

ROBOTIC CHAMBER CLEANING AND MAINTENANCE

1. Field of the Invention

[0001] The present embodiments relate to systems and methods for using a cleaning cart with one or more end-effectors operatable by a robot to automate maintenance operations in a semiconductor fabrication facility.

BACKGROUND

2. Description of the Related Art

[0002] A substrate undergoes various fabrication operations in one or more process chambers (also referred to as “process modules”) to generate semiconductor electronic devices. The process chambers can be part of a cluster tool and the cluster tool can be part of a fabrication facility. The various fabrication operations may be performed in process chambers within a single cluster tool. Alternately, a first fabrication operation may be performed in process chambers of a first cluster tool, a second fabrication operation may be performed in process chambers of a second cluster tool, and so on. The fabrication facility can include a number of cluster tools with each cluster tool having a number of process chambers. The number of cluster tools and the number of process chambers are used in the device manufacturing process to improve the yield by processing a number of substrates parallelly while ensuring that the quality of the electronic devices is consistently maintained.

[0003] In order to maintain consistency in the quality of electronic devices, the process chambers have to undergo frequent maintenance. In some cases, the frequency of maintenance may depend on the hours a process chamber has been operating since the last maintenance and the type of operation performed in the process chamber. Depending on the hours of operation and the type of operation performed, some of the process chambers may need to be serviced more often (e.g., once a month, bi-weekly, daily, after an amount of time or number of operations, etc.) while other process chambers may need to be serviced less often.

[0004] Depending on a scale of a fabrication facility used for processing a wafer to generate the electronic devices, there may be hundreds or thousands of the process chambers distributed in different cluster tools within the fabrication facility. As different process chambers are engaged to perform different types of operations, keeping track of the maintenance of the process chambers and servicing the many process chambers becomes a complex and time-consuming process. Currently, keeping track of the maintenance and actual servicing of the process chambers is done manually by humans. However, certain maintenance operations are very specific and require skilled or trained service personnel (e.g., field service engineers and/or

maintenance technicians) to follow specific maintenance patterns. For example, one of the basic maintenance operations is providing access to the inside of a process chamber for cleaning. Access can be provided by disassembling a top cover of the process chamber, and once cleaning operation is complete, re-assembling the process chamber cover. Currently, depending on the size of the process chamber cover, each process chamber cover may be secured using anywhere from 30 – 60 bolts. The bolts have to be removed in proper sequence and with precision torquing so as to prevent the wearing on the bolts and ensuring proper installation of the cover. Due to the high volume of process chambers that need to be maintained and frequency of maintenance, these tasks can be repetitive, physically demanding and mentally challenging as the service personnel have to remember the type of maintenance that needs to be done at each process chamber, the maintenance schedule, the sequencing steps, parametric values (e.g., torquing values, etc.) to follow, etc., for each process chamber. As the number of process chambers that need to be maintained, the complexity of scheduling and performing the maintenance operations increase, leading to potential human error. Human error introduced during servicing of process chamber can be correlated to costly and unscheduled equipment downtime. In addition to the volume and frequency, these operations have to be performed within confined work spaces of a fabrication facility using tools (e.g., torque wrenches for tightening bolts), which require higher than average physical strength and/or skills.

[0005] Additionally, some of the maintenance operations, such as a cleaning operation, can vary from one person to another, as the concept of clean can vary from person to person. Currently, the cleaning operations are performed manually by vigorously scrubbing the inside sidewalls of the process chamber to release polymeric deposits adhering to the inside sidewalls and then cleaning up the released particulates using wipes soaked in solvents. This is a labor intensive and time-consuming operation. Furthermore, cleaning is process chamber specific as are chemistries used in the process chamber. As a result, the manual cleaning has to account for chamber-to-chamber variations in the type and amount of cleaning that needs to be done to remove the polymeric deposits adhering to the inner sidewalls, in addition to the operator-to-operator variations.

[0006] It is in this context that embodiments described in the present disclosure arise.

