DEGAS MODULE FOR PULSED LASER DEPOSITION

BACKGROUND

[0001] Integrated device fabrication processes involve many steps of material deposition, patterning and removal to form integrated circuits on substrates. As an example, pulsed laser deposition (PLD) can be used to deposit a film of material onto a substrate. In PLD, a high-power pulsed laser is used to focus laser energy onto a source material. The laser energy vaporizes material on a surface of the source material to create a plasma plume. The plasma plume comprises energetic species, such as atoms, molecules, electrons, ions, clusters, and particulates. The plasma plume is directed towards a target substrate. The ablation material deposits onto the substrate whereby the energetic species nucleate to form a layer of film. PLD is performed at high vacuum conditions to avoid plasma species scattering from trace gases in the processing chamber.

SUMMARY

[0002] This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter. Furthermore, the claimed subject matter is not limited to implementations that solve any or all disadvantages noted in any part of this disclosure.

[0003] Examples are disclosed that relate to treating a substrate in a degas module to remove water vapor prior to depositing a film by pulsed laser deposition. One example provides a processing tool. The processing tool comprises a transfer module. The processing tool further comprises a pulsed laser deposition module connected to the transfer module. The processing tool further comprises a degas module connected to the transfer module. The degas module comprises a substrate support. The degas module further comprises a cryopump configured to form a high vacuum ($P \leq 10^{-5}$ Torr) in the degas module and the transfer module. The degas module further comprises an infrared radiation source.

[0004] In some such examples, the infrared radiation source is configured to heat a substrate to a temperature of 200 ºC to 300 ºC in 60 seconds or less.

[0005] Additionally or alternatively, in some such examples, the processing tool further comprises infrared reflectors to direct infrared light towards the substrate support.

[0006] Additionally or alternatively, in some such examples, the processing tool further comprises a proximity thermocouple configured to sense a temperature of a substrate positioned in the substrate support.

[0007] Additionally or alternatively, in some such examples, the infrared radiation source is positioned to provide infrared radiation to a top side of a substrate holder and the proximity thermocouple is positioned to sense temperature at a bottom side of the substrate holder.

[0008] Additionally or alternatively, in some such examples, the proximity thermocouple is positioned to be separated from a substrate positioned in the substrate holder by 0.025 inches or less.

[0009] Additionally or alternatively, in some such examples, the processing tool omits a valve between the degas module and the transfer module.

[0010] Another example provides a degas module. The degas module comprises a substrate support configured to support a substrate in the degas module. The degas module further comprises an infrared radiation source configured to apply infrared radiation to the substrate. The degas module further comprises a high vacuum pump configured to form a vacuum comprising a pressure $\leq 10^{-5}$ Torr in the degas module, wherein the degas module is configured to connect to a transfer module without a valve between the degas module and the transfer module.

[0011] In some such examples, the degas module is incorporated into a substrate processing tool comprising the transfer module connected to the degas module.

[0012] Additionally or alternatively, in some such examples, the degas module further comprises one or more pulsed laser deposition modules attached to the transfer module.

[0013] Additionally or alternatively, in some such examples, the infrared radiation source is configured to heat a substrate to a temperature of 200 ºC to 300 ºC in 60 seconds or less.

[0014] Additionally or alternatively, in some such examples, the degas module further comprises a proximity thermocouple configured to sense a temperature of a substrate positioned in the substrate support.

[0015] Additionally or alternatively, in some such examples, the infrared radiation source provides infrared radiation to a first side of the substrate and the proximity thermocouple is located proximate to an opposite side of the substrate when the substrate is positioned in the substrate support.

[0016] Additionally or alternatively, in some such examples, the proximity thermocouple is positioned to be separated from the substrate by 0.025 inches or less when the substrate is positioned in the substrate support.

[0017] Additionally or alternatively, in some such examples, the degas module further comprises infrared reflectors to direct infrared light towards a substrate when the substrate is positioned in the substrate support.

[0018] Additionally or alternatively, in some such examples, wherein the substrate support comprises three contacts configured to support the substrate, and wherein each contact of the three contacts has a contact area with the substrate that is less than 1 cm^3 when the substrate is positioned in the substrate support.

[0019] Another example provides a method for removing water from a substrate. The method comprises pumping down a degas module and a transfer module to a pressure of 10^{-5} Torr or lower with a cryopump in the degas module. The method further comprises positioning a substrate on a substrate support within the degas module. The method further comprises applying infrared radiation to the substrate in the degas module to heat the substrate to a temperature sufficient to remove water vapor from the substrate.

