US012656688B2

(12) **United States Patent**
Kemp et al.

(10) **Patent No.: US 12,656,688 B2**
(45) **Date of Patent: Jun. 16, 2026**

(54) **LOW OXYGEN SCANNING UV SOURCE WITH LOCALIZED PURGE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 582 days.

(21) Appl. No.: **18/085,649**

(22) Filed: **Dec. 21, 2022**

(65) **Prior Publication Data**

US 2023/0229086 A1 Jul. 20, 2023

(30) **Foreign Application Priority Data**

Jan. 20, 2022 (IN) 202241003329

(51) **Int. Cl.**
G03F 7/20 (2006.01)
B41M 7/00 (2006.01)

(52) **U.S. Cl.**
CPC ***G03F 7/2002*** (2013.01); ***B41M 7/0081*** (2013.01)

(58) **Field of Classification Search**
CPC G03F 7/2002; G03F 7/38; B41M 7/0081
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,434,562 A * 3/1984 Bubley B41F 23/0409 422/186
8,298,458 B2 * 10/2012 Rogers B29D 11/00134 264/494
2012/0132618 A1 * 5/2012 Baluja ..... G02B 5/22 118/723 R

(Continued)

FOREIGN PATENT DOCUMENTS

DE 102015226316 B3 * 4/2017
WO WO-2007001281 A1 * 1/2007 ..... H01L 21/67115

OTHER PUBLICATIONS

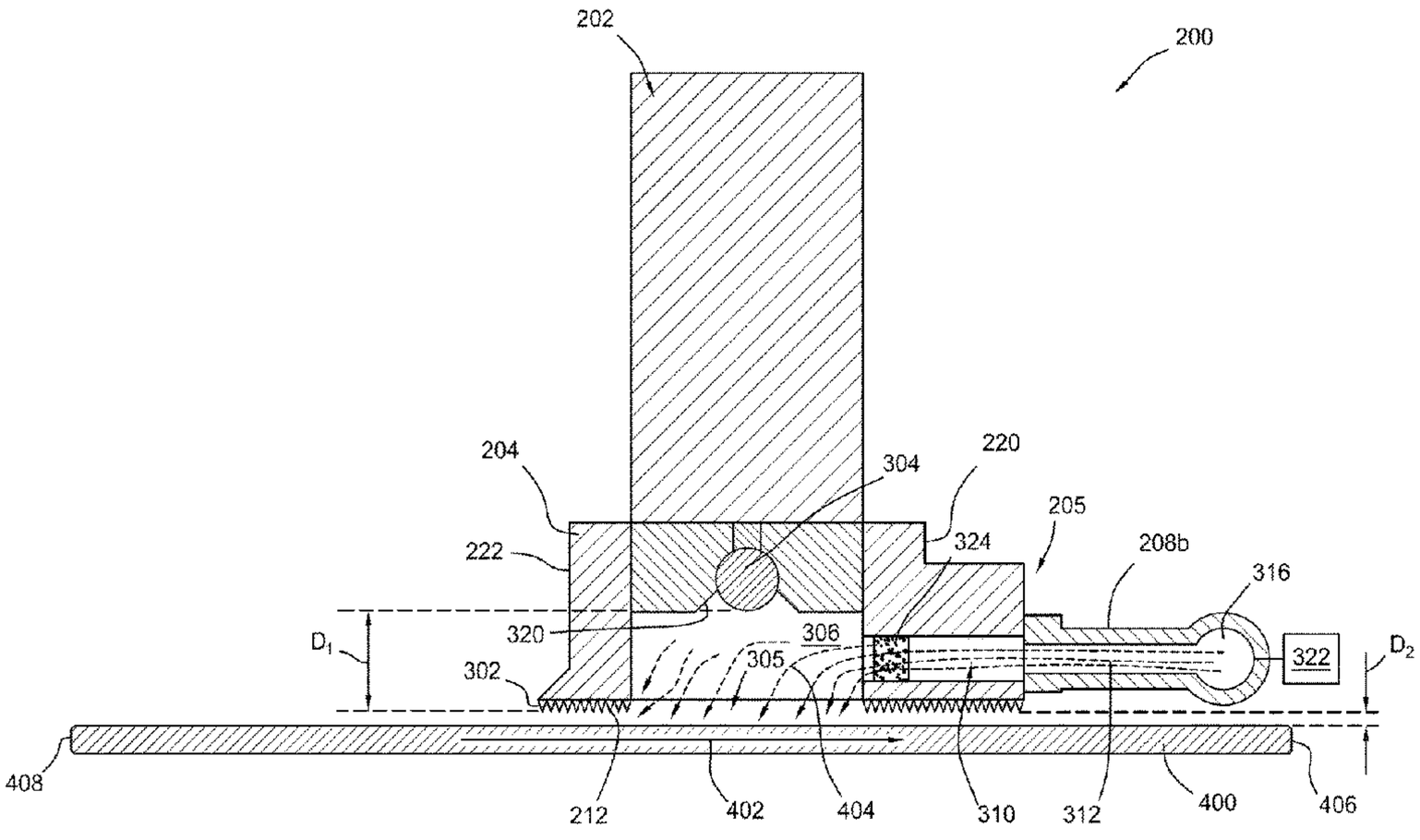
International Search Report and Written Opinion for International Application No. PCT/US2022/053581 dated May 3, 2023.

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(57) **ABSTRACT**

A method and apparatus for curing a substrate are described. The apparatus includes a curing apparatus with a casing and an ultraviolet (UV) radiation assembly coupled to the casing. The ultraviolet radiation assembly further includes a line UV radiation source. The casing includes an opening on one end. A substrate passes by the opening and is exposed to the UV radiation of the line UV radiation source. The curing apparatus further includes a purge assembly configured to continuously purge the process volume and the volume directly above the exposed portion of the substrate. The curing apparatus is configured to only cure a portion of the substrate at any one point in time, such that the curing apparatus is a scanning curing apparatus and includes a small process volume.

20 Claims, 4 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

2013/0160946	A1*	6/2013	Smargiassi	H01L 21/02348 156/345.5
2014/0099798	A1*	4/2014	Tsuji	H01L 21/2686 438/795
2014/0220489	A1	8/2014	Kozuma et al.	
2015/0132973	A1*	5/2015	Hung	H01L 21/67115 438/795
2015/0371894	A1*	12/2015	Kaneda	H01L 21/67109 156/345.52