SUMMARY

[0007] The various implementations describe apparatuses, systems and methods for automating routine maintenance operations of the various process chambers used in a fabrication facility. The automation is enabled using end-effectors that are operatable using a robot disposed within the fabrication facility. Each one of the end-effectors is used for performing a certain cleaning or a maintenance operation inside the process chamber. The end-effectors used for cleaning are

housed in a mobile cart (also referred to as a “cleaning cart”). The mobile cleaning cart is a detachable unit and allows the end-effectors to be brought proximal to a process chamber, when a cleaning operation is to be performed at the process chamber, and moved away once the cleaning operation is completed. More than one end-effector can be disposed on the cleaning cart and used to perform different cleaning and/or other maintenance operations. For example, a first end-effector can be used to apply a cleaning chemistry to release the polymer residues and to remove them from the inside sidewalls of the process chamber, and a second end-effector can be used to wipe the inside sidewalls clean after the first cleaning operation has been completed. In addition to the aforementioned end-effectors, additional end-effectors may be disposed on the cleaning cart and engaged to perform additional cleaning and/or maintenance operations.

[0008] To enable autonomous cleaning, the end-effectors are coupled to a robot arm of a robot available within the fabrication facility. The robot can be disposed on a mobile cart and used to engage with and operate the end-effectors disposed on the cleaning cart. The mobile cart on which the robot is disposed can be different from the cleaning cart. The mobile cart can just house the robot or can accommodate additional components used for performing other cleaning and/or maintenance operations. To differentiate from the cleaning cart, the mobile cart housing the robot is also referred to henceforth as a “main cart”. Similar to the cleaning cart, the main cart is a mobile, detachable unit that can be moved proximal to the process chamber to perform one or more maintenance operations and, upon conclusion of the maintenance operations, can be moved away. Alternately, the robot can be disposed on the cleaning cart itself or can be disposed on and/or operated by an overhead transport (OHT) mechanism used in the fabrication facility.

[0009] When a maintenance operation, such as a cleaning operation, is to be performed at a process chamber, the robot and the cleaning cart are brought proximal to the process chamber. In the case where the robot is disposed on the main cart, the cleaning cart is docked to a first side of the main cart and a second side of the main cart is docked to the process chamber. The robot is used to operate the end-effector that is designed for the cleaning operation by moving the end-effector into the process chamber and guiding the end-effector within the process chamber during the cleaning operation.

[0010] The automation takes into account human safety, form factor, portability, consistency, etc., when performing the cleaning operation. The form factor requirements dictate mobility, size and maneuverability within confined spaces of the fabrication facility and the end-effector is designed to satisfy these requirements. The automation also allows data related to status of the process chambers including the type(s) of operations performed, usage (i.e., frequency of each type of operation performed), type of chemicals used for performing the type(s) of the

operations, etc., to be collected and maintained for each process chamber in the fabrication facility, so that the type and frequency of maintenance operation that has to be performed at each process chamber can be intelligently predicted and appropriately scheduled. The maintenance data can be collected centrally for all the process chambers by a controller operating the robot or locally at each process chamber. The maintenance data collected from the different process chambers provides a detailed record keeping for the maintenance operations performed at each process chamber and such data can be used to perform quick diagnosis and correct any problem as it arises, thereby reducing costly and unscheduled downtime.

[0011] The precision and consistency of the different maintenance operations can be easily replicated by the robot as it is programmed to meet the strict requirements of each maintenance operation. The robot is equipped with sensors, vision systems and image capturing devices to precisely locate a site or area within the process chamber that has to be maintained, identify the type of maintenance operation that has to be performed, identify and operate the appropriate end-effector to perform the maintenance operation, and ensure that the maintenance operation meets the established standard. As the automation depends on the robot and not the humans to perform the maintenance operation, the automation avoids the maintenance personnel from getting exposed to toxic chemicals, reduces the time needed for performing the different maintenance operations, and avoids human introduced errors.