[0020] In some such examples, the method further comprises, at a proximity thermocouple in the degas chamber, sensing the temperature of the substrate when applying the infrared radiation to the substrate.

[0021] Additionally or alternatively, in some such examples, the method further comprises, after applying the infrared radiation to the substrate to remove water vapor from the substrate, transferring the substrate to a pre-clean module connected to the transfer module, and etching the substrate at the pre-clean module to remove oxide from a surface of the substrate.

[0022] Additionally or alternatively, in some such examples, applying the infrared radiation to the substrate comprises heating the substrate to a temperature of 200 ℃ or greater in 60 seconds or less.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] FIG. 1 schematically shows an example processing tool comprising a transfer module, a degas module, and pulsed laser deposition (PLD) module.

[0024] FIG. 2 schematically shows a more detailed view of the example degas module of FIG. 1.

[0025] FIG. 3 schematically shows a bottom view of a substrate supported by a plurality of contacts and a proximity thermocouple positioned adjacent to the back side of the substrate.

[0026] FIG. 4 shows a side view of the substrate and proximity thermocouple of FIG. 3.

[0027] FIG. 5 illustrates a flow diagram for an example method of processing a substrate using a degas module.

[0028] FIG. 6 schematically shows a block diagram of an example computing system.

DETAILED DESCRIPTION

[0029] The term "cryogenic pump" ("cryopump") generally represents a vacuum pump that removes gases from an enclosure by trapping the gases on a cold surface.

[0030] The term "degas module" generally represents a processing module of a processing tool that is configured to remove water vapor and/or other adsorbed gases from a substrate.

[0031] The term "diffusion pump" generally represents a vacuum pump that uses a high-speed jet of vapor to direct gas molecules towards an exhaust.

[0032] The term "high vacuum pump" generally represents a pump that can form a vacuum comprising a pressure of 10^{-3} Torr or lower. Examples include cryogenic pumps, turbomolecular pumps, and diffusion pumps.

[0033] The term "high vacuum" generally represents pressures below $1x10^{-3}$ Torr. The term "high vacuum" as used herein includes ultrahigh vacuums of $1x10^{-8}$ Torr and lower.

[0034] The term "infrared radiation source" generally represents a device configured to emit infrared light.

[0035] The term "pre-clean module" generally represents a processing module of a processing tool that is configured to process substrates by etching the substrate to remove a layer of oxide from the substrate surface.

[0036] The term "processing tool" generally represents a tool comprising one or more processing modules for processing substrates.

[0037] The term "pulsed laser deposition (PLD)" generally represents a deposition method whereby laser energy is used to eject a plasma plume from a source material to be deposited onto a target. PLD is performed under high vacuum conditions.

[0038] The term "PLD module" generally represents a processing module configured for performing PLD.

[0039] The term "roughing pump" generally represents a vacuum pump that can evacuate gas from a container to reduce pressure from atmospheric pressure down to a low vacuum pressure (e.g. approximately 1 millitorr (mTorr, $1x10^{-3}$ Torr) in some examples).

[0040] The term "substrate" generally represents any object onto which a film can be deposited.

[0041] The term "transfer module" generally represents a component of a processing tool configured to transfer substrates between processing modules.

[0042] The term "turbomolecular pump" generally represents a vacuum pump that uses spinning blades to remove gas molecules from an enclosure. A turbomolecular pump can achieve a pressure of approximately 10^{-4} torr to 10^{-8} torr.

[0043] As discussed above, pulsed laser deposition (PLD) can be used to deposit a film of material onto a surface of a substrate. As an example, scandium aluminum nitride (ScAlN) is a piezoelectric material that can be deposited by PLD. ScAlN can be used in various applications, such as radiofrequency acoustic wave resonators, filters, and micro-electro-mechanical systems. Other examples of films that can be formed by PLD include films containing molybdenum, copper, and/or tungsten.