* cited by examiner

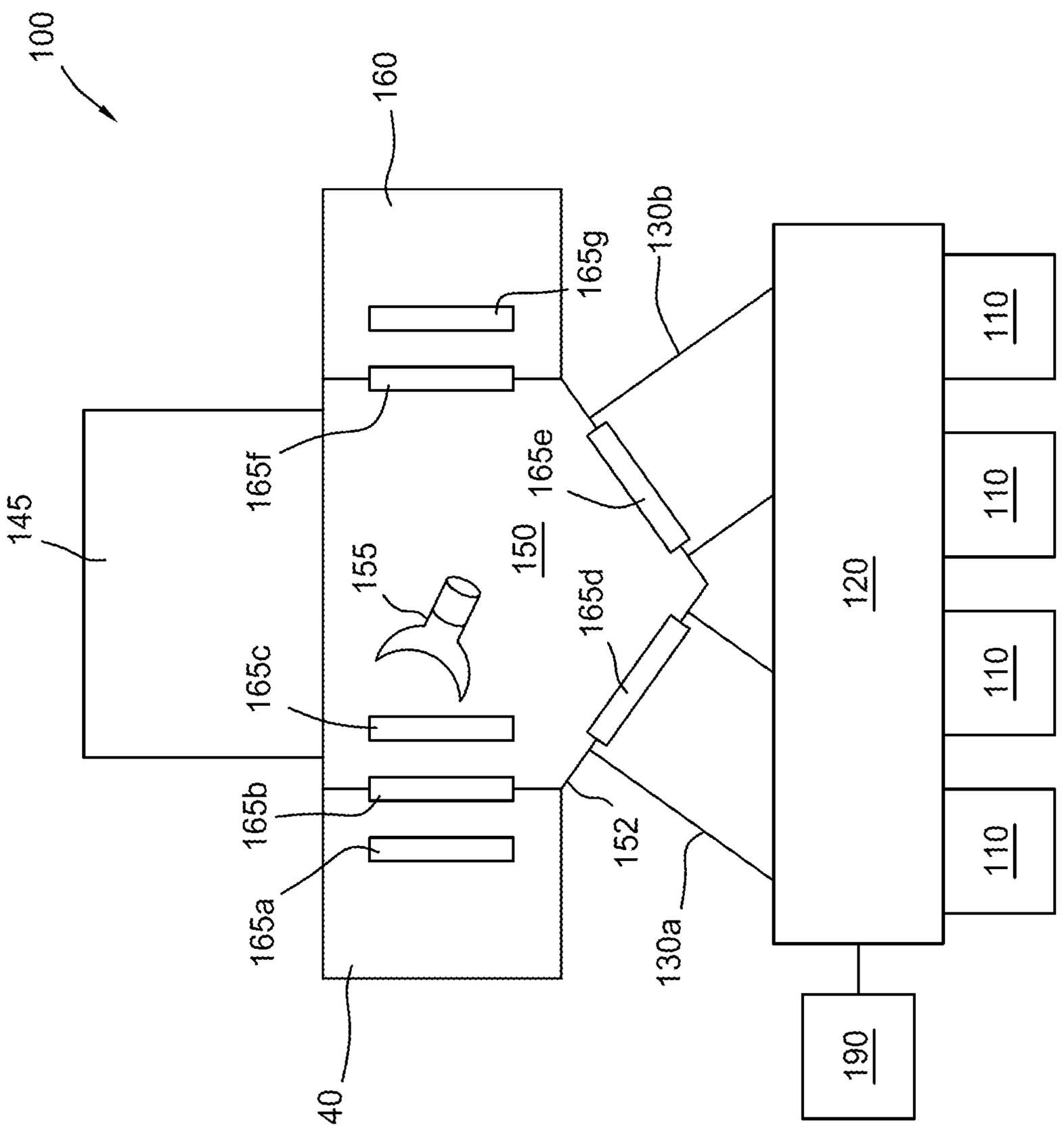

100
160
165g
130b
165f
165e
145
150
155
165d
165c
120
110
110
110
110
165b
152
165a
130a
140
190