[0012] In one implementation, an end-effector for use to perform a maintenance operation within a process module disposed in a fabrication facility, is disclosed. The end-effector includes an upper tubular extension coupled to a cleaning chemistry source at a first end. A top portion of a lower tubular extension is coupled to a second end of the upper tubular extension. A bottom portion of the lower tubular extension has a cleaning head with an opening defined to cover an area. An interlock stopper is disposed between the second end of the upper tubular extension and the bottom portion of the lower tubular extension. The interlock stopper is coupled to the lower tubular extension and is configured to move the lower tubular extension into the process module for performing the maintenance operation. The end-effector includes a chemical channel that is embedded within and extends a length between the first end of the upper tubular extension and the cleaning head of the lower tubular extension. The chemical channel is coupled to the cleaning chemistry source at the first end and to a nozzle at the cleaning head. The chemical channel is configured to flow a cleaning chemistry. The end-effector also includes a vacuum flow channel embedded within and extending the length between the first end of the upper tubular extension and the cleaning head at the bottom portion of the lower tubular extension. The vacuum flow channel is coupled to a vacuum machine at the first end. The vacuum machine is configured to apply the vacuum within the vacuum flow

channel to allow extraction of the cleaning chemistry and any polymer residues released from the area. An end-effector robot interface is disposed in a portion of the upper tubular extension. The end-effector robot interface is configured to mate with an end-effector connector disposed on a robot available within the fabrication facility. The end-effector is housed in a cleaning cart and is configured to be autonomously operated by the robot to perform the maintenance operation.

[0013] In another implementation, an end-effector for use to perform a maintenance operation within a process module disposed in a fabrication facility, is disclosed. The end-effector includes a wand handle extending a length between a top portion and a bottom portion. The bottom portion of the wand handle includes a hinge mechanism. A wipe head is disposed on a shaft of the hinge mechanism defined in the bottom portion of the wand handle. The shaft allows a portion of the wipe head to pivot around an axis of rotation. The wipe head includes an upper arm, a lower arm, the hinge mechanism disposed at the first end coupling the upper arm and the lower arm, and a clip mechanism is disposed at the second end. The clip mechanism includes a snap-fit feature and an actuator to couple the upper and the lower arms. The end-effector is housed in a cleaning cart and is configured to be handled by a robot available within the fabrication facility for performing the maintenance operation.

[0014] In yet another implementation, a chamber cover used for sealing an opening of a process chamber disposed within a fabrication facility, during a maintenance operation, is disclosed. The chamber cover includes a base plate providing a supporting surface for the chamber cover. A sliding ring is disposed over the base plate. The sliding ring has a rotating bearing to allow rotation of the sliding ring along an axis of rotation. A mid ring is disposed over the sliding ring. A cover plate is disposed over the mid ring. The cover plate has a hole defined in a portion of a surface to provide access to an inside of the process module. The chamber cover is installed over the opening of the process chamber. The cover plate is coupled to the mid ring and the sliding ring to form a unitary component. The mid ring provides a sealing interface between the cover plate and the sliding ring. An interlock face plate is disposed to provide a lining for the hole defined in the portion of the cover plate. The interlock face plate includes a locking component to lock an end-effector received through the hole of the cover plate, during the maintenance operation. The locking allows the end-effector to rotate the cover plate along an axis of rotation and the locking component ensures that the end-effector received inside the interlock face plate remains in place, the rotation allowing different portions of an inside surface of the process module to be exposed to a cleaning chemistry applied through the end-effector. The chamber cover is housed in a cleaning cart and is configured to be handled by a robot

available within the fabrication facility for sealing the opening of the process module during the maintenance operation.

[0015] In another implementation, a bolt used for securing a top plate to an opening of a process module disposed in the fabrication facility, is disclosed. The bolt includes a bolt head, a bolt body and a bolt thread. The bolt head is defined in a top portion of the bolt and includes a chamfer on an inside top edge and a recess to engage a hex key used for installing and de-installing the bolt onto the top plate. The chamfer extends for a length. The bolt body is disposed immediately below the bolt head and the bolt thread is defined in a bottom portion of the bolt body. The bolt thread is used to secure the top plate over the opening of the process module.