[0044] However, the quality of films deposited by PLD onto a substrate can be negatively affected by the presence of contaminants on the substrate. For example, water vapor can adsorb to the substrate surface when the substrate is exposed to air. Further, substrate materials comprising metal can oxidize to form a metal oxide on the surface of the substrate. Water vapor and/or metal oxides can cause a lattice mismatch

with the film material being deposited. This can lead to weak adhesion between the substrate and the film. In some examples, a PLD processing chamber can utilize a heated pedestal to help drive water vapor from the substrate. However, pedestal heating can be slow and lead to incomplete water vapor removal. Further, pedestal heating does not remove oxides from a substrate surface.

[0045] Accordingly, examples are disclosed that relate to treating a substrate in a degas module and a pre-clean module to remove such contaminants as water vapor and an oxide layer. The degas module comprises an infrared (IR) radiation source to heat the substrate and remove water vapor (H_2O) and/or other adsorbed gases from the substrate. The degas module further comprises a high vacuum pump, such as a cryogenic pump, a turbomolecular pump, or a diffusion pump. The high vacuum pump can form a vacuum comprising a pressure within a range of 10^{-5} Torr to 10^{-9} Torr. This helps to remove water vapor and/or other adsorbed gases from the degas module. After removing adsorbed gases from the substrate, a transfer module can transfer the substrate to a pre-clean module. The pre-clean module can perform an etching process to remove oxide (e.g., metal oxide) from the substrate surface. Then, the substrate can be transferred to a PLD module for film deposition by PLD. By including a high vacuum pump and an IR radiation source, the degas module and pre-clean module can help to provide for better adhesion of a film deposited by PLD than processing tools that lack such features.

[0046] As explained in more detail below, the degas module can be connected to the transfer module without a slit valve that isolates the transfer module from the degas module. In this manner, the cryogenic pump of the degas module also can pump down a transfer module connected to the degas module. This can help reduce hardware costs. Further, use of an IR radiation source can remove water vapor more efficiently than other methods, such as a heated pedestal. The IR radiation source can comprise reflectors to focus IR radiation onto the substrate surface. Additionally, the substrate can be supported by contacts having a smaller contact area compared to a pedestal support. As such, heat transfer out of the substrate is slowed and the substrate can be heated faster. This can help increase throughput and lower costs associated with PLD processing.

[0047] FIG. 1 shows an example processing tool 100 comprising various processing modules including a degas module 200. A more detailed view of the degas module 200 is shown in FIG. 2. The processing tool 100 is configured with PLD

modules to deposit films of materials onto substrate. However, in other examples, film deposition can be performed using a different processing module, such as a chemical vapor deposition (CVD) module configured for CVD.

[0048] Processing tool 100 further comprises a transfer module 102. Transfer module 102 comprises one or more robots 104 configured for transferring substrates between different modules connected to transfer module 102. Transfer module 102 is connected to an inbound load lock 106, an outbound load lock 108, a degas module 200, a pre-clean module 110, and two PLD modules 112A, 112B.

[0049] Processing tool 100 further comprises a front-end robot 118 Substrates are transferred by front-end robot 117 from a from FOUP 120 into inbound load lock 106 through an atmospheric port 122. After transferring a substrate to inbound load lock 106, the atmospheric port 122 is closed and inbound load lock 106 can be pumped down to a suitable vacuum pressure. Then, robot 104 of transfer module 102 can transfer the module from inbound load lock 106 through a transfer port 124 into transfer module 102. During substrate processing, transfer module 102 can transfer a substrate sequentially to degas module 200, pre-clean module 110, and one of the PLD modules 112A, 112B. After processing, transfer module 102 can transfer the processed substrate through a transfer port 126 to outbound load lock 108. Front-end robot 118 can then transfer processed substrates out of outbound load lock 108 through an atmospheric port 128 to FOUP 120.

[0050] As mentioned above, the quality of a film deposited by PLD can be affected by presence of adsorbed gases (e.g. water vapor) and/or oxide on the surface of the substrate. Thus, degas module 200 and pre-clean module 110 can help to prepare the surface of the substrate for PLD by removing these from the surface of the substrate.

[0051] FIG. 2 schematically shows a more detailed view of degas module 200. Degas module 200 comprises one or more high vacuum pumps to evacuate gas from the degas module. Degas module 200 is connected to transfer module 102 by a transfer port 202 that omits a valve. By not including a valve, the vacuum pump hardware of degas module 200 also can pump down transfer module 102. This can avoid cost of additional vacuum pump hardware. In other examples, transfer port 202 can comprise any suitable valve, such as a slit valve.

[0052] Degas module 200 comprises a degas processing chamber 204, and a substrate support 206 located in the processing chamber. Substrate support 206 is configured to support a substate in the degas module. In the depicted example, the

substrate support comprises a plurality of contacts 208 configured to support a substrate 210 when the substrate is positioned in degas processing chamber 204. FIG. 3 schematically shows a bottom view of substrate 210 supported by contacts 208. Each contact 208 is configured to have a relatively small contact area with substrate 210. In some examples, each contact 208 has a contact area with the substrate 210 within a range of 0.1 to 1 cm^3. In other examples, a value outside this range can be used. By contacting substrate 210 at a relatively small contact area, heat transfer out of the substrate can be significantly reduced. As described below, this helps to heat the substrate 210 more efficiently. In some examples, at least three contacts 208 are used. In other examples, any suitable number of contacts can be used to support substrate 210 (e.g., four or more contacts).

[0053] Degas module 200 further comprises a cryogenic pump 212 connected to degas processing chamber 204 by a gate valve 214. Cryogenic pump 212 is connected to a compressor 216 that is configured to supply compressed helium gas to cryogenic pump 212. In other examples, any other suitable high vacuum pump can be used, such as a diffusion pump or a turbomolecular pump. In some examples, a combination of two or more high vacuum pumps can be used. Further, in some examples, liquid nitrogen can be used as a cold trap to help remove water vapor and/or solvents, such as oils, from degas processing chamber 204. In such examples, a diffusion pump or turbomolecular pump can be used to remove other gases from degas processing chamber 204.

[0054] Degas module 200 further comprises a roughing pump 220. Roughing pump 220 is configured to form a vacuum pressure within a range of 0.1 Torr to 1 mTorr. Cryogenic pump 212 is capable of forming a vacuum comprising a pressure of $5x10^{-5}$ Torr to $1x10^{-7}$ Torr. In some examples, a pressure outside this range can be used. When gate valve 214 is open, the roughing pump 220 and/or cryogenic pump 212 can evacuate air from degas processing chamber 204. However, cryogenic pumps are not operable at relatively higher pressures (e.g., pressures $\geq$ 0.1 Torr). As such, the roughing pump 220 can be controlled to reduce the pressure in degas processing chamber 204 and transfer module 102 before operating the cryogenic pump 212. In some examples, roughing pump 220 is controlled to pump down degas processing chamber 204 to a pressure of approximately 30 mTorr, or lower. Once a suitably low pressure is achieved, cryogenic pump 212 is controlled to further reduce the pressure, e.g. to within a range

of $5x10^{-5}$ Torr to $1x10^{-7}$ Torr. Cryogenic pump 212 can pump down degas processing chamber 204 relatively quickly. In some examples, cryogenic pump 212 can reduce the pressure from 30 mTorr to $5x10^{-6}$ Torr in 20 minutes or less.

[0055] Cryogenic pump 212 also is connected to an exhaust line 222 and a clean dry air (CDA) supply line 224. During regeneration, gate valve 214 is closed and cryogenic pump 212 can be warmed to evaporate trapped gases, including water vapor. The evaporated gases can be removed through exhaust line 222. During regeneration, clean dry air can be flowed into cryogenic pump 212 through CDA supply line 224. This can help remove water vapor and other gases. After regeneration, roughing pump 220 can be controlled to pump down degas processing chamber 204 to a suitable pressure (e.g., 5 mTorr to 1 mTorr). Then cryogenic pump 212 can be controlled to further reduce the pressure in degas processing chamber 204.

[0056] Degas module 200 further comprises a high vacuum pressure gauge, such as an ionization gauge 226, configured to sense a pressure inside degas processing chamber 204. Roughing pump 220 and/or cryogenic pump 212 can be operated based on a pressure sensed by ionization gauge 226.

[0057] As mentioned above, degas module 200 is connected to transfer module 102 at transfer port 202 that omits a valve. As such, opening transfer port 124 or transfer port 126 can cause a pressure spike inside transfer module 102 and degas module 200. Cryogenic pump 212 can reduce the pressure inside degas module 200 following a pressure spike from a load lock. However, if degas module 200 is returned to atmospheric pressure, roughing pump 220 can be operated to form a vacuum prior to operating cryogenic pump 212. By operating roughing pump 220 in pressure regimes where cryogenic pump 212 is less efficient, regeneration cycles of cryogenic pump 212 can performed less frequently.

[0058] Degas module 200 further comprises an IR radiation source 230. IR radiation source 230 is configured to apply IR radiation 232 through a window 234 to substrate 210 when the substrate is positioned in degas module 200. Window 234 can comprise any suitable material that is sufficiently transparent to IR radiation to allow a desired heating rate to be achieved. As one example, window 234 can be made of quartz. IR radiation 232 is incident on a first side 236 of substrate 210. In some examples, IR radiation source 230 comprises IR reflectors to help direct and focus IR radiation 232 towards substrate 210. Use of IR reflectors can help heat the substrate more efficiently than an IR radiation source without IR reflectors.

[0059] Degas module 200 further comprises a proximity thermocouple (TC) 238. Proximity thermocouple 238 is located proximate to a second side 240 of substrate 210. In other examples, a thermocouple can be located elsewhere within degas module 200.

[0060] FIG. 4 shows a more detailed view of substrate 210 and proximity thermocouple 238. As indicated by separation distance 400, proximity thermocouple 238 is positioned close to substrate 210 but does not contact substrate 210. In some examples, proximity thermocouple is separated from the substrate 210 by a distance within a range of 5×10^{-3} to 2.5×10^{-2} inches. In other examples, a separation distance outside this range can be used. By avoiding contact between proximity thermocouple 238 and substrate 210, heat transfer out of substrate 210 can be avoided. This can help heat substrate 210 efficiently.

[0061] Proximity thermocouple 238 is configured to sense radiation emission (e.g., IR radiation) from substrate 210 to determine the temperature of substrate 210. As such, IR radiation source 230 can be controlled to heat substrate 210 based at least on a substrate temperature detected by proximity thermocouple 238. For example, IR radiation source 230 can be controlled to heat substrate 210 to a selected temperature. Examples include temperatures within a range of 200 °C to 300 °C. In some examples, IR radiation source is controlled to maintain a substrate temperature within a range of 200 °C to 300 °C. As such, IR radiation source 230 can be controlled to heat at a relatively higher power to reach a selected substrate temperature and then controlled to heat at a relatively lower power to maintain the selected temperature. In some examples, substrate 210 can be maintained at a temperature of ≥ 200 °C for a duration of 10 to 30 seconds. This can help remove more water vapor from substrate 210 than shorter heating durations. In other examples, any other suitable duration can be used.

[0062] As mentioned above, IR reflectors can be used to focus IR radiation 232 and heat substrate 210. Further, the use of a proximity thermocouple 238 and low-contact area contacts can help avoid conducting heat out of substrate 210. As such, the substrate 210 can be heated faster and more efficiently than examples that lack such features. In some examples, IR radiation source 230 can heat substrate 210 to a selected temperature of 200 °C or greater within 60 seconds. This can help lower processing times and increase throughput.

[0063] Degas module 200 further comprises a controller 250. Controller 250 can comprise any suitable computing system. Example computing systems are described in more detail below with regard to FIG. 6. Controller 250 is operatively connected to cryogenic pump 212, roughing pump 220, ionization gauge 226, IR radiation source 230, proximity thermocouple 238, and other components within degas module 200. Controller 250 is configured to control operation of cryogenic pump 212 and roughing pump 220 to form a vacuum in degas processing chamber 204. Controller 250 further is configured to receive a signal from ionization gauge 226 indicating a pressure inside degas processing chamber 204. Controller 250 further is configured to control IR radiation source 230 to heat a substrate 210. Controller 250 further is configured to receive a signal from proximity thermocouple 238 indicating a temperature of substrate 210. Controller 250 further is configured to operate one or more valves (e.g., gate valve 214) in degas module 200, as well as control other components within degas module 200 to perform substrate processing. In other examples, controller 250 can be located remote to degas module 200 and/or located elsewhere within processing tool 100.

[0064] Returning to FIG. 1, after performing degassing within degas module 200, robot 104 of transfer module 102 can transfer substrate 210 to pre-clean module 110. Pre-clean module 110 can perform an etching process to remove oxide from the surface of the substrate. Here, the etching process is performed on a same side of the substrate as the IR radiation treatment, e.g., first side 236 of substrate 210. This helps prepare a relatively pristine surface for film deposition by PLD. The etching process can comprise any suitable technique, such as a plasma-based etch. Further, the etching process can be performed under vacuum. As such, pre-clean module 110 can comprise a high vacuum pump, such as a turbomolecular pump or cryogenic pump.

[0065] After processing the substrate at pre-clean module 110, robot 104 can transfer the substrate to one of PLD module 112A or PLD module 112B. PLD modules 112A, 112B are configured to deposit a film onto a substrate surface by PLD. Each PLD module 112A, 112B can comprise a high vacuum pump. Performing a PLD process under vacuum helps to avoid scattering between the plasma plume and trace gases in the processing chamber.

[0066] By including two or more PLD modules, processing tool 100 can process substrates in parallel. Due to water vapor removal at degas module 200 and oxide removal at pre-clean module 110, the substrate surface can be made more pristine

than examples that omit such processing steps. As water vapor and oxide layers can affect film quality, a processing tool that includes a degas module and a pre-clean module can help to form higher quality PLD films than other processing tools. As mentioned above, processed substrates can be transferred out of processing tool 100 through outbound load lock 108.

[0067] Processing tool 100 can comprise one or more controllers configured to control atmospheric ports 122, 128, load locks 106, 108, transfer ports 124, 126, and transfer module 102. The one or more controllers also can be configured to control processing modules, including degas module 200, pre-clean module 110, and PLD modules 112B. In some examples, the processing modules each can comprise a respective controller (e.g., controller 250 of degas module 200).

[0068] FIG. 5 shows a flow diagram of an example method 500 for removing water vapor from a substrate. Method 500 can be performed using degas module 200 of processing tool 100, for example. Optional processes in FIG. 5 are indicated by dashed-line boxes.

[0069] At 502, method 500 optionally comprises pumping down a degas module to a pressure of 5×10^{-3} Torr or lower with a roughing pump in the degas module. In some examples a pressure within a range of 1×10^{-3} Torr to 5×10^{-3} Torr can be used.

[0070] At 504, method 500 comprises pumping down the degas module to a pressure of 1×10^{-5} Torr or lower with a high vacuum pump in the degas module. For example, a pressure of 1×10^{-5} Torr to 1×10^{-7} Torr can be used. In other examples, a pressure outside this range can be used. In some examples, at 506, the high vacuum pump comprises a cryogenic pump (such as cryogenic pump 212). In other examples, any other suitable high vacuum pump can be used, such as a turbomolecular pump or a diffusion pump. In some examples, at 508, the degas module is connected to a transfer module and method 500 comprises pumping down the transfer module with the degas module. In some such examples, the degas module is connected to the transfer module without a valve.

[0071] Continuing, at 509, method 500 comprises positioning a substrate on a substrate support within the degas module. In some examples, the substrate support comprises a plurality of contacts that have a relatively low contact area with the substrate.

[0072] At 510, method 500 further comprises applying infrared radiation to the substrate in the degas module to heat the substrate to a temperature sufficient to remove water vapor from the substrate. In some examples, at 511, the substrate is heated to a temperature of 200 °C to 300 °C. In other examples, a temperature outside this range can be used. In some examples, at 512, method 500 comprises heating the substrate to a selected temperature range within 60 seconds or less. In some examples, at 514, the degas chamber comprises a proximity thermocouple and method 500 comprises sensing the temperature of the substrate when operating the IR radiation source to heat the substrate. For example, the IR radiation source can be operated at a relatively higher power to heat the substrate to the selected temperature range and operated at a relatively lower power once the selected substrate temperature is reached. In some such examples, at 516, heating the substrate comprises applying IR radiation to a first side of the substrate and sensing the temperature at an opposite side of the substrate. For example, as shown in FIGS. 2-4, proximity thermocouple 238 is located on second side 240 of substrate 210, the second side 240 being opposite to first side 236 that receives IR radiation 232.

[0073] Continuing, at 518, method 500 optionally comprises transferring the substrate though the transfer module to a pre-clean module (e.g., pre-clean module 110). At 520, method 500 optionally comprises, at the pre-clean module, etching the substrate at the pre-clean module to remove oxide from the surface of the substrate. Removal of oxide can help deposit a high-quality film onto the substrate.

[0074] Continuing, at 522, method 500 optionally comprises transferring the substrate though the transfer module to a PLD module (e.g., PLD module 112A, 112B). At 524, method 500 optionally comprises operating the PLD module to deposit a film of material onto the substrate. By processing the substrate at the degas module at step 504 and step 510, method 500 can remove water vapor from the substrate to help deposit a high-quality film at step 524.

[0075] FIG. 6 schematically shows a non-limiting example of a computing system 600 that can enact one or more of the methods and processes described above. Computing system 600 is shown in simplified form. Computing system 600 can take the form of one or more personal computers, workstations, computers integrated with substrate processing tools, and/or network accessible server computers.

[0076] Computing system 600 includes a logic subsystem 602 and a storage subsystem 604. Computing system 600 can optionally include a display subsystem 606,

input subsystem 608, communication subsystem 610, and/or other components not shown in FIG. 6. Controller 250 is an example of computing system 600.

[0077] Logic subsystem 602 includes one or more physical devices configured to execute instructions. For example, the logic subsystem can be configured to execute instructions that are part of one or more applications, services, programs, routines, libraries, objects, components, data structures, or other logical constructs. Such instructions can be implemented to perform a task, implement a data type, transform the state of one or more components, achieve a technical effect, or otherwise arrive at a desired result.

[0078] The logic subsystem can include one or more processors configured to execute software instructions. Additionally or alternatively, the logic subsystem can include one or more hardware or firmware logic subsystems configured to execute hardware or firmware instructions. Processors of the logic subsystem can be single-core or multi-core, and the instructions executed thereon can be configured for sequential, parallel, and/or distributed processing. Individual components of the logic subsystem optionally can be distributed among two or more separate devices, which can be remotely located and/or configured for coordinated processing. Aspects of the logic subsystem can be virtualized and executed by remotely accessible, networked computing devices configured in a cloud-computing configuration.

[0079] Storage subsystem 604 includes one or more physical devices configured to hold instructions 612 executable by the logic subsystem to implement the methods and processes described herein. When such methods and processes are implemented, the state of storage subsystem 604 can be transformed—e.g., to hold different data.

[0080] Storage subsystem 604 can include removable and/or built-in devices. Storage subsystem 604 can include optical memory (e.g., CD, DVD, HD-DVD, Blu-Ray Disc, etc.), semiconductor memory (e.g., RAM, EPROM, EEPROM, etc.), and/or magnetic memory (e.g., hard-disk drive, floppy-disk drive, tape drive, MRAM, etc.), among others. Storage subsystem 604 can include volatile, nonvolatile, dynamic, static, read/write, read-only, random-access, sequential-access, location-addressable, file-addressable, and/or content-addressable devices.

[0081] It will be appreciated that storage subsystem 604 includes one or more physical devices. However, aspects of the instructions described herein alternatively

can be propagated by a communication medium (e.g., an electromagnetic signal, an optical signal, etc.) that is not held by a physical device for a finite duration.

[0082] Aspects of logic subsystem 602 and storage subsystem 604 can be integrated together into one or more hardware-logic components. Such hardware-logic components can include field-programmable gate arrays (FPGAs), program- and application-specific integrated circuits (PASIC / ASICs), program- and application-specific standard products (PSSP / ASSPs), system-on-a-chip (SOC), and complex programmable logic devices (CPLDs), for example.

[0083] When included, display subsystem 606 can be used to present a visual representation of data held by storage subsystem 604. This visual representation can take the form of a graphical user interface (GUI). As the herein described methods and processes change the data held by the storage subsystem, and thus transform the state of the storage subsystem, the state of display subsystem 606 can likewise be transformed to visually represent changes in the underlying data. Display subsystem 606 can include one or more display devices utilizing virtually any type of technology. Such display devices can be combined with logic subsystem 602 and/or storage subsystem 604 in a shared enclosure, or such display devices can be peripheral display devices.

[0084] When included, input subsystem 608 can comprise or interface with one or more user-input devices such as a keyboard, mouse, or touch screen. In some examples, the input subsystem can comprise or interface with selected natural user input (NUI) componentry. Such componentry can be integrated or peripheral, and the transduction and/or processing of input actions can be handled on- or off-board. Example NUI componentry can include a microphone for speech and/or voice recognition, and an infrared, color, stereoscopic, and/or depth camera for machine vision and/or gesture recognition.

[0085] When included, communication subsystem 610 can be configured to communicatively couple computing system 600 with one or more other computing devices. Communication subsystem 610 can include wired and/or wireless communication devices compatible with one or more different communication protocols. As non-limiting examples, the communication subsystem can be configured for communication via a wireless telephone network, or a wired or wireless local- or wide-area network. In some examples, the communication subsystem can allow

computing system 600 to send and/or receive messages to and/or from other devices via a network such as the Internet.

[0086] It will be understood that the configurations and/or approaches described herein are exemplary in nature, and that these specific examples are not to be considered in a limiting sense, because numerous variations are possible. The specific routines or methods described herein can represent one or more of any number of processing strategies. As such, various acts illustrated and/or described can be performed in the sequence illustrated and/or described, in other sequences, in parallel, or omitted. Likewise, the order of the above-described processes can be changed.

[0087] The subject matter of the present disclosure includes all novel and non-obvious combinations and sub-combinations of the various processes, systems and configurations, and other features, functions, acts, and/or properties disclosed herein, as well as any and all equivalents thereof.

CLAIMS:

1. A processing tool, comprising:

a transfer module;

a pulsed laser deposition module connected to the transfer module;

a degas module connected to the transfer module, the degas module comprising

a substrate support,

a cryopump configured to form a vacuum comprising a pressure $\leq 10^{-5}$ Torr in the degas module and the transfer module, and

an infrared radiation source.

2. The processing tool of claim 1, wherein the infrared radiation source is configured to heat a substrate to a temperature of 200 °C to 300 °C in 60 seconds or less.

3. The processing tool of claim 1, further comprising infrared reflectors to direct infrared light towards the substrate support.

4. The processing tool of claim 1, further comprising a proximity thermocouple configured to sense a temperature of a substrate positioned in the substrate support.

5. The processing tool of claim 4, wherein the infrared radiation source is positioned to provide infrared radiation to a top side of a substrate holder and the proximity thermocouple is positioned to sense temperature at a bottom side of the substrate holder.

6. The processing tool of claim 5, wherein the proximity thermocouple is positioned to be separated from a substrate positioned in the substrate holder by 0.025 inches or less.

7. The processing tool of claim 1, wherein the processing tool omits a valve between the degas module and the transfer module.

8. A degas module comprising:

a substrate support configured to support a substrate in the degas module,

an infrared radiation source configured to apply infrared radiation to the substrate, and

a high vacuum pump configured to form a vacuum comprising a pressure $\leq 10^{-5}$ Torr in the degas module, wherein the degas module is configured to connect to a transfer module without a valve between the degas module and the transfer module.

9. The degas module of claim 8, wherein the degas module is incorporated into a substrate processing tool comprising the transfer module connected to the degas module.

10. The degas module of claim 9, further comprising one or more pulsed laser deposition modules attached to the transfer module.

11. The degas module of claim 8, wherein the infrared radiation source is configured to heat a substrate to a temperature of 200 °C to 300 °C in 60 seconds or less.

12. The degas module of claim 8, further comprising a proximity thermocouple configured to sense a temperature of a substrate positioned in the substrate support.

13. The degas module of claim 12, wherein the infrared radiation source provides infrared radiation to a first side of the substrate and the proximity thermocouple is located proximate to an opposite side of the substrate when the substrate is positioned in the substrate support.

14. The degas module of claim 13, wherein the proximity thermocouple is positioned to be separated from the substrate by 0.025 inches or less when the substrate is positioned in the substrate support.

15. The degas module of claim 8, further comprising infrared reflectors to direct infrared light towards the substrate support.

16. The degas module of claim 8, wherein the substrate support comprises three contacts configured to support the substrate, and wherein each contact of the three contacts has a contact area with the substrate that is less than 1 cm^3 when the substrate is positioned in the substrate support.

17. A method for removing water vapor from a substrate, the method comprising:

pumping down a degas module and a transfer module to a pressure of 10^{-5} Torr or lower with a cryopump in the degas module;

positioning a substrate on a substrate support within the degas module; and

applying infrared radiation to the substrate in the degas module to heat the substrate to a temperature sufficient to remove water vapor from the substrate.

18. The method of claim 17, further comprising, at a proximity thermocouple in the degas chamber, sensing the temperature of the substrate when applying the infrared radiation to the substrate.

19. The method of claim 17, further comprising:

after applying the infrared radiation to the substrate to remove water vapor from the substrate, transferring the substrate to a pre-clean module connected to the transfer module; and

etching the substrate at the pre-clean module to remove oxide from a surface of the substrate.

20. The method of claim 17, wherein applying the infrared radiation to the substrate comprises heating the substrate to a temperature of 200 °C or greater in 60 seconds or less.