FIG. 1

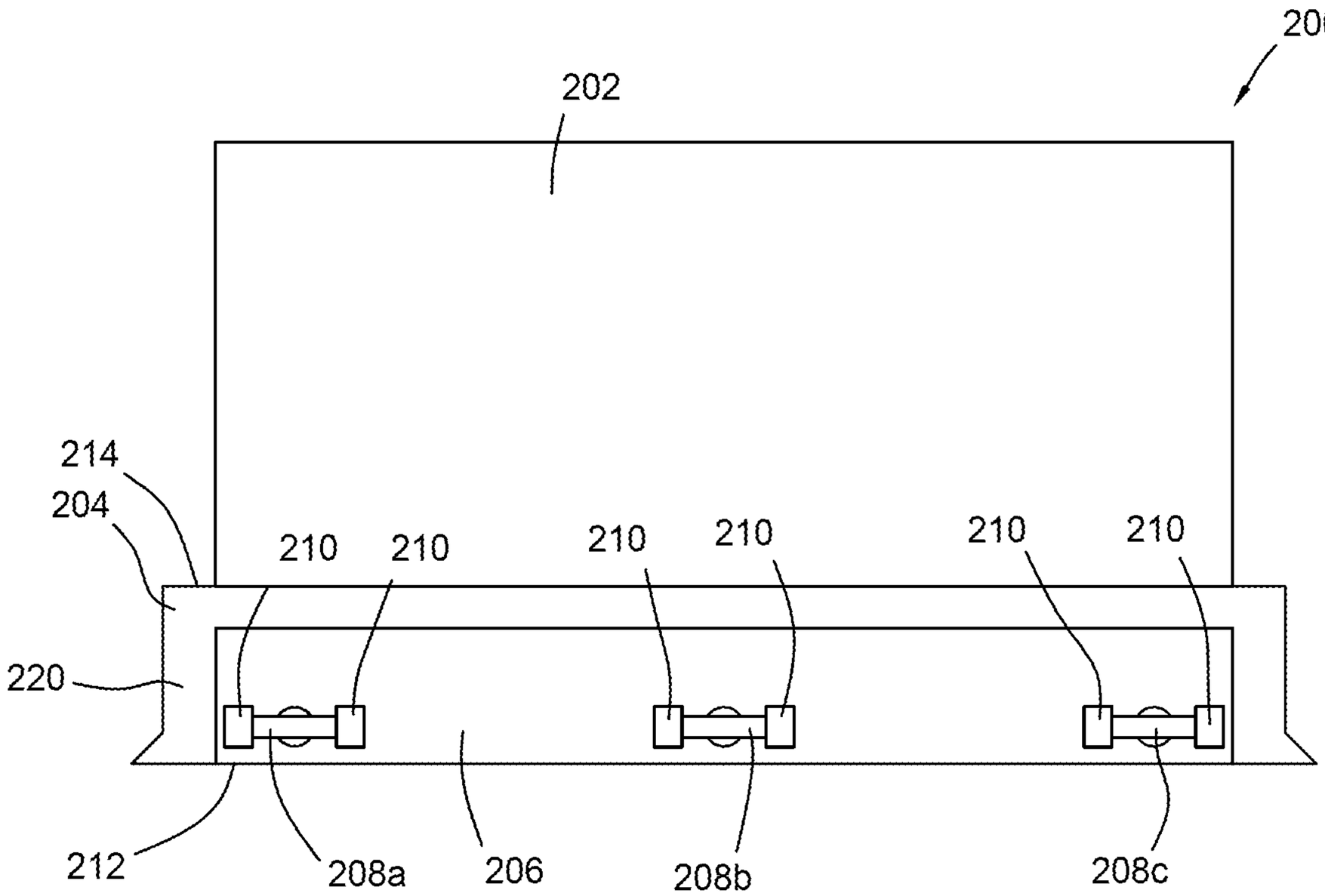

200
202
214
204
210
210
210
210
210
210
220
212
208a
206
208b
208c

FIG. 2A

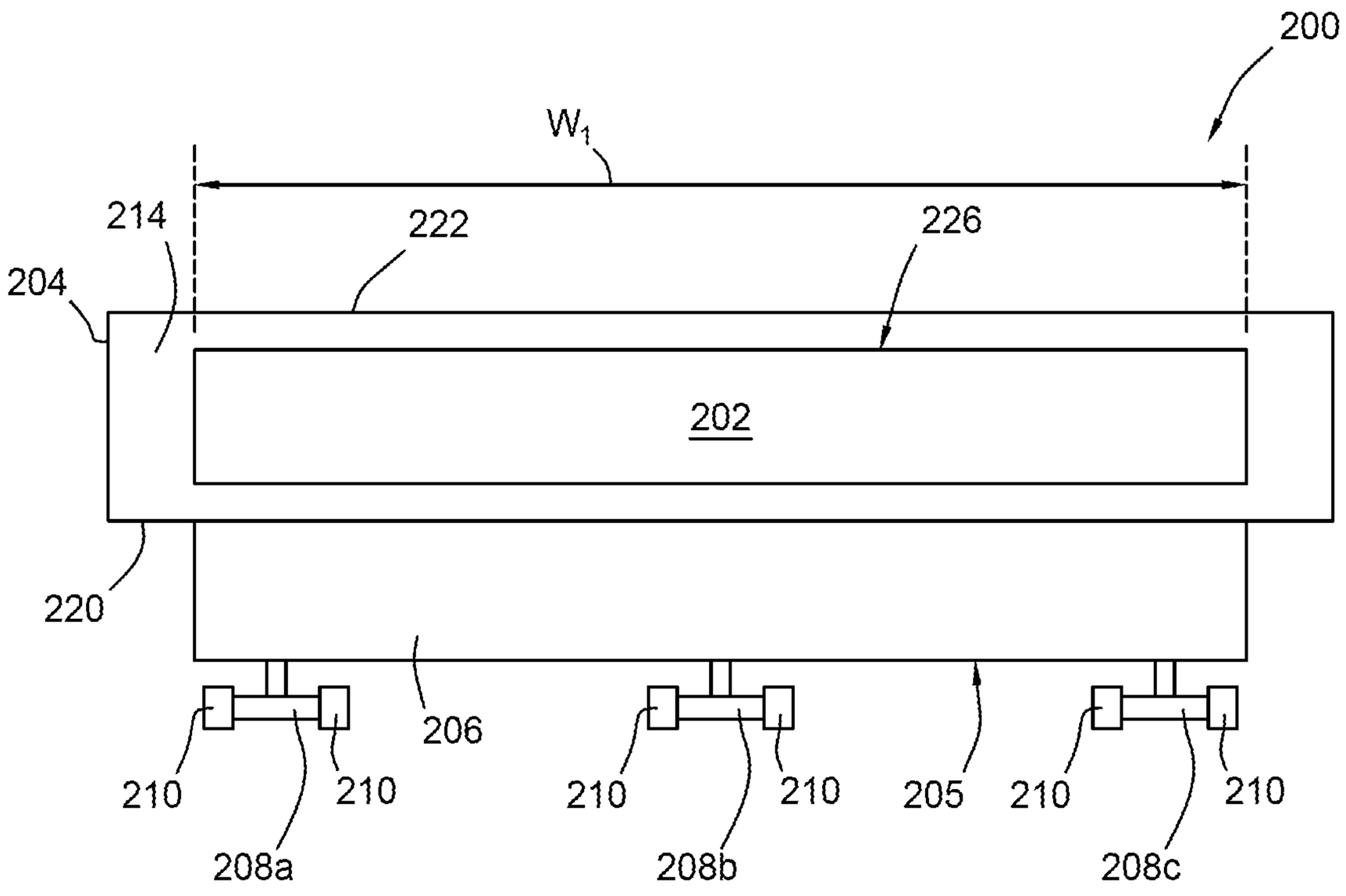

200
W_1
214
222
226
204
202
220
206
210
210
210
210
205
210
210
208a
208b
208c

FIG. 2B

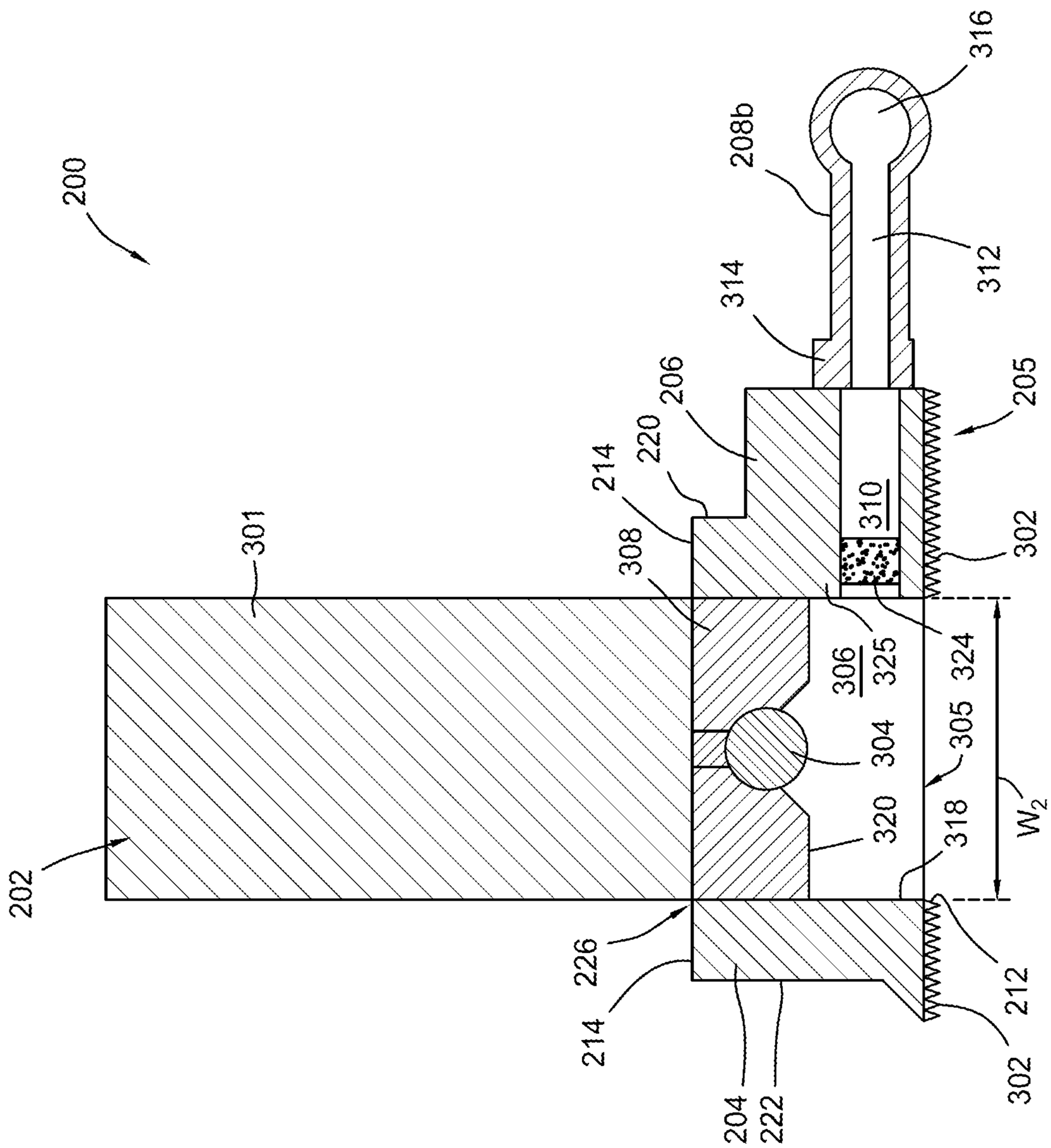

200
202
301
214
220
206
308
310
205
302
306
325
324
304
305
320
318
W_2
316
208b
314
312
226
214
204
222
212
302