[0016] In yet another implementation, a valve sealing tray for use during a cleaning operation of a process module disposed within a fabrication facility, is disclosed. The valve sealing tray includes a valve bowl and a mounting flange. The valve bowl is defined to fit into a valve slot disposed below a lower electrode of the process module. A dimension of the valve bowl matches an inside dimension of the valve slot. The mounting flange with through holes defined therein is used for securing to a side of the valve bowl. The mounting flange is designed to cover an opening of the valve slot, when the valve sealing tray is inserted into the valve slot. The valve bowl is configured to be received on and pivoted around a vertical shaft of a hinge defined in the valve slot.

[0017] In another implementation, an end-effector for use to install a gel strip on a consumable part used within the process module disposed in a fabrication facility, is disclosed. The end-effector includes at least one vacuum port defined in a body of the end-effector. The at least one vacuum is connected to a vacuum pump to provide a suction force. A suction cup is used for gripping and removing a backer layer disposed on the gel strip. A vacuum plate is disposed in a bottom portion of the end-effector. The vacuum plate is used to retrieve the gel strip from a holding container (e.g., gel strip container), hold, move and place the gel strip at a gel applicator site defined on a portion of the consumable part received on a turntable. A vision system is used to illuminate the gel applicator site to precisely place the gel strip. The end-effector is housed in a cleaning cart and is configured to be handled by a robot available within the fabrication facility for installing the gel strip.

[0018] Other aspects will become apparent from the following detailed description, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] The embodiments may best be understood by reference to the following description taken in conjunction with the accompanying drawings.

[0020] Figure 1 illustrates a simplified view of a cleaning cart housing a plurality of end-effectors used for performing maintenance operation within a process chamber disposed in a fabrication facility, in accordance with one implementation.

[0021] Figure 1A illustrates a front perspective view of the cleaning cart and Figure 1B illustrates a side perspective view of the cleaning cart, in accordance with one implementation.

[0022] Figure 2A illustrates an overhead view of the cleaning cart with one or more end-effectors housed therein docked to a main cart having a robot, in accordance with one implementation.

[0023] Figure 2B illustrates an overhead view of a portion of the main cart with the top plate being moved out so as to provide a robot to access a gel station received on a second portion of the main cart, in accordance with one implementation.

[0024] Figure 3A illustrates a simplified view of the various components of a chamber cover used to seal an opening of a process chamber within a fabrication facility, when performing a cleaning operation, in accordance with one implementation.

[0025] Figure 3B illustrates a side perspective view of a portion of an end-effector used for performing a cleaning operation aligned over a hole defined in the chamber cover, in accordance with one implementation.

[0026] Figure 3C illustrates a perspective view of the end-effector of Figure 3B being received into the opening of the chamber cover in preparation for performing a cleaning operation, in accordance with one implementation.

[0027] Figure 4A illustrates a vertical cross-sectional view of an end-effector used for performing a cleaning operation, in accordance with one implementation.

[0028] Figure 4B illustrates a side perspective view of the end-effector illustrated in Figure 4A, in accordance with one implementation.

[0029] Figure 4C illustrates a vertical cross-sectional view of an interlock stopper used in the end-effector of Figures 4A and 4B, in accordance with one implementation.

[0030] Figure 4D illustrates a vertical cross-sectional view of the chemical channel and the vacuum flow channel embedded within the end-effector, in accordance with one implementation.

[0031] Figure 4E illustrates alternate structures of a nozzle disposed at an end of the chemical channel of the end-effector used for performing a cleaning operation, in accordance with some implementations.

[0032] Figure 4F illustrates an expanded view of a cleaning head defined at a bottom portion of the end-effector used for cleaning, in accordance with one implementation.

[0033] Figure 4G illustrates a view of an interlock stopper showing a heat shield disposed between the interlock stopper and upper tubular extension of an end-effector used for performing a cleaning operation, in accordance with one implementation.

[0034] Figure 4H illustrates an expanded view of an interlock stopper showing a pair of springs used for pushing a lower tubular extension inside a process chamber for performing a cleaning operation, in accordance with one implementation.

[0035] Figure 5A illustrates a side cross-sectional view of a process chamber with a pair of cleaning wand end-effectors used for cleaning different surfaces between an electrostatic chuck disposed in the process chamber and inside sidewalls of the process chamber, in accordance with some implementations.

[0036] Figures 5B and 5C illustrate different cleaning wand end-effectors that are engaged for cleaning the different inside surfaces of components received in the process chamber within a fabrication facility, in accordance with some implementations.

[0037] Figures 5D-5F and Figure A illustrate a view of a clip mechanism and a hinge mechanism used in the cleaning wand end-effectors of Figures 5A-5C for receiving a cleaning wipe used for cleaning inside surface of a process chamber, in some implementations.

[0038] Figures 5G-5J illustrate alternate implementations of cleaning wand end-effectors used for cleaning surfaces within the process chamber, in accordance with some alternate implementations.

[0039] Figures 6A-6C illustrate an expanded view of a hinge mechanism used to hold the different arms of a cleaning wand end-effector, in accordance with some implementations.

[0040] Figure 7A illustrates a vertical cross-sectional view of a bottom portion of a process chamber showing a valve slot used for inserting a valve sealing tray unit for collecting polymer residues released during a cleaning operation, in accordance with one implementation.

[0041] Figure 7B illustrates an example of a valve sealing tray unit that is designed to be inserted manually into the valve slot defined in the process chamber, in accordance with one implementation.

[0042] Figures 8A and 8B illustrate different views of a gel applicator end-effector that can be operated by a robot for applying gel strips onto a consumable part, such as an edge ring, in accordance with some implementations.

[0043] Figure 8C illustrates a view of a robot arm handling the gel applicator end-effector during application of gel strips on to an edge ring, in accordance with some implementations.

[0044] Figure 9A illustrates components of a turntable fixture used to secure the consumable part, such as an edge ring, for applying gel strips using the gel application end-effector of Figures 8A-8C.

[0045] Figures 9B-9E illustrate a cam-based locking mechanism used for securing the consumable part, such as the edge ring, in accordance with some implementations.

[0046] Figures 10A-10H illustrate a sample gel strip placement sequence followed using a gel applicator end-effector operated by a robot, in accordance with one implementation.

[0047] Figures 11A and 11B illustrate a view of a bolt used for securing a top plate onto a plasma chamber disposed within a fabrication facility, in accordance with one implementation. Figure 11A provides a top perspective view of a bolt head of the bolt and Figure 11B illustrates a cross-sectional view of the bolt with a chamfered bolt head.

[0048] Figures 11C and 11D illustrate a lateral cross-sectional view of the bolt, in accordance with some implementations.

[0049] Figures 12A-12D illustrate perspective views of a bolt-head end-effector used to install bolts onto a top plate used for covering an opening of the process chamber, in accordance with some implementations.

[0050] Figures 13A-13E illustrate a gel strip package used for storing gel strips that are used for placing on a consumable part used within a process chamber, in some implementations. Figure 13F illustrates a gel tray defined on a main cart and accessed by a robot to retrieve the gel strips for placement on a portion of an edge ring, in some implementations.

[0051] Figures 14A-14C illustrate different components of a ring press fixture used for pressing gel strips received over an entire surface of a consumable part, in some implementations.

[0052] Figures 14D-14F illustrate variations to the ring press fixture illustrated in Figures 14A-14C, in some alternate implementations.

[0053] Figures 15A-15D illustrate different components of a nest used for storing the ring press fixture, in some implementations.

[0054] Figures 16A-16C illustrate a cart on which the nest used for storing the ring press fixture and a ring receiving surface for receiving the consumable part for gel strip installation are disposed, in some implementations.

[0055] Figures 17A-17C illustrate different components of a swing clamp used for providing a clamp force to the ring press fixture for conveying to the gel strips, in some implementations.

[0056] Figures 17D-17F illustrate components of a clamp used for providing a clamp force to the ring press fixture, in accordance to some alternate implementations.

[0057] Figure 18 illustrates a simplified schematic diagram of a computer system for implementing embodiments.

DETAILED DESCRIPTION

[0058] The following embodiments describe apparatuses, systems and methods for performing maintenance operations, such as cleaning, wiping, gel strip application, etc., on different process chambers (alternately referred to herein as “process modules”) within a fabrication facility using robots. A plurality of end-effectors are provided on a mobile cart and a robot is used to retrieve the end-effectors from the mobile cart and manage insertion and operation of them within the process module. The automation ensures that precision and consistency of repeatable tasks are maintained while mitigating any operator introduced errors. The automation takes into account human safety, form factor, portability, and consistency in the operation (e.g., cleaning operation), while ensuring that repeatable actions are performed with high precision and minimal variability. It will be apparent that the present embodiments may be practiced without some or all of these specific details. In other instances, well known operations have not been described in detail in order not to unnecessarily obscure the present embodiments.

[0059] Figure 1 illustrates a cleaning cart 10 that is configured to provide housing for a plurality of end-effectors used in performing maintenance operations within a process chamber disposed in a fabrication facility, in one implementation. The cleaning cart 10, as shown, is a mobile cart and includes a set of casters to enable the cleaning cart 10 to be moved around in the fabrication facility, including proximate to a process chamber within a cluster tool assembly distributed in the fabrication facility. The cleaning cart 10 provides housing for a plurality of end-effectors that are used for performing maintenance operations within the process chambers. When a maintenance operation is to be performed at a process chamber, the cleaning cart is brought proximate to the process chamber, and an end-effector disposed in a housing is engaged to perform the maintenance operation. Once the maintenance operation is completed, the end-effector is returned back to the housing on the cleaning cart 10 and the cleaning cart 10 is moved away from the process chamber.

[0060] A process chamber (i.e., process module) can be used to perform one or more fabrication operations on a surface of a substrate received within to define semiconductor devices. In the process, the inside surface of the process module can get exposed to the process chemistries used in the fabrication operations. These process chemistries can adhere to the inside surfaces and have to be cleaned periodically to prevent the contaminants from getting accidentally released from the inside surfaces during subsequent fabrication operation and contaminating the semiconductor devices that are being processed.

[0061] Toward this end, the cleaning cart 10 can include one or more housings to receive a cleaning end-effector (e.g., end-effector 118), a wiping end-effector, a gel=strip application end-effector, a fastener end-effector, etc. In some implementations, the aforementioned and

additional end-effectors used for performing the various maintenance operations can all be accommodated on a single cleaning cart while in other implementations, the end-effectors can be stored in more than one cleaning cart. The number of end-effectors disposed on a single cleaning cart can depend on the size of the cart, the size of the end-effectors, amount of clearance available in the fabrication facility, to name a few.

[0062] The end-effector 118 can be a cleaning tool used for cleaning inside sidewalls of the process module. When engaged to perform the cleaning operation, the end-effector 118 is moved into the process module and is activated to apply a blast of cleaning agent (e.g., cleaning chemistry) from a cleaning agent source to the inside sidewalls. The various application parameters of the cleaning chemistry, such as a type, concentration, amount, force, application time, etc., are all controlled to ensure optimal cleaning is achieved (i.e., the polymer residues adhering to the inside sidewalls are substantially released) in the portion of the inside sidewall exposed to the cleaning chemistry. The cleaning operation also includes extracting the cleaning chemistry and the polymer residues released from the inside sidewalls of the process module. Additional cleaning operation can follow, wherein the inside sidewalls that were cleaned by the prior cleaning operation are wiped using a second end-effector (not shown) to remove any leftover polymer residues from the initial cleaning operation.

[0063] In addition to the end-effectors, the cleaning cart 10 can also provide housing to store one or more other components, such as a chamber cover 100 used to cover an opening of the process chamber for performing a maintenance operation (e.g., cleaning operation). The chamber cover 100 used to cover the opening is specific in that it includes a hole on the surface to accommodate an end-effector used for performing the maintenance operation. The hole provides the end-effector with access to the inside of the process module to perform the maintenance operation. The hole of the chamber cover 100 is lined with an interlock face plate 112. The interlock face plate 112 includes a locking mechanism to hold the end-effector in place, allow the end-effector received therein to extend to different heights within the process module, and to securely lock the end-effector at different heights.

[0064] The end-effector (e.g., end-effector 118) disposed on the cleaning cart 10 includes an end-effector robot interface 119 that is used to couple to a corresponding robot end-effector connector (156a) disposed on a robot arm 156 of a robot (152 – not shown) available in the fabrication facility. In some implementations, the robot is disposed by itself on a main cart (not shown) that is different from the cleaning cart 10. In other implementations, the robot is disposed on the main cart with other components. In some other implementations, the robot is disposed on an overhead transport mechanism of the fabrication facility, or on other moveable unit or surface.

[0065] When a maintenance operation, such as the cleaning operation, is to be performed in a process module (not shown), the robot available within the fabrication facility is brought proximate to the process module. In the case where the robot is disposed on the main cart, the main cart with the robot is brought proximate to and docked with the process module. Similarly, the cleaning cart 10 with the one or more end-effectors used for cleaning is brought proximate to the main cart. The cleaning cart 10 is docked to the main cart so that the robot on the main cart can retrieve the appropriate end-effector (e.g., end-effector 118) from the cleaning cart 10 and insert it into the process module through the hole in the chamber cover 100 and initiate the cleaning operation. A robot end-effector connector 156a disposed on a robot arm 156 of the robot (152) is used to couple with the end-effector robot interface 119 of the end-effector 118 to manage insertion and operation of the end-effector 118, for example, in the process chamber and the interlock face plate locks the end-effector in place during the cleaning operation.

[0066] Figure 1A illustrates a front view and Figure 1B illustrates a side perspective view of the cleaning cart 10 used for housing one or more end-effectors that are used for performing the one or more maintenance operations within a process module, in some implementations. In addition to the end-effectors, the cleaning cart 10 includes other components disposed in different portions to make the cleaning cart 10 a self-sustaining, independent unit. Broadly speaking, the cleaning cart 10 is broadly divided into 3 major portions - a bottom cart 16 defined in a bottom portion, a middle assembly 14 defined immediately above the bottom cart 16, and a top assembly 12 defined immediately above the middle assembly 14. Each portion includes one or more components. In one example illustration, the bottom cart 16 includes a coldjet machine 21, a vacuum cleaner 22, a filter 23 and an ice box 24. The coldjet machine 21, in some implementations, is used to receive a cleaning chemistry that has been chilled to a predefined temperature prior to applying the chilled cleaning chemistry as a cold jet through an end-effector 118 to an area within a process module (not shown). The ice box 24, in some implementations, is configured to receive the cleaning chemistry from the cleaning chemistry source and chill it to the predefined temperature prior to supplying the chilled cleaning chemistry to the coldjet machine 21. In some implementations, the chemistry used for cleaning is carbon dioxide and the ice box 24 is used to cool the carbon dioxide to dry ice (i.e., cooled carbon dioxide) so that the dry ice can be applied as a cold jet to an inside surface area of the process module that needs to be cleaned. The filter 23 and the vacuum cleaner 22 can work hand-in-hand to extract the polymer residues (i.e., particulates) released during the cleaning operation from the process module. In some implementations, the filter 23 is a high efficiency particulate air (HEPA) filter that is capable of removing the fine particulates. In some implementations, the vacuum cleaner

22 is connected to a scrubber exhaust disposed in the fabrication facility so that the cleaning chemistry and the polymer residues extracted from the process module are safely exhausted out. [0067] The middle assembly 14 of the cleaning cart 10, in some embodiments, is used to house one or more end-effectors. In the illustrations of Figures 1A and 1B, an end-effector 118 used to clean the inside sidewalls of the process module (also referred to as a “cleaning end-effector”) is shown to be disposed in the middle assembly 14. The cleaning end-effector 118 includes a cleaning head that is similar to the one shown in Figure 1 and is configured to perform the same function of supplying the cleaning chemistry to a portion of the inside sidewall, when received in a process chamber, and remove the cleaning chemistry with any polymer residues released during the cleaning operation. The top assembly 12, in some embodiments, is configured to house one or more hoses (collectively referred to by reference numeral 27), one or more hose retractors 28 and a chamber cover 100 that is used to cover an opening of the process module when performing a cleaning or any other maintenance operation. The one or more hoses, in some implementations, are used to couple one or more components to one another (e.g., connecting the cleaning chemistry source to the ice box, connecting the ice box to the coldjet machine) and the components to the corresponding end-effector used for performing the cleaning or maintenance operation. For example, the top assembly 12 can include coldjet and vacuum hoses. The coldjet hose (also referred to as a “cleaning hose” as it is used to supply cleaning chemistry) is used to connect the coldjet machine 21 to the end-effector 118 so that the chilled cleaning chemistry (e.g., dry ice) from the coldjet machine 21 can be supplied through the end-effector 118 to the inside sidewalls of the process module. Similarly, the vacuum hose is used to couple the vacuum cleaner to the end-effector 118 so that vacuum can be applied through the end-effector 118 to extract the cleaning chemistry and released polymer residues from the process module. Depending on the type of end-effectors and components provided on the cleaning cart 10, additional hoses and/or connectors for coupling the different components and for connecting the different components to respective end-effectors can be provisioned on the cleaning cart 10.

[0068] The hoses can come in the way of the robot arm 156 trying to perform a maintenance operation or can come in the way when one or more components have to be moved out of the way for the robot arm 156 to reach an area or component that is to be used for performing the maintenance operation. To prevent the hoses from coming in the way of performing the maintenance operations, the cleaning cart 10 can be equipped with hose retractors 28 so that the hoses can be extended when needed and retracted when not in use. For instance, a vacuum hose retractor is provided to house the vacuum hose and a coldjet hose retractor is provided to house

the coldjet hose. Depending on the type and number of hoses provided, additional hose retractors may be provided on the cleaning cart 10.

[0069] Figure 2A illustrates an overhead view of a cleaning cart 10 in use, in accordance with some implementations. As noted, the cleaning cart 10 is configured to house a plurality of end-effectors, which can be used for performing maintenance operations in the process modules. The type of end-effectors disposed on the cleaning cart 10 drive the type of maintenance operations that can be performed at the process module. The cleaning cart 10 is a mobile, detachable unit that can be moved proximate to a process module, when a maintenance operation is to be performed, and moved away after the maintenance operation has been completed.

[0070] In some implementations, the cleaning cart 10 is sized to move comfortably into the space between process modules and/or between different components of a fabrication facility and the casters on the cleaning cart 10 allow the cleaning cart 10 to move in any direction and within small confines. The fabrication facility usually houses hundreds or even thousands of process modules. In some implementations, the fabrication facility can include a number of cluster tools, with each cluster tool having a set number of process modules. Each cluster tool of process modules can be defined to perform a single fabrication operation parallelly. Alternately, each cluster tool of process modules can be defined to perform the different fabrication operations needed to define semiconductor devices. The fabrication facility can have hundreds of cluster tools. Due to the sheer number of process modules disposed in the fabrication facility, the clearance between process modules within a cluster tool and between cluster tools can be very tight. Therefore, in order to perform the maintenance operation on the process modules, the cleaning cart 10, in some implementations, is sized to be small and is equipped with casters to assist in easy maneuvering of the cart 10 within tight spaces. In some implementations, the width of the cleaning cart 10 is defined to be between about 18 inches and about 22 inches. In other implementations, the width of the cleaning cart 10 is defined to be about 20 inches. Although certain measurements have been provided, the dimension of the cleaning cart 10 is not restricted to the aforementioned dimension and cleaning cart with other dimensions outside of the aforementioