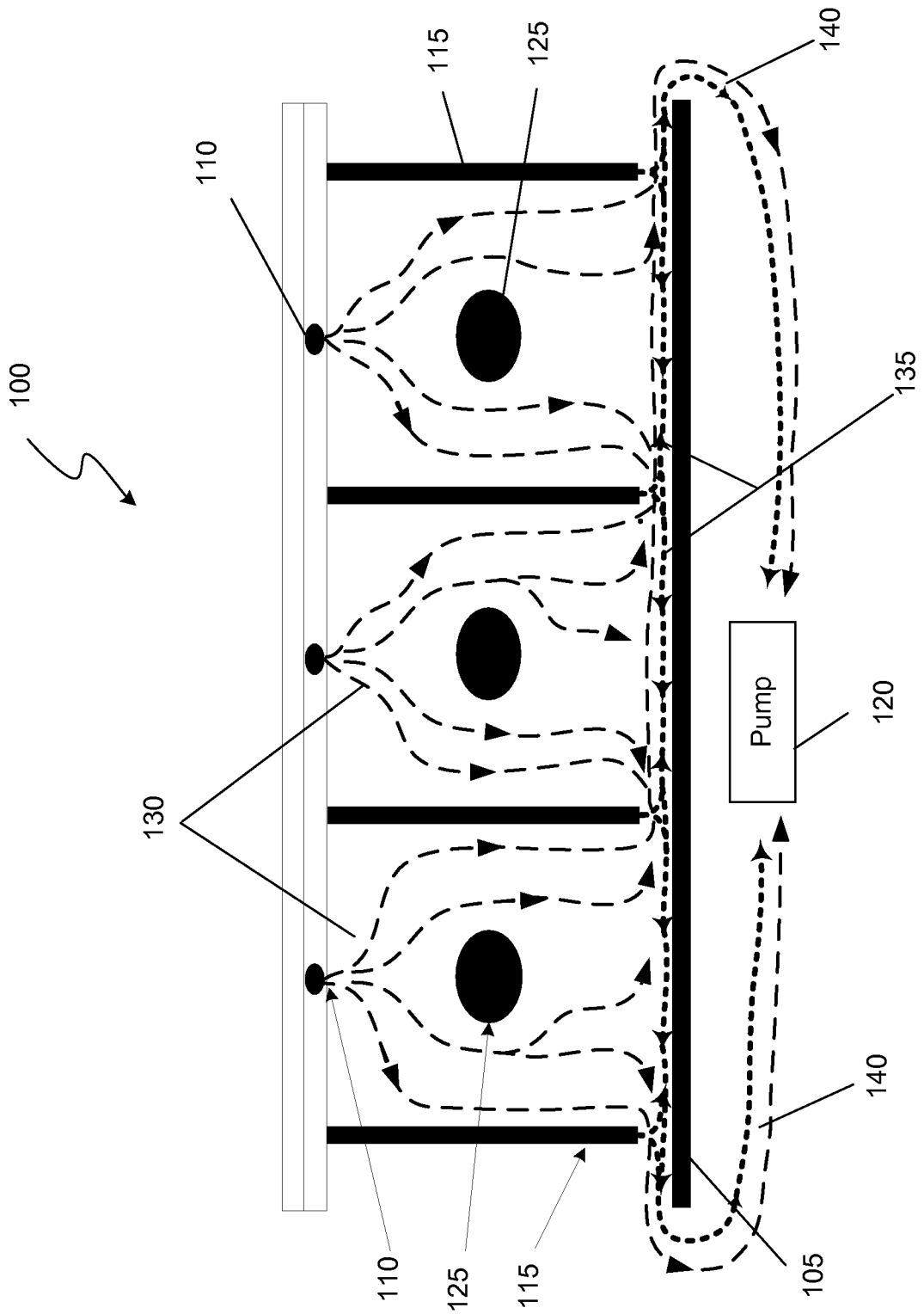


Fig. 1

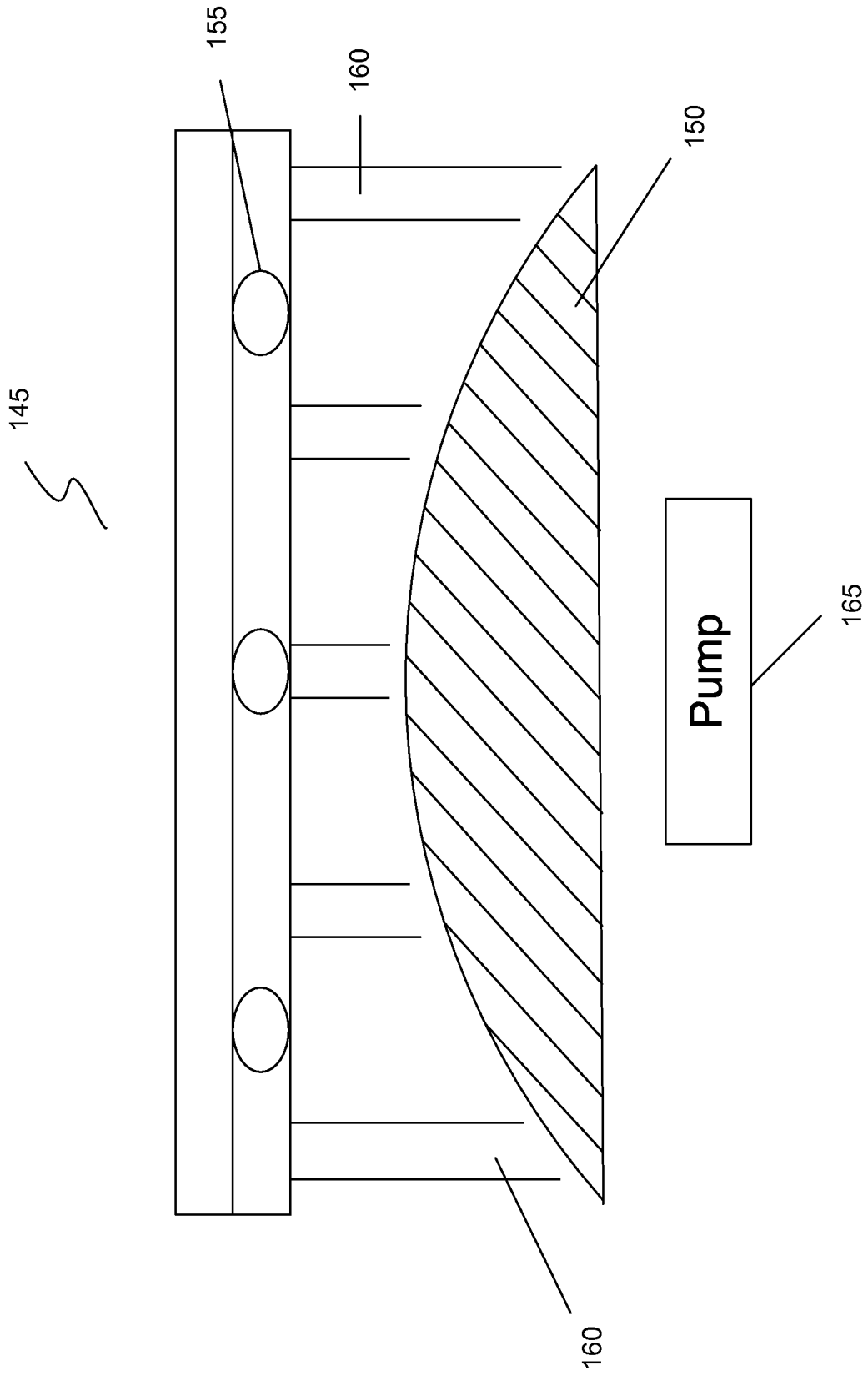


Fig. 2

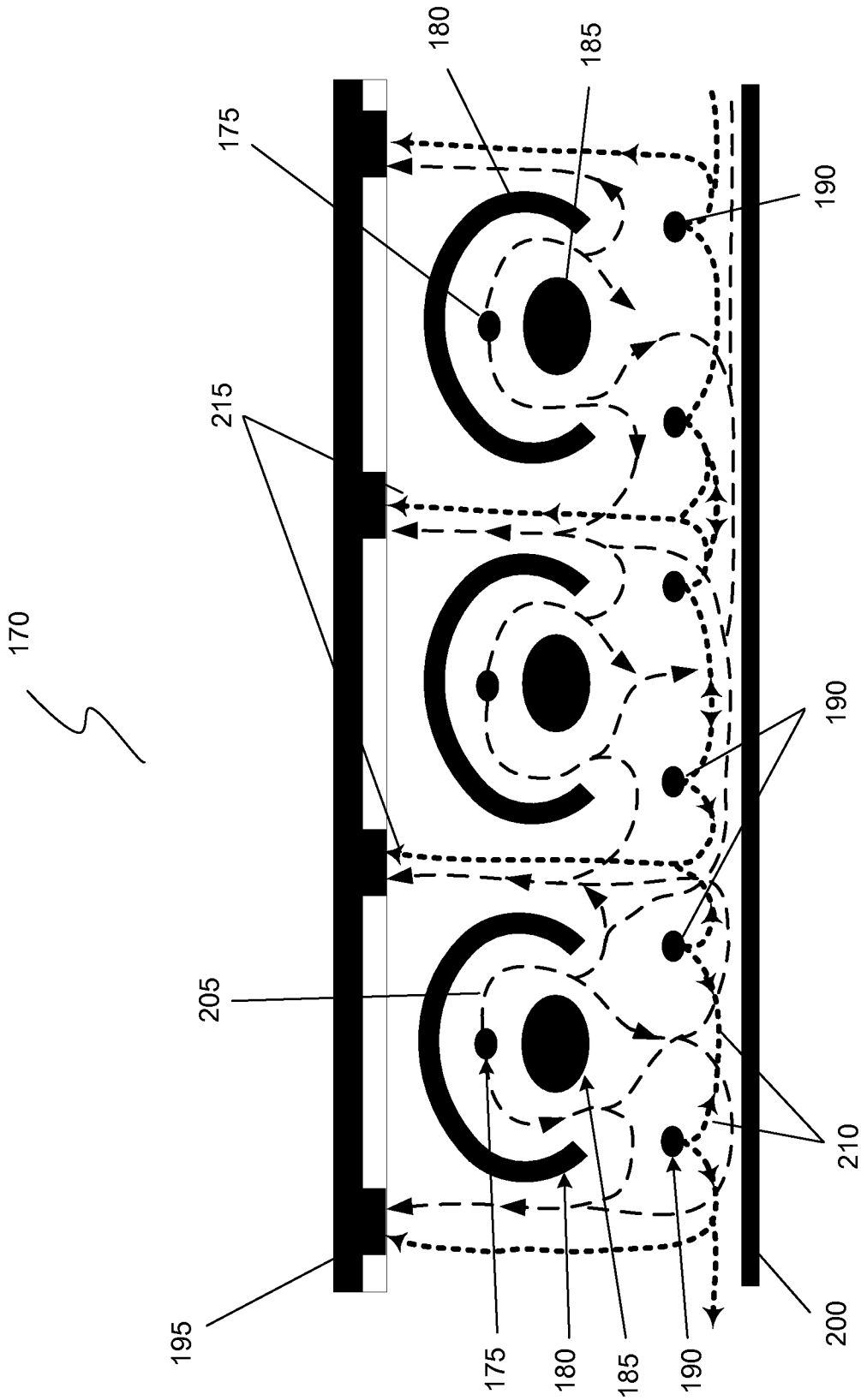


Fig. 3

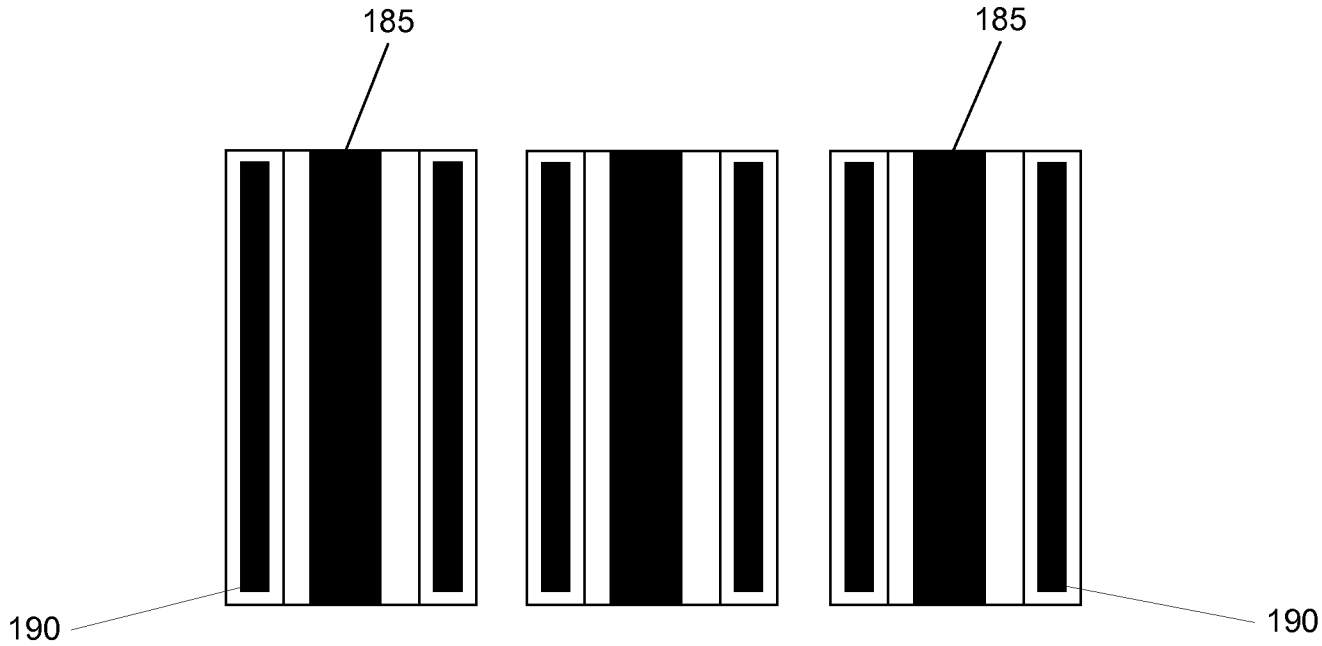


Fig. 4

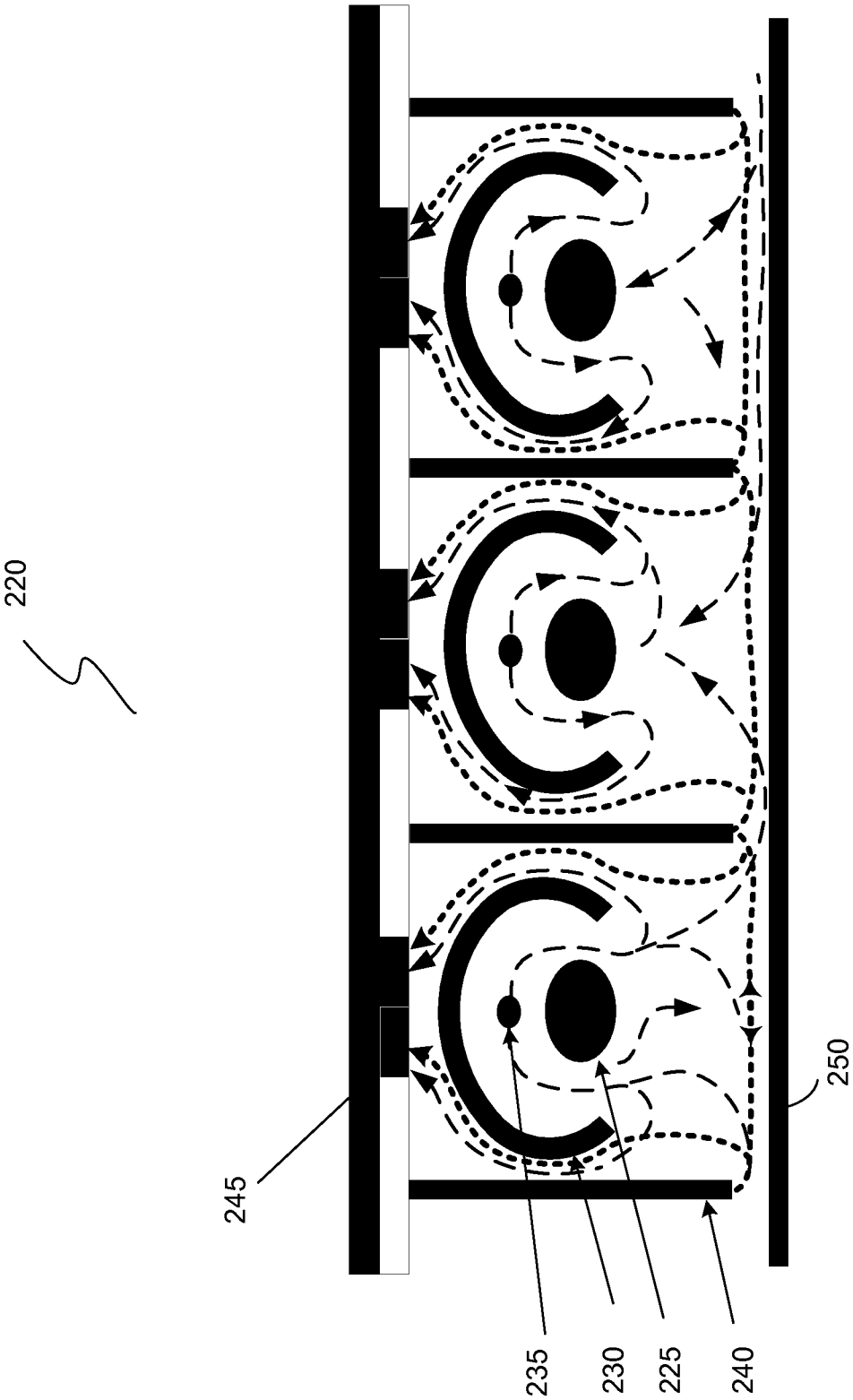


Fig. 5

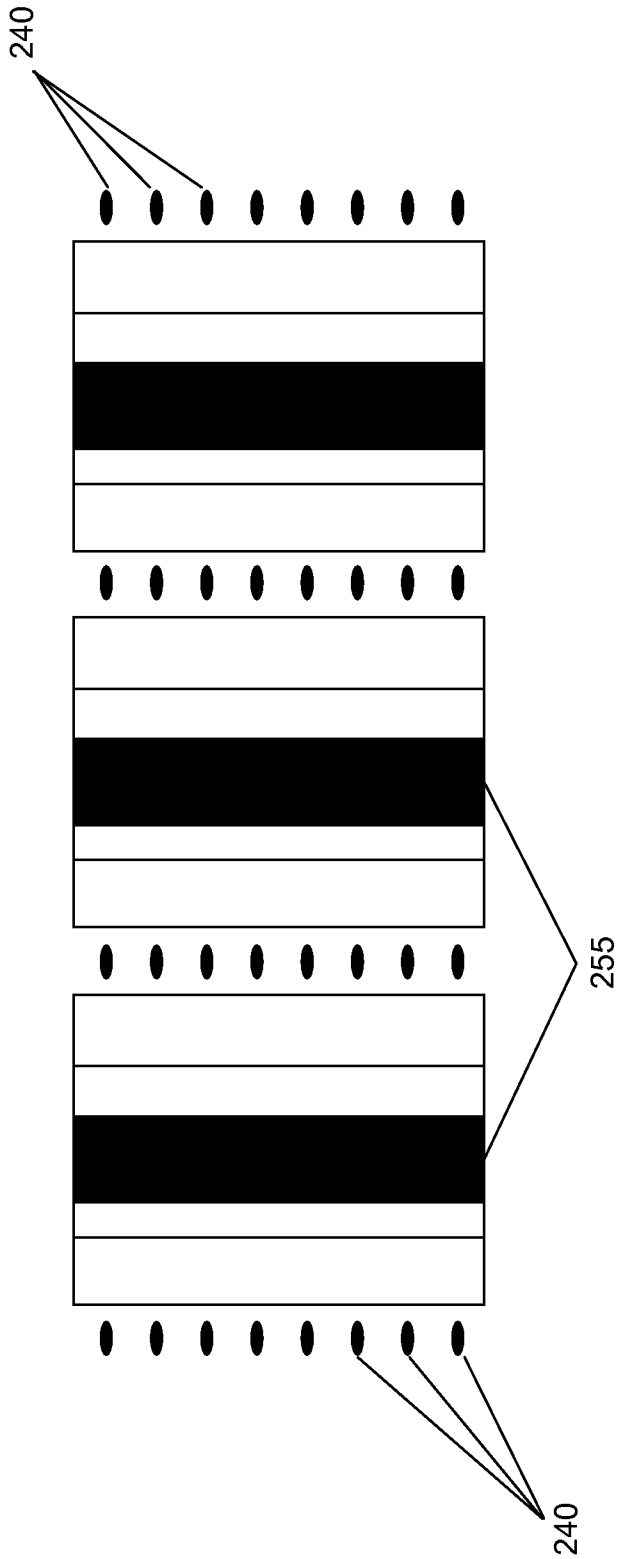


Fig. 6

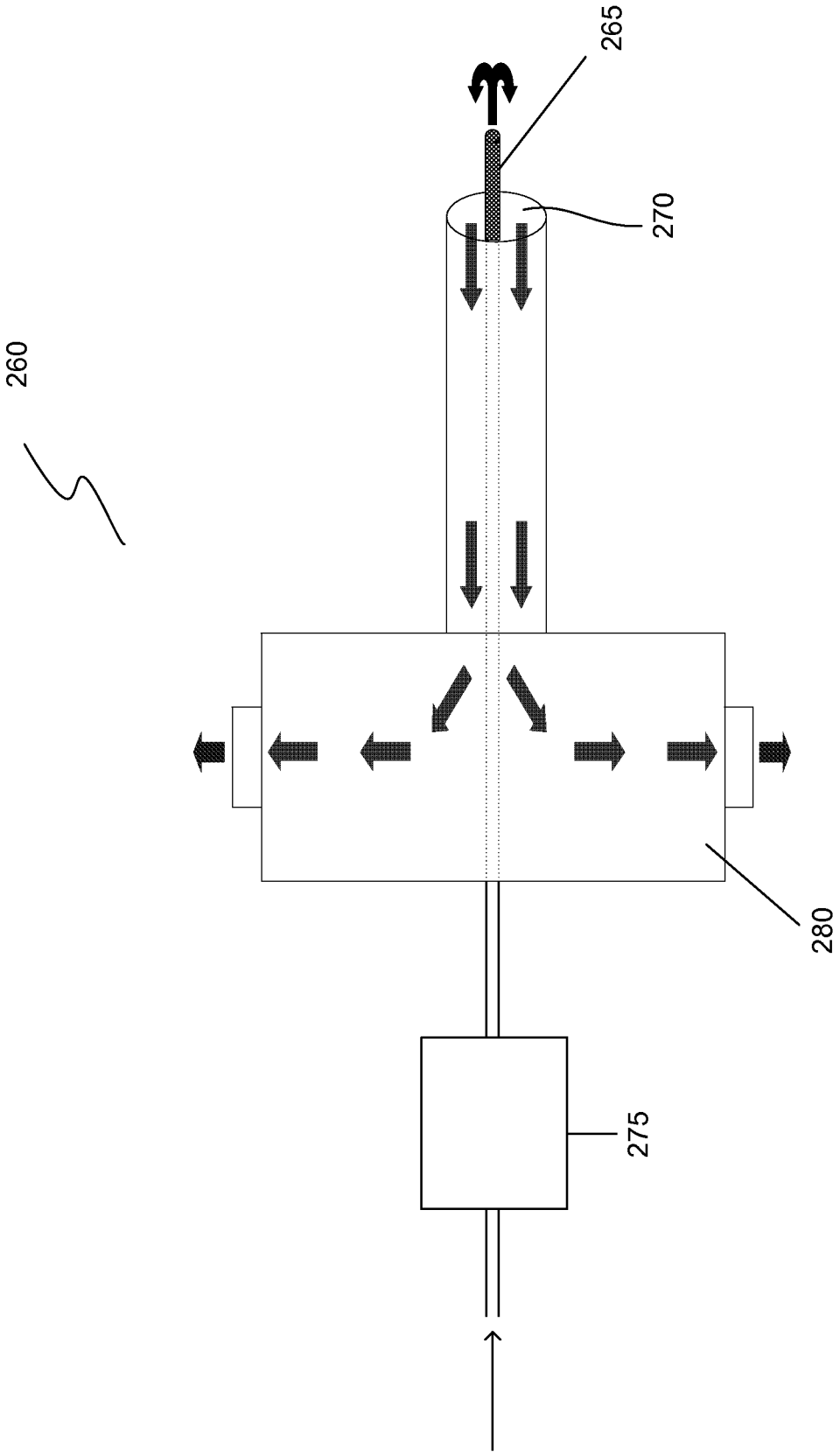


Fig. 7

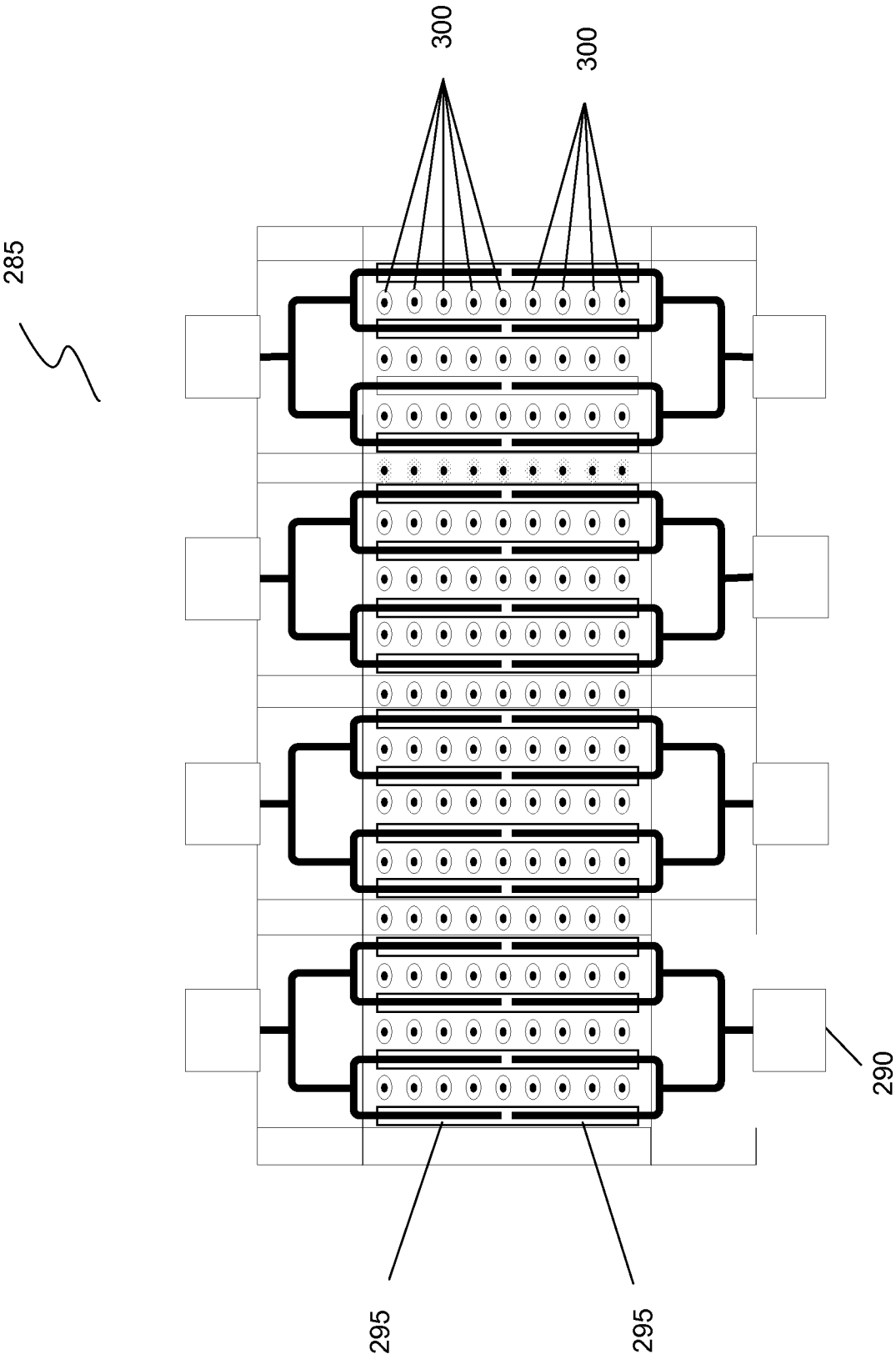


Fig. 8

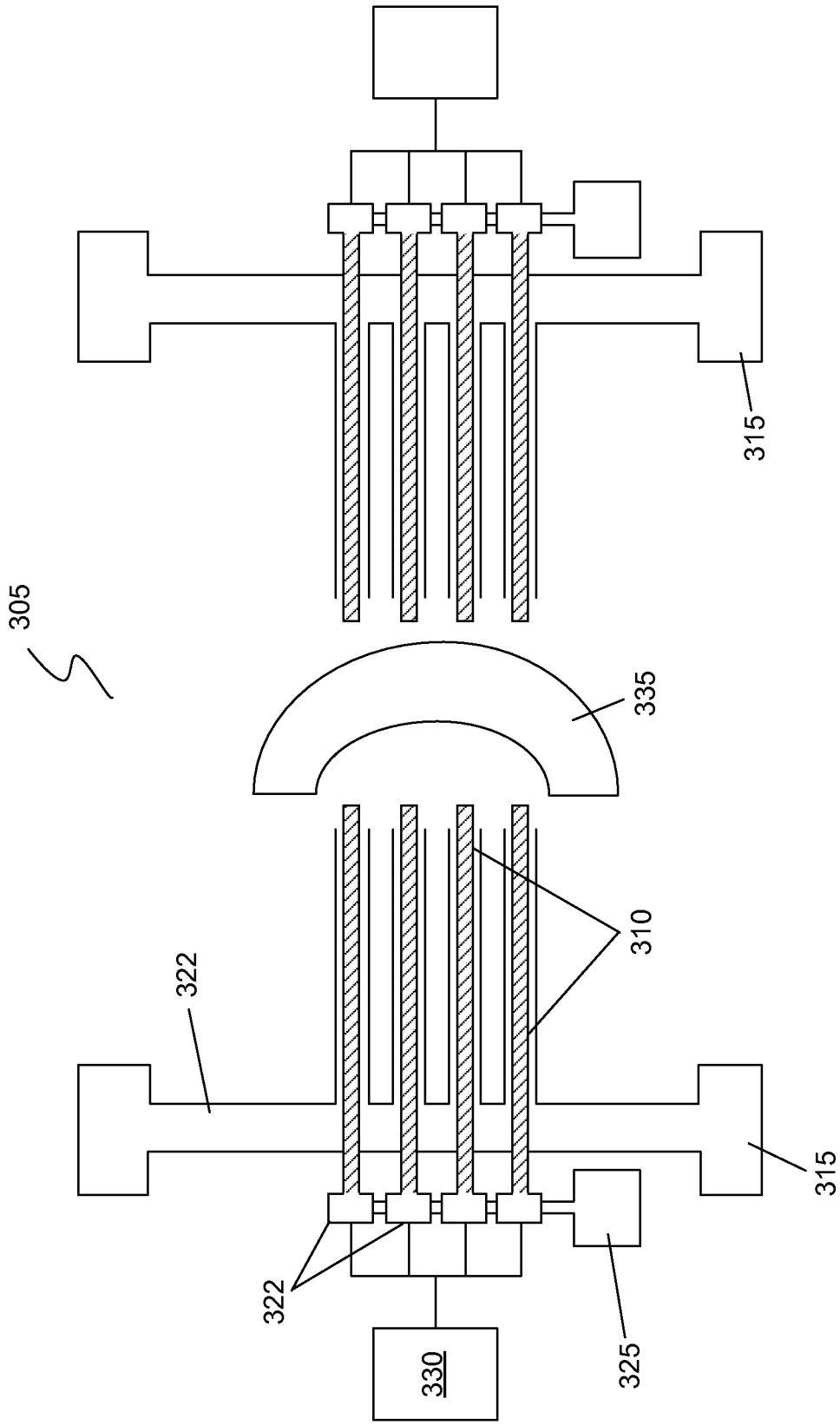


Fig. 9

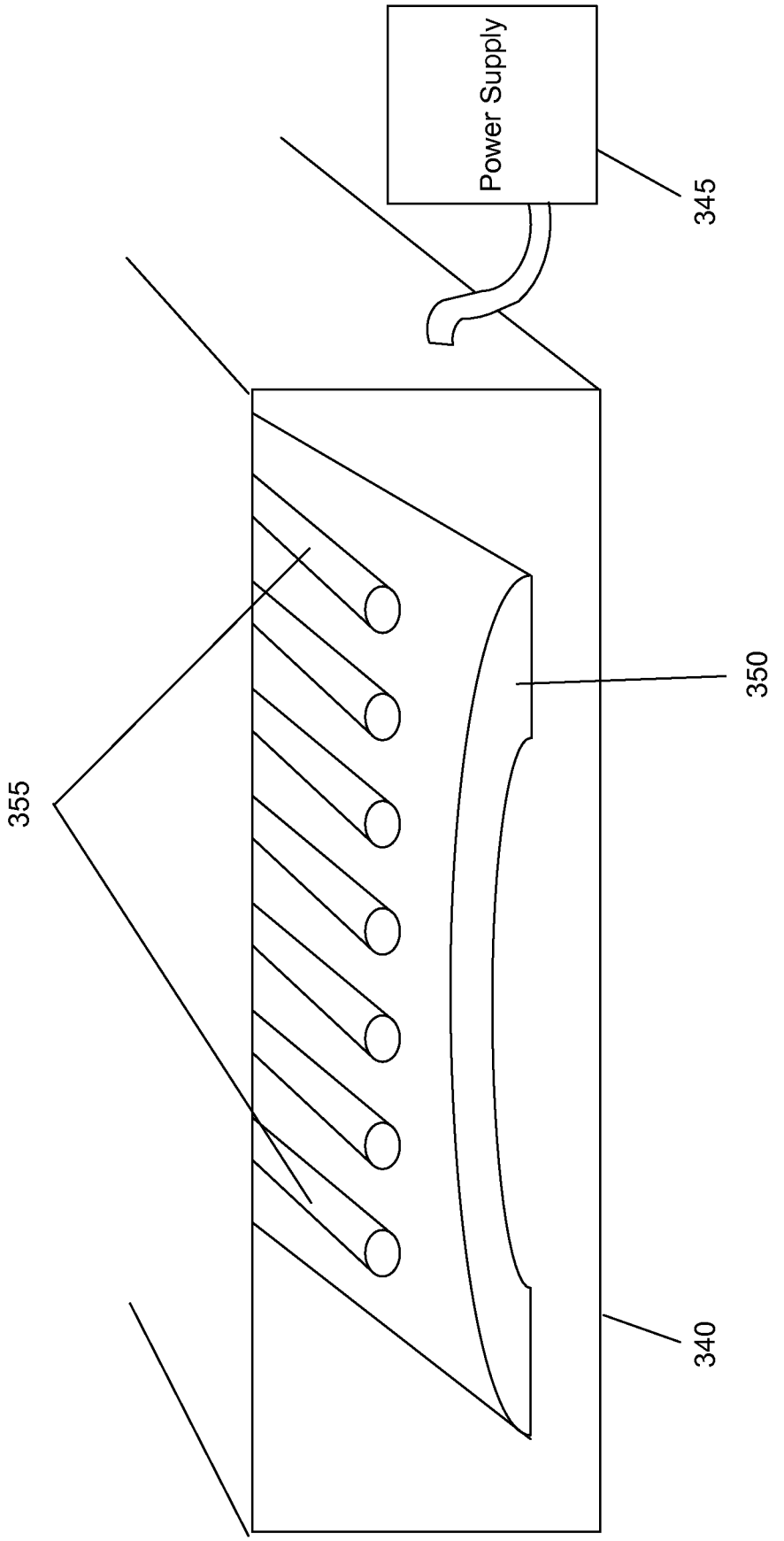


Fig. 10

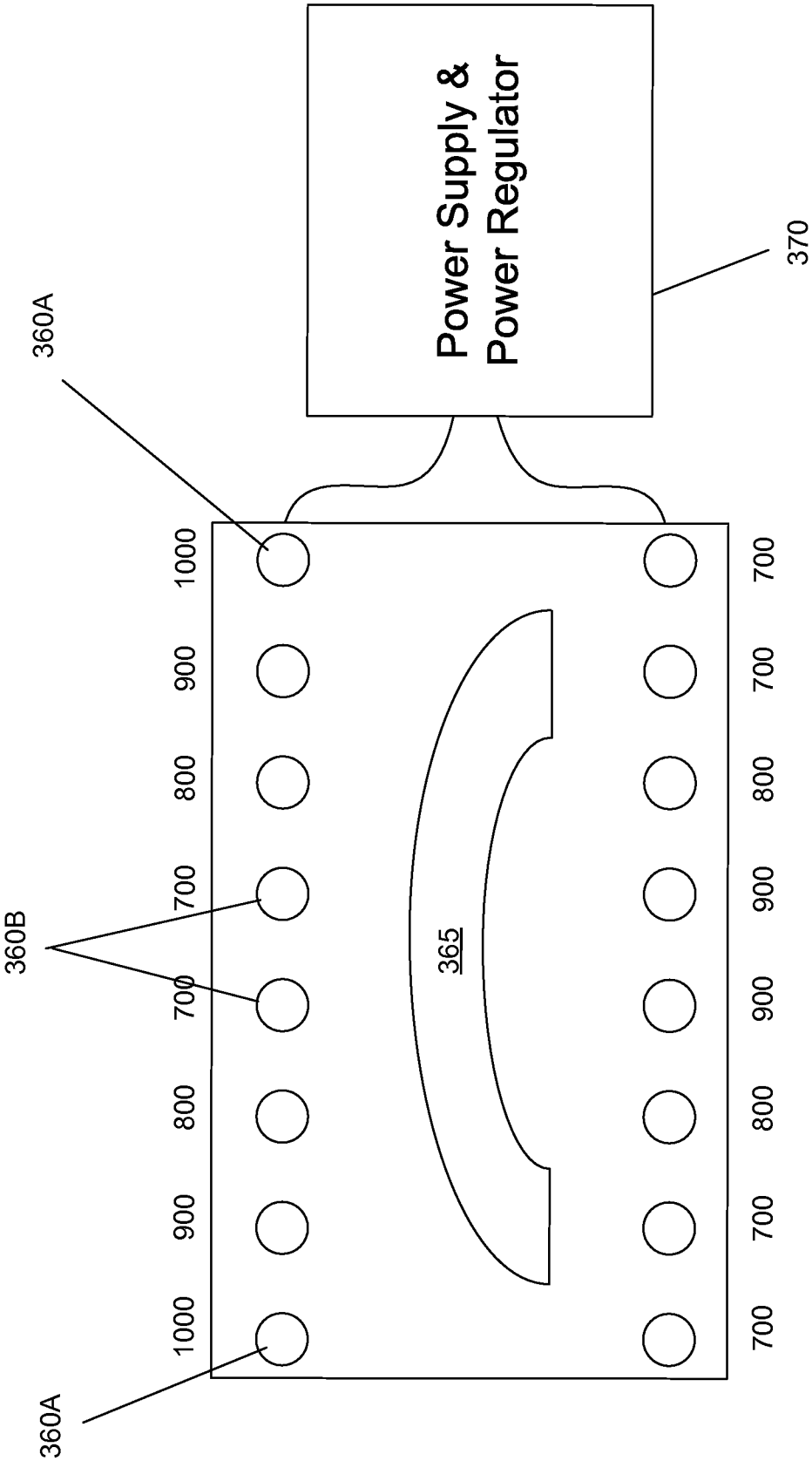

Power Supply &
Power Regulator
370
360A
360B
360A
1000
900
800
700
700
800
900
1000
700
700
800
900
700
700
800
900
365

Fig. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 07/62204

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - H01L 21/00 (2007.10)
USPC - 438/795
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)
USPC -- 438/795, 438/758, 438/800, 438/771

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC -- 438/795, 438/758, 438/800, 438/771 - text word limited - see below

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WEST -- PGPB,USPT,USOC,EPAB,JPAB; Dialog Classic Files 351, 2, 6, 35, 65; Google Patents; Google Scholar; USPTO Web Page
Search terms -- substrate, film, deposition, PECVD, power sources, uniform thickness, distances, power regulator

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2006/0011231 A1 (UEDA et al.) 19 January 2006 (19.01.2006) para [0005]-[0008], [0011], [0036], [0044]-[0046], [0048], [0052], Fig 3, 4c, 5a, 5c	1-8
Y	US 2004/0053478 A1 (MOUSTAKAS) 18 March 2004 (18.03.2004) para [0009], [0012], [0029], [0035], [006], [0058], Fig 1, 13a-13c	1-8
Y	US 6,217,695 B1 (GOLDBERG et al.) 17 April 2001 (17.04.2001) col 7, ln 20-25, col 20, ln 22-29, Fig 10b	5
Y	US 2006/0048894 A1 (YAMAZAKI et al.) 09 March 2006 (09.03.2006) para [0019], [0020], [0062], Fig 14	8

☐ Further documents are listed in the continuation of Box C. ☐

* 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
11 December 2007 (11.12.2007)	13 MAR 2008
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (April 2007)