FIG. 3

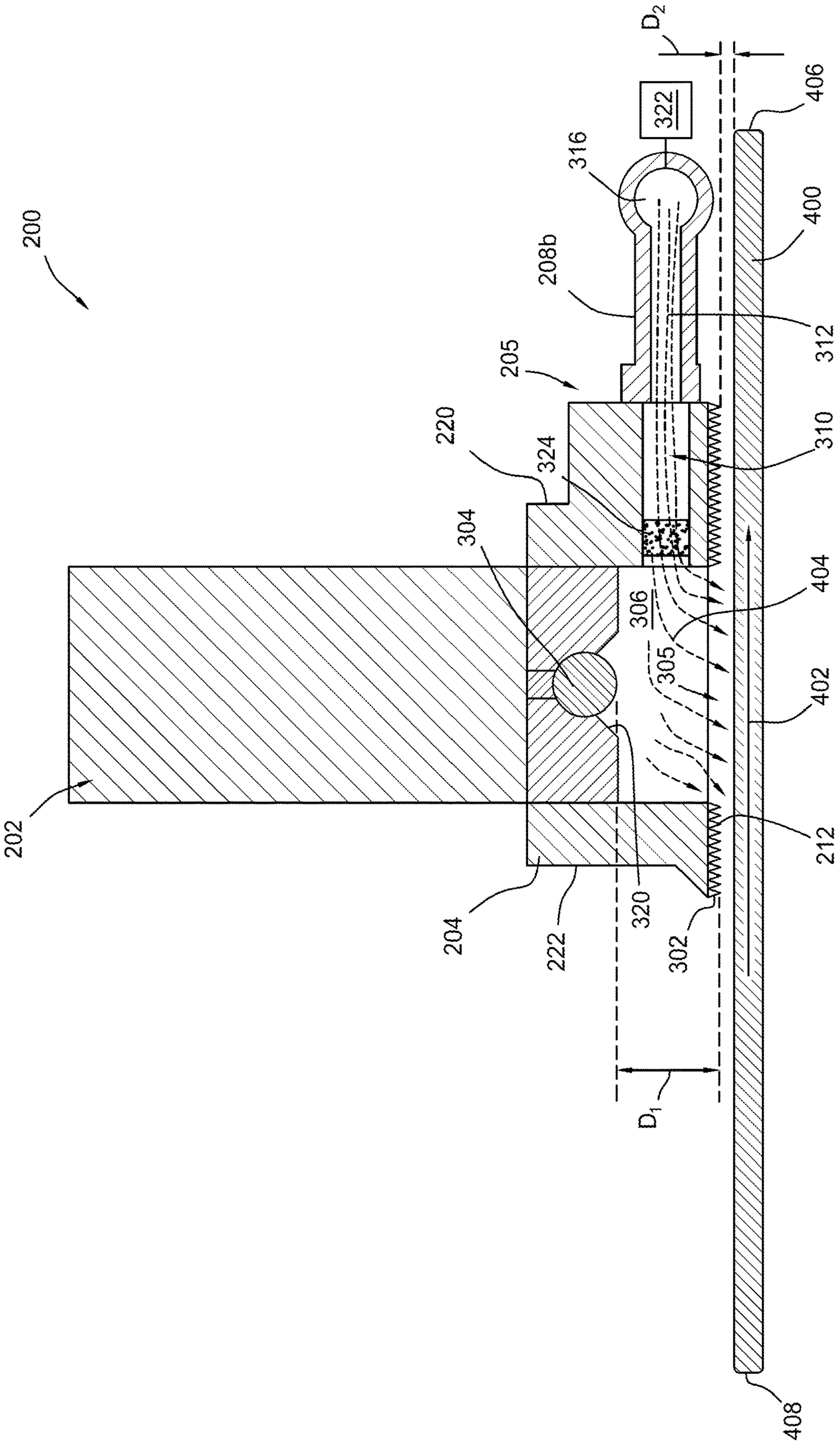

200
202
204
205
208b
212
220
222
302
304
305
306
310
312
316
320
322
324
400
402
404
406
408
D_1
D_2

FIG. 4

LOW OXYGEN SCANNING UV SOURCE WITH LOCALIZED PURGE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims benefit of India Provisional Application No. 202241003329, filed Jan. 20, 2022, which is herein incorporated by reference in its entirety.

BACKGROUND

Field

Embodiments of the present disclosure generally relate to apparatus and methods of curing a substrate. More specifically, embodiments of the present disclosure relate to apparatus for curing a layer of a semiconductor substrate.

Description of the Related Art

During semiconductor and optical device processing, curing operations are utilized periodically to, among other things, remove solvent from a layer, harden a layer, or change the characteristics of a layer. Curing a substrate includes exposing the substrate to radiation, such as ultraviolet (UV) radiation, until the substrate has achieved a targeted property. Curing is performed at a variety of temperatures and pressures.

In some curing operations, a resist material is baked before or after patterning to set the exposure pattern. The baking of the resist material may further assist in cross-linking of portions of the resist layer.

Substrates are generally cured using an area-type exposure. The area-type exposure positions the substrate in a bake or a cure chamber and exposes an entirety of the substrate simultaneously. The bake and/or cure chamber has a large volume and utilizes a large quantity of purge gas during the bake and/or cure operation. The area-type exposure also suffers from poor cure uniformity as the radiation exposure of the substrate is non-uniform.

Therefore, what is needed are improved apparatus and methods of curing substrates.

SUMMARY

The present disclosure generally relates to apparatus for curing a substrate, suitable for use during semiconductor manufacturing. The apparatus includes a casing comprising a top surface and a bottom surface. A first opening is disposed through the top surface and a second opening is disposed through the bottom surface. An ultraviolet (UV) radiation assembly is disposed through the first opening and includes a line UV radiation source. The line UV radiation source is disposed within a volume between the top surface and the bottom surface. A purge gas inlet is disposed through a wall of the casing.

In another embodiment, another apparatus for curing a substrate is provided. The apparatus includes a casing defining a volume. A UV radiation assembly is disposed through a first opening through a top surface of the casing and includes a line UV radiation source. The line UV radiation source is disposed within the volume. A purge gas inlet is disposed through a first sidewall of the casing and in fluid communication with the volume.

In yet another embodiment, another apparatus for curing a substrate is provided. The apparatus includes a transfer chamber, one or more processing chambers coupled to the transfer chamber, and a UV curing system. The UV curing system includes a casing forming a volume. A UV radiation assembly is disposed through a first opening through a top surface of the casing and includes a line UV radiation source. The line UV radiation source is disposed within the volume. A purge gas inlet is disposed through a first sidewall of the casing and in fluid communication with the volume.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the above-recited features of the present disclosure can be understood in detail, a more particular description of the disclosure, briefly summarized above, may be had by reference to embodiments, some of which are illustrated in the appended drawings. It is to be noted, however, that the appended drawings illustrate only exemplary embodiments and are therefore not to be considered limiting of its scope, as the disclosure may admit to other equally effective embodiments.

FIG. **1** illustrates a schematic plan view of a processing assembly for processing a substrate, according to embodiments described herein.

FIG. **2**A illustrates a schematic first side view of a curing apparatus for curing a substrate, according to embodiments described herein.

FIG. **2**B illustrates a schematic plan view of the curing apparatus of FIG. **2**A, according to embodiments described herein.

FIG. **3** illustrates a schematic cross-sectional second side view of the curing apparatus of FIGS. **2**A and **2**B, according to embodiments described herein.

FIG. **4** illustrates a schematic cross-sectional second side view of the curing apparatus of FIG. **3** while curing a substrate, according to embodiments described herein.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

DETAILED DESCRIPTION

The present disclosure is directed towards a curing apparatus for curing a substrate. More specifically, the present disclosure is directed towards a line UV curing apparatus for curing a substrate. The line UV curing apparatus is configured to have a substrate pass underneath a line UV source. The line UV source is a UV source which is extended over a length of at least a portion of the substrate. In some embodiments, the line UV source extends over an entire diameter of a substrate. The line UV curing apparatus only exposes a small portion of the area of the substrate at once. The area of the substrate exposed is a line across the substrate, such that the entire area of the substrate passes underneath the line UV source of the line UV curing apparatus to cure the substrate.

The line UV curing apparatus is compact and may be integrated within a processing chamber and/or a transfer chamber. In some embodiments, the line UV curing apparatus is disposed between two chambers, such that as the substrate is passed from a first chamber to a second chamber, the substrate passes beneath the line UV source and is cured. The compact nature of the line UV curing apparatus provides process and assembly flexibility.

The small size of the UV curing volume further enables the amount of purge gas utilized to be reduced. As the UV curing volume is smaller, less volume is being purged during the curing operations. The reduced purge gas usage reduces cost of ownership and may reduce the size of gas panels associated with the curing system. In some embodiments, the purge gas utilized is a nitrogen (N_2) purge gas.

The line UV source and exposure of the substrate as a line exposure further enables a higher UV output per area to the substrate. Higher UV output per area enables a faster UV cure of the substrate. The line UV curing apparatus may further utilize an air-cooling system to remove difficulties associated with liquid cooling UV sources.

The line UV curing apparatus includes a purge assembly which is configured to provide a purge flow over the portion of the substrate being exposed by the line UV source. The purge gas is introduced into the curing volume through a diffusion member. The diffusion member filters particles in the purge gas line and diffuses the purge gas before the purge gas is introduced into the curing volume.

FIG. **1** illustrates a schematic plan view of a processing assembly **100** for processing a substrate. The processing assembly **100** includes one or more load lock chambers **130***a*, **130***b*, a transfer chamber **150**, a plurality of processing chambers **140**, **145**, **160**, a front end factory interface (FI) **120**, and a plurality of front opening unified pods (FOUPs) **110**. The load lock chambers **130***a*, **130***b* are coupled to an outer surface **152** of the transfer chamber **150**. The plurality of processing chambers **140**, **145**, **160** are further coupled to the outer surface **152** of the transfer chamber **150**. In the embodiment of FIG. **1**, there are two load lock chambers **130***a*, **130***b* and three processing chambers **140**, **145**, **160**. The load lock chambers **130***a*, **130***b* are disposed between the transfer chamber **150** and a front end factory interface "FI" **120**. A substrate is passed through the load lock chambers **130***a*, **130***b* when being transferred from the front end FI **120** to the transfer chamber **150** and from the transfer chamber **150** to the front end FI **120**. The load lock chambers **130***a*, **130***b* connect to a vacuum pump (not shown), for example a roughing pump, the output of which is connected to an exhaust duct (not shown), to reduce the pressure within the load lock chambers **130***a*, **130***b* to a sub-atmospheric pressure on the order of about 10-3 Torr. The load lock chambers **130***a*, **130***b* may be connected to a vacuum pump dedicated thereto, or a vacuum pump shared with one or more components within the processing assembly **100**, or to a house exhaust other than a vacuum pump to reduce the pressure therein. In each case, valves are disposed on either end of each of the load lock chambers **130***a*, **130***b*.

A first valve is disposed between each of the load lock chambers **130***a*, **130***b* and the front end FI **120**. A second valve is disposed between each of the load lock chambers **130***a*, **130***b* and the transfer chamber **150**. The first valve enables a seal to be formed between the front end FI **120** and the load lock chambers **130***a*, **130***b* while the load lock chambers **130***a*, **130***b* are being de-pressurized. The first valve further prevents the transfer chamber **150** from being exposed to atmospheric or ambient pressure conditions while the second valve is open and a substrate is being transferred to the load lock chambers **130***a*, **130***b* from the transfer chamber **150** or from the transfer chamber **150** to the load lock chambers **130***a*, **130***b*. The second valve enables a seal to be formed between the transfer chamber **150** and the load lock chambers **130***a*, **130***b* while the load lock chambers **130***a*, **130***b* are pressurized or in fluid communication with the front end FI **120**. The second valve prevents the transfer chamber **150** from being exposed to atmospheric or ambient pressure conditions while the first valve is open and a substrate is being transferred to the load lock chambers **130***a*, **130***b* from the front end FI **120** or from the front end FI **120** to the load lock chambers **130***a*, **130***b*.

The transfer chamber **150** is configured to transfer one or more substrates between each of the load lock chamber **130***a*, **130***b*, and the processing chambers **140**, **145**, **160**. As shown herein, the transfer chamber **150** includes a plurality of sidewalls, such that the transfer chamber **150** may have four sidewalls, five sidewalls, six sidewalls, seven sidewalls, or eight sidewalls. The transfer chamber **150** may include a transfer robot **155** or a carousel (not shown) for moving a substrate therein. The transfer robot **155** or carousel has one or more blades for holding the substrate and is actuated around a central axis of the transfer chamber **150**. A transfer volume within the transfer chamber **150** is held at a vacuum during substrate processing, such as on the order of about 10-3 Torr or less.

Each of the processing chambers **140**, **145**, **160** are coupled to the transfer chamber **150**. While three processing chambers **140**, **145**, **160** are shown, more or less processing chambers are also contemplated. Each of the processing chambers **140**, **145**, **160** may be one of a deposition chamber, a lithography chamber, or a curing chamber. In some embodiments, the first processing chamber **140** is a deposition chamber, the second processing chamber **145** is a lithography chamber, and the third processing chamber **160** is a curing chamber. In some embodiments, the third processing chamber **160** is a second deposition chamber or a second lithography chamber.

The deposition chamber may be any suitable deposition chamber, such as an inkjet printing chamber or apparatus. The lithography chamber may be a suitable lithography processing chamber, such as a nanoimprint lithography chamber, an immersion lithography chamber, and/or an optical lithography chamber. The lithography chamber is configured to pattern a layer of a substrate. The curing chamber is configured to heat a substrate and/or expose the substrate to UV radiation to cure a layer of the substrate. In some embodiments, the curing chamber is integrated with the deposition chamber.

In some embodiments, the processing assembly **100** further includes one or more pre-clean module (not shown). The pre-clean modules may be coupled to the transfer chamber **150**, the front end FI **120**, and/or the load lock chambers **130***a*, **130***b*. Each of the pre-clean modules are configured to perform a pre-clean process on one or more substrates disposed therein. The pre-clean process may include a plasma etch process.

The location of one or more line UV curing apparatus **165***a*-**165***g* is further illustrated in FIG. **1**. The one or more line UV curing apparatus **165***a*-**165***g* may be positioned in any of the locations illustrated in FIG. **1**. The small size of the UV curing apparatus **165***a*-**165***g* enables the UV curing apparatus **165***a*-**165***g* to be positioned in various positions around the processing assembly **100**. For example, the UV curing apparatus **165***a*-**165***g* may be located within one or more of the processing chambers **140**, **145**, **160**, such as the first processing chamber **140** and/or the third processing chamber **160**. The UV curing apparatus **165***a*-**165***g* may further be disposed between adjacent chambers, such as between the transfer chamber **150** and one of the processing chambers **140**, **145**, **160**. The UV curing apparatus **165***a*-**165***g* may also be disposed between the transfer chamber **150** and the load lock chambers **130***a*, **130***b*. Disposing the UV curing apparatus **165***a*-**165***g* between two chambers enables a substrate to be cured as the substrate passes from

a first chamber to a second chamber without utilizing additional apparatus or processing chambers.

In the embodiment of FIG. **1**, a first UV curing apparatus **165***a* is disposed within the first processing chamber **140**, a second UV curing apparatus **165***b* is disposed between the first processing chamber **140** and the transfer chamber **150**, a third UV curing apparatus **165***c* is disposed within the transfer chamber **150**, a fourth UV curing apparatus **165***d* is disposed between the first load lock chamber **130***a* and the transfer chamber **150**, the fifth UV curing apparatus **165***e* is disposed between the second load lock chamber **130***b* and the transfer chamber **150**, the sixth UV curing apparatus **165***f* is disposed between the transfer chamber **150** and the third processing chamber **160**, and a seventh UV curing apparatus **165***g* is disposed within the third processing chamber **160**.

A controller **190** is coupled to the processing assembly **100** and is configured to supply instructions to each of the front end FI **120**, the transfer chamber **150**, the load lock chambers **130***a*, **130***b*, and the processing chambers **140**, **145**, **160**. The controller **190** further receives input from sensors within the processing assembly **100**. For example, the controller **190** is configured to control a flow of various gases within the processing assembly and coordinate operation of power sources to facilitate substrate processing. The controller **190** may also be configured to control all aspects of heating within the processing assembly **100**.

The controller **190** includes a programmable central processing unit (CPU) that is operable with a memory and a mass storage device, an input control unit, and a display unit (not shown), such as power supplies, clocks, cache, input/output (I/O) circuits, and the like, coupled to the various components of the processing assembly **100** to facilitate control of substrate processing. The controller **190** also includes hardware or software for monitoring substrate processing through sensors in the processing chambers **140**, **145**, **160** and the transfer chamber **150**, including sensors monitoring flow, RF power, electric field and the like. Other sensors that measure system parameters such as substrate temperature, chamber atmosphere pressure and the like, may also provide information to the controller **190**.

To facilitate control of the processing assembly **100**, the CPU may be one of any form of general purpose computer processor that can be used in an industrial setting, such as a programmable logic controller (PLC), for controlling various chambers and sub-processors. The memory is coupled to the CPU and the memory is non-transitory and may be one or more of readily available memory such as random access memory (RAM), read only memory (ROM), floppy disk drive, hard disk, or any other form of digital storage, local or remote. Support circuits are coupled to the CPU for supporting the processor in a conventional manner. The layer formation, curing, and other processes are generally stored in the memory, typically as a software routine. The software routine may also be stored and/or executed by a second CPU that is remotely located from the hardware being controlled by the CPU.

The memory is in the form of computer-readable storage media that contains instructions, that when executed by the CPU, facilitates the operation of UV curing apparatus **165***a*-**165***g*. The instructions in the memory are in the form of a program product such as a program that implements the method of the present disclosure. The program code may conform to any one of a number of different programming languages. In one example, the disclosure may be implemented as a program product stored on computer-readable storage media for use with a computer system. The program(s) of the program product define functions of the embodiments (including the methods described herein).

In certain embodiments, the program(s) embody machine learning capabilities. Various data features include process parameters such as processing times, temperatures, pressures, voltages, polarities, powers, gas species, precursor flow rates, and the like. Relationships between the features are identified and defined to enable analysis by a machine learning algorithm to ingest data and adapt processes being performed by the UV curing apparatus **165***a*-**165***g*. The machine learning algorithms may employ supervised learning or unsupervised learning techniques. Examples of machine learning algorithms embodied by the program include, but are not limited to, linear regression, logistic regression, decision tree, state vector machine, neural network, naïve Bayes, k-nearest neighbors, K-Means, random forest, dimensionality reduction algorithms, and gradient boosting algorithms, among others.

Illustrative computer-readable storage media include, but are not limited to: (i) non-writable storage media (e.g., read-only memory devices within a computer such as CD-ROM disks readable by a CD-ROM drive, flash memory, ROM chips or any type of solid-state non-volatile semiconductor memory) on which information is permanently stored; and (ii) writable storage media (e.g., floppy disks within a diskette drive or hard-disk drive or any type of solid-state random-access semiconductor memory) on which alterable information is stored. Such computer-readable storage media, when carrying computer-readable instructions that direct the functions of the methods described herein, are embodiments of the present disclosure. In some embodiments, the controller **190** is an etherCAT controller.

FIG. **2**A illustrates a schematic first side view of a curing apparatus **200** for curing a substrate. The curing apparatus **200** includes a casing **204**, a UV radiation assembly **202** coupled to the casing **204**, and a purge module **205** coupled to the casing **204**. The curing apparatus **200** may be utilized in place of any one of the UV curing apparatus **165***a*-**165***g* of FIG. **1**. The curing apparatus **200** is a line curing apparatus and is configured to have a substrate pass across an exposure region of the curing apparatus **200**.

The casing **204** is configured to hold each of the UV radiation assembly **202** and the purge module **205**. The casing **204** includes a top surface **214** and a bottom surface **212**. The UV radiation assembly **202** is disposed partially through a first opening **226** (FIG. **2**B) within the top surface **214**. A second opening **305** (FIG. **3**) is disposed through the bottom surface **212**. The top surface **214** and the bottom surface **212** are disposed opposite one another. The bottom surface **212** is configured to face a substrate, such that as a substrate passes beneath the curing apparatus **200**, the substrate is cured through the second opening **305** within the bottom surface **212**.

The casing **204** further includes a plurality of outer sidewalls, such as a back outer sidewall **220**. The back outer sidewall **220** is disposed between the top surface **214** and the bottom surface **212**. The back outer sidewall **220** is perpendicular to one or both of the top surface **214** and the bottom surface **212**. The upper distal end of the back outer sidewall **220** is connected to the top surface **214** and the lower distal end of the back outer sidewall **220** is connected to the bottom surface **212**. The back outer sidewall **220** may be referred to as a first sidewall or a first outer sidewall.

The purge module **205** is disposed at least partially through the back outer sidewall **220**. The purge module **205** includes one or more purge gas distributors **208***a*-**208***c*

coupled to a gas distribution body **206**. The one or more purge gas distributors **208***a*-**208***c* may include one purge gas distributor, two purge gas distributors, three purge gas distributors, or greater than three purge gas distributors. The curing apparatus **200** of FIG. **2**A includes a plurality of purge gas distributors **208***a*-**208***c*, such as a first purge gas distributor **208***a*, a second purge gas distributor **208***b*, and a third purge gas distributor **208***c*. The purge gas distributors **208***a*-**208***c* are spaced along an outer wall of the gas distribution body **206**. The multiple purge gas distributors **208***a*-**208***c* assist in distributing the purge gas, which is introduced into the gas distribution body **206** through the multiple purge gas distributors **208***a*-**208***c*. In some embodiments, the purge gas distributors **208***a*-**208***c* act as purge gas connections.

Each of the purge gas distributors **208***a*-**208***c* may have one or more gas inlets **210**. In some examples, each of the purge gas distributors **208***a*-**208***c* have two gas inlets **210**. A gas line is configured to be attached to each of the purge gas distributors **208***a*-**208***c* via one of the gas inlets **210**. Each of the gas inlets **210** may serve as a connection point with a gas line, such that purge gas is introduced into the purge gas distributors **208***a*-**208***c* via each of the gas inlets **210**. The purge gas distributors **208***a*-**208***c* may be a linear fitting, a T-shaped fitting, a Y-shaped fitting, or an elbow joint fitting. As shown in FIG. **2**A, each of the purge gas distributors **208***a*-**208***c* are the same shape and have the same number of gas inlets **210**. However, it is envisioned the purge gas distributors **208***a*-**208***c* may have different shapes and have different numbers of gas inlets **210**.

The gas distribution body **206** is the portion of the purge module **205** disposed through and/or attached to the back outer sidewall **220** of the casing **204**. The gas distribution body **206** is configured to receive the gas from each of the purge gas distributors **208***a*-**208***c* and diffuses the gas into a larger area within the gas distribution body **206** before the gas is introduced into the casing **204**.

FIG. **2**B illustrates a schematic plan view of the curing apparatus **200**. A front outer sidewall **222** of the casing **204** is disposed opposite the back outer sidewall **220**. The front outer sidewall **222** is perpendicular to one or both of the top surface **214** and the bottom surface **212**. The front outer sidewall **222** may sometimes be referred to as a second sidewall or a second outer sidewall. The upper distal end of the front outer sidewall **222** is connected to the top surface **214** and the lower distal end of the front outer sidewall **222** is connected to the bottom surface **212**. The top surface **214** and the bottom surface **212** are disposed between the front outer sidewall **222** and the back outer sidewall **220** of the casing **204**. The UV radiation assembly **202** is disposed through the first opening **226** between the front outer sidewall **222** and the back outer sidewall **220**. The UV radiation assembly **202** has a first width W_1 along a length of the UV radiation assembly **202**. The first width W_1 is also the length of a line UV radiation source **304** (FIG. **3**) of the UV radiation assembly **202**. The first width W_1 is also the length of a process volume **306** within the casing **204**.

The first width W_1 is greater than about 100 mm, such as greater than about 150 mm, such as greater than about 200 mm, such as greater than about 250 mm, such as about 250 mm to about 350 mm. The first width W_1 is great enough to enable a substrate to be cured by passing beneath the curing apparatus **200**. In embodiments wherein a 100 mm substrate is utilized, the first width W_1 is greater than about 100 mm, such as about 110 mm to about 150 mm. In embodiments wherein a 200 mm substrate is utilized, the first width W_1 is greater than about 200 mm, such as about 210 mm to about 250 mm. In embodiments wherein a 300 mm substrate is utilized, the first width W_1 is greater than about 300 mm, such as about 310 mm to about 350 mm. In some embodiments, a multi-pass approaching for curing the substrate is utilized. If a multi-pass approach is utilized, the first width W_1 may be smaller than the diameter of the substrate being cured.

FIG. **3** illustrates a schematic cross-sectional second side view of the curing apparatus **200** of FIGS. **2**A and **2**B. A process volume **306** is disposed within the casing **204**. The process volume **306** is in fluid communication with a line UV radiation source **304**, the plurality of purge gas distributors **208***a*-**208***c* (the second purge gas distributor **208***b* illustrated), and the second opening **305**. The second opening **305** is disposed through the casing **204** opposite the line UV radiation source **304** and the first opening **226**.

The UV radiation assembly **202** includes the line UV radiation source **304** as well as one or more radiation guides **320** disposed along the length of the line UV radiation source **304**. The body **301** of the UV radiation assembly **202** is disposed above the line UV radiation source **304** and at least partially through the first opening **226**. The body **301** may further include one or more cooling channels, one or more power distribution lines, or one or more power modulators.

The one or more radiation guides **320** are portions of the UV radiation assembly **202** which are disposed around the line UV radiation source **304**. The one or more radiation guides **320** are configured to direct the radiation emitted by the line UV radiation source **304** towards the second opening **305** and a substrate. The one or more radiation guides **320** may be shaped, such that the radiation guides **320** are disposed around the sides of the line UV radiation source **304** which face the first opening **226**, a front inner casing sidewall **318**, and a back inner casing sidewall **325**. The portion of the line UV radiation source **304** which faces the second opening **305** is therefore the portion of the line UV radiation source **304** which is open to the process volume **306**.

The front inner casing sidewall **318** and the back inner casing sidewall **325** are parallel surfaces. The front inner casing sidewall **318** and the back inner casing sidewall **325** form at least a portion of the process volume **306**. The front inner casing sidewall **318** and the back inner casing sidewall **325** form part of the second opening **305**. The back inner casing sidewall **325** may sometimes be referred to as a first inner sidewall. The front inner casing sidewall **318** may sometimes be referred to as a second inner sidewall.

The line UV radiation source **304** is a radiation source configured to emit radiation in the ultraviolet spectrum. The line UV radiation source **304** may further be configured to emit radiation in other spectrums, such as infrared radiation, light, or microwave radiation. Different radiation types may be utilized in different curing operations. When the line UV radiation source **304** is configured as an ultraviolet emitting radiation source, the line UV radiation source **304** is configured to emit radiation with a wavelength of about 5 nm to about 500 nm, such as about 10 nm to about 400 nm, such as about 200 nm to about 400 nm, such as about 300 nm to about 400 nm. The line UV radiation source **304** is configured to supply a high power density radiation to a substrate as the substrate passes across the second opening **305**. The power emitted by the line UV radiation source **304** is greater than about 0.5 W/m^2, such as greater than about 1 W/m^2, such as about 1.5 W/m^2 to about 2 W/m^2.

The line UV radiation source **304** may be an elongated UV bulb, an optical fiber, a plurality of optical fibers, or an elongated black body. When an optical fiber or a plurality of

optical fibers are utilized, one side of the optical fiber is configured to emit the UV radiation passing therethrough.

The surfaces of the one or more radiation guides **320** and the inner sidewalls of the casing **204** (such as the front inner casing sidewall **318** and the back inner casing sidewall **325**) are non-reflective surfaces. Therefore, the one or more radiation guides **320** and the inner sidewalls of the casing **204** have a reflectance of less than about 25% across the UV wavelengths described above, such as less than about 10%, such as less than about 7%. The one or more radiation guides **320** and the inner sidewalls of the casing **204** may therefore include a coating disposed thereon. The coating is configured to reduce the reflectivity of the casing **204** and the components of the UV radiation assembly **202**.

The bottom surface **212** of the casing **204** forms a radiation baffle, such that the bottom surface **212** includes a plurality of projections **302** to form a jagged or ridged surface. The plurality of projections **302** are small bumps or ridges formed from the bottom surface **212**. Each of the projections **302** have a depth of about 0.2 mm to about 1 mm, such as about 0.3 mm to about 0.8 mm, such as about 0.4 mm to about 0.6 mm, such as about 0.5 mm. The bottom surface **212** has a Ra surface roughness of about Ra μm to about Ra 20 μm, such as about 8 μm to about Ra 15 μm, such as about 10 μm to about 13 μm, such as about 12 μm to about 13 μm. The bottom surface **212** and the plurality of projections **302** are non-reflective surfaces. The plurality of projections **302** serve as a baffle and reduce the amount of reflected radiation which scatters across a substrate and outside of the process volume **306**. The non-reflective surfaces of each of the bottom surface **212**, the one or more radiation guides **320**, and the inner sidewalls of the casing **204** further reduce the amount of radiation which is scattered across the substrate and outside of the process volume **306**.

The purge module **205** is disposed from the backside of the casing **204**. The purge module **205** includes the purge gas distributors **208***a*-**208***c* and a gas distribution body **206** extending from the back outer sidewall **220**. The second purge gas distributor **208***b* is illustrated in FIG. **3**. Each of the first purge gas distributor **208***a* and the third purge gas distributor **208***c* are similar to the second purge gas distributor **208***b*.

The second purge gas distributor **208***b* includes a gas inlet cavity **316** and a gas flow passage **312** extending from the gas inlet cavity **316** to the gas distribution body **206**. The gas inlet cavity **316** is an opening within the second purge gas distributor **208***b* which is configured to receive a process gas via the one or more gas inlets **210** (FIGS. **2**A and **2**B). The gas is flowed into the gas inlet cavity **316** and to the gas distribution body **206** via the gas flow passage **312**. The gas flow passage **312** is a fluid flow passage disposed within the second purge gas distributor **208***b* between the gas inlet cavity **316** and a gas distribution passage **310** within the gas distribution body **206**. The second purge gas distributor **208***b* is coupled to the gas distribution body **206** using a coupling **314**. The coupling **314** may be a mechanical fastener. In some embodiments, the coupling **314** is a bolt or one or more screws utilized to couple the second purge gas distributor **208***b* and the gas distribution body **206**.

The gas distribution passage **310** is configured to distribute the gas flowed therein from the gas flow passage **312**. The gas distribution passage **310** extends along the length of the back inner casing sidewall **325** and the process volume **306**. The gas distribution passage **310** is directly coupled to each of the purge gas distributors **208***a*-**208***c*, such that gas from each of the purge gas distributors **208***a*-**208***c* is distributed within the same gas distribution passage **310** to form a sheet of purge gas therein. The distribution of the purge gas within the gas distribution passage **310** is further assisted by the use of a diffuser **324** disposed within the gas distribution passage **310**. The diffuser **324** is disposed between the gas flow passage **312** and the process volume **306**. The gas distribution passage **310** may sometimes be referred to as a purge gas inlet and is a part of the purge gas inlet.

The diffuser **324** is configured to assist in diffusing the purge gas along the length of the back inner casing sidewall **325** before the purge gas enters the process volume **306**. The diffuser **324** may be a perforated plate or a perforated mesh. The perforated plate may be a solid plate with a plurality of fluid flow passages disposed along the length of the process volume, such that the perforated plate acts similarly to a showerhead plate. The perforated mesh serves a similar purpose as the perforated plate. The diffuser **324** further catches contaminants and/or particles within the purge gas before the purge gas enters the process volume **306**. In some embodiments, the diffuser **324** is formed of a stainless steel or aluminum material, such that the diffuser **324** is a stainless steel or aluminum mesh. The diffuser **324** further increases the backpressure within the gas distribution passage **310** so the inert gas diffuses along the length of the gas distribution passage **310** and the process volume **306**. The diffuser **324** has a permeability of about 500 $m^3/h \cdot m^2 \cdot kPa$ to about 1500 $m^3/h \cdot m^2 \cdot kPa$, such as about 600 $m^3/h \cdot m^2 \cdot kPa$ to about 1200 $m^3/h \cdot m^2 \cdot kPa$, such as about 700 $m^3/h \cdot m^2 \cdot kPa$ to about 1000 $m^3/h \cdot m^2 \cdot kPa$, such as about 750 $m^3/h \cdot m^2 \cdot kPa$ to about 850 $m^3/h \cdot m^2 \cdot kPa$.

The second opening **305** has a length and a width. The length of the second opening **305** is the first width W_1 as described above and measures the length along which the second opening **305** extends. The first width W_1 therefore spans the length of the second opening **305** in a first direction. The second width W_2 is perpendicular to the first width W_1, such that the second width W_2 extends in a second direction perpendicular to the first direction. The second width W_2 is the distance between the front inner casing sidewall **318** and the back inner casing sidewall **325**. The second width W_2 is less than about 50 mm, such as less than about 35 mm, such as less than about 30 mm, such as less than about 20 mm. The small second width W_2 of the second opening **305** enables the scanning of a substrate where only a small portion of the substrate is exposed at one time. Reducing the width of the substrate exposed to the UV source at one time assists in improving curing uniformity by enabling greater control of the radiation exposure of each portion of the substrate. The small second width W_2 further assists in reducing the overall volume of the process volume **306**. Having a smaller volume of the process volume **306** assists in reducing the amount of purge gas utilized during curing of a substrate. The ratio of the first width W_1 to the second width W_2 is therefore greater than about 4:1, such as greater than about 5:1, such as greater than about 6:1, such as greater than about 8:1.

FIG. **4** illustrates a schematic cross-sectional second side view of the curing apparatus **200** of FIG. **3** while curing a substrate **400**. The substrate **400** is disposed beneath the curing apparatus **200**. However, the substrate **400** and the curing apparatus **200** may be oriented in different directions, such that the substrate **400** may alternatively be disposed to the side of or above the curing apparatus **200**. The substrate **400** is disposed adjacent to the second opening **305**. The substrate **400** is configured to be scanned across the second opening **305**, such that the substrate **400** moves in a forward direction **402**. The substrate **400** passes beneath the second

opening **305**, such that a front end **406** of the substrate **400** passes beneath the second opening **305** and then a back end **408** of the substrate **400** passes beneath the second opening **305**. Only a portion of the substrate **400** is in line of sight of the line UV radiation source **304** at any one time.

A purge gas flow **404** is flowed through the process volume **306** from the gas distribution passage **310**. The purge gas is supplied by a purge gas source **322**, which is fluidly coupled to the gas inlet cavities **316** and the gas flow passage **312**. The purge gas is flowed from the purge gas source **322**, to the gas inlet cavities **316** before flowing into the gas flow passage **312**, before flowing into the gas distribution passage **310**, before flowing through the diffuser **324** and into the process volume **306**. The purge gas is flowed through the process volume **306** and out of the second opening **305** towards the substrate **400** and across the surface of the substrate **400**. The purge gas flow **404** is configured to reduce the flow rate of the purge gas across the top surface of the substrate. The purge gas flow rate across the surface of the substrate adjacent to the front inner casing sidewall **318** is further reduced compared to the purge gas flow rate across the surface of the substrate adjacent to the back inner casing sidewall **325**. The configuration of the purge module **205** along the back inner casing sidewall **325** assists in reducing the purge gas flow rate across the top surface of the substrate adjacent to the front inner casing sidewall **318**. Reduced flow rate adjacent to the front inner casing sidewall **318** is beneficial in that the portion of the substrate adjacent the front inner casing sidewall **318** is not yet cured. As the substrate is cured, the flow rate of the purge gas across the top surface of the substrate may be increased without negatively impacting the substrate.

The distance between the bottom surface **212** of the casing **204** and the line UV radiation source **304** is a first distance D_1. The first distance D_1 is less than about 15 mm, such as less than about 12 mm, such as about 5 mm to about 12 mm, such as about 7 mm to about 11 mm, such as about 9 mm to about 10 mm. The first distance D_1 is further described as a distance between the line UV radiation source **304** and a plane parallel to the bottom surface **212** of the casing **204** and tangent to the bottom surface **212** of the casing **204**. The substrate **400** is separated from the bottom surface **212** of the casing **204** by a second distance D_2. The second distance D_2 is about 0.05 mm to about 3 mm, such as about 0.1 mm to about 1 mm, such as about 0.1 mm to about 0.5 mm. The distance between the substrate **400** and the bottom surface **212** of the casing **204** is small to reduce the purge gas flow utilized. The first distance D_1 between the bottom surface **212** of the casing **204** and the line UV radiation source **304** is reduced to reduce the overall power utilized by the line UV radiation source **304** and enable better control of the radiation delivered to the substrate **400**. The first distance D_1 between the bottom surface **212** of the casing **204** and the line UV radiation source **304** further reduces the overall volume of the process volume **306** and therefore reduces the amount of purge gas utilized during each curing operation.

The curing apparatus **200** described herein therefore provides a more efficient and cost-effective method of curing a substrate. The small process volume **306** enables a reduced purge gas flow. The use of the line UV radiation source **304** and a partial exposure of the substrate enables more uniform UV curing of the substrate. The compact nature of the curing apparatus **200** further enables the curing apparatus **200** to be easily integrated with other portions of the processing assembly **100**. Therefore, the curing apparatus **200** may be utilized in place of any one of the UV curing apparatuses **165***a*-**165***g*.

While the foregoing is directed to embodiments of the present disclosure, other and further embodiments of the disclosure may be devised without departing from the basic scope thereof, and the scope thereof is determined by the claims that follow.

What is claimed is:

1. An apparatus for curing a substrate, suitable for use during semiconductor manufacturing, comprising:

a casing comprising:

a top surface;

a bottom surface opposite the top surface;

a first sidewall disposed between the top surface and the bottom surface; and

a second sidewall opposite the first sidewall and disposed between the top surface and the bottom surface, wherein a first opening is disposed through the top surface, a second opening is disposed through the bottom surface, and a process volume is defined between the top surface, the bottom surface, the first sidewall, and the second sidewall;

an ultraviolet (UV) radiation assembly disposed through the first opening and comprising:

a line UV radiation source, the line UV radiation source disposed within the process volume between the top surface and the bottom surface; and

a purge gas inlet disposed through the first sidewall of the casing,

wherein the second opening has a length extending in a first direction along a length of the line UV radiation source and a width extending in a second direction between the first sidewall and the second sidewall, the second direction perpendicular to the first direction, the length of the second opening greater than about 100 mm, the width less than about 50 mm, and a ratio of the length of the second opening to the width is greater than about 4:1, and

wherein the second opening is sized to enable scanning of only a line portion of the substrate at a time by the line UV radiation source as the substrate is scanned beneath the line UV radiation source.

2. The apparatus of claim **1**, wherein the bottom surface comprises a ridged surface.

3. The apparatus of claim **1**, wherein inner sidewalls of the casing have a reflectivity of less than about 25%.

4. The apparatus of claim **1**, wherein a distance between the line UV radiation source and a plane tangent to the bottom surface is less than about 15 mm.

5. The apparatus of claim **1**, wherein the process volume is defined by the length of the second opening and the width.

6. The apparatus of claim **5**, wherein the purge gas inlet has an inlet length of greater than about 100 mm adjacent to the volume.

7. The apparatus of claim **5**, wherein a diffuser is disposed within the purge gas inlet.

8. The apparatus of claim **7**, wherein the diffuser is one of a perforated plate or a mesh.

9. The apparatus of claim **1**, wherein the purge gas inlet comprises a plurality of gas distributors spaced along a width of the casing.

10. An apparatus for curing a substrate, suitable for use during semiconductor manufacturing, comprising:

a casing forming a volume;

an ultraviolet (UV) radiation assembly disposed through a first opening through a top surface of the casing and comprising a line UV radiation source, the line UV radiation source disposed within the volume; and

a purge gas inlet disposed through a first sidewall of the casing and in fluid communication with the volume,

wherein the casing comprises a bottom surface having a second opening, the second opening having a length extending in a first direction along a length of the line UV radiation source and a width extending in a second direction perpendicular to the first direction, the length of the second opening greater than about 100 mm, the width less than about 50 mm, and a ratio of the length of the second opening to the width is greater than about 4:1, and

wherein the second opening is sized to enable scanning of only a line portion of the substrate at a time by the line UV radiation source as the substrate is scanned beneath the line UV radiation source.

11. The apparatus of claim **10**, wherein the volume has a first width of greater than about 100 mm and the line UV radiation source is disposed along the first width.

12. The apparatus of claim **11**, wherein the length of the line UV radiation source is greater than about 100 mm.

13. The apparatus of claim **12**, wherein the volume has a second width between the first sidewall and a second sidewall opposite the first sidewall and the second width is less than about 50 mm.

14. The apparatus of claim **10**, wherein the line UV radiation source has an output of greater than about 0.5 W/m^2.

15. The apparatus of claim **10**, wherein the bottom surface comprises a ridged non-reflective surface having a roughness (Ra) of about 8 to 15 μm.

16. The apparatus of claim **10**, wherein the bottom surface is a ridged surface.

17. The apparatus of claim **10**, wherein an inner surface of the casing has a reflectivity of less than about 25%.

18. An apparatus for curing a substrate, suitable for use during semiconductor manufacturing, comprising:

a transfer chamber;

one or more processing chambers coupled to the transfer chamber;

an ultraviolet (UV) curing system comprising:

a casing forming a volume;

a UV radiation assembly disposed through a first opening through a top surface of the casing and comprising a line UV radiation source, the line UV radiation source disposed within the volume; and

a purge gas inlet disposed through a first sidewall of the casing and in fluid communication with the volume,

wherein the casing comprises a bottom surface having a second opening, the second opening having a length extending in a first direction along a length of the line UV radiation source and a width extending in a second direction perpendicular to the first direction, the length of the second opening greater than about 100 mm, the width less than about 50 mm, and a ratio of the length of the second opening to the width is greater than about 4:1, and

wherein the second opening is sized to enable scanning of only a line portion of the substrate at a time by the line UV radiation source as the substrate is scanned beneath the line UV radiation source.

19. The apparatus of claim **18**, further comprising a purge gas source fluidly coupled to the purge gas inlet and configured to supply a purge gas to the volume.

20. The apparatus of claim **18**, wherein the length of the line UV radiation source is greater than about 100 mm and is configured to cure the substrate as the substrate passes beneath the UV curing system.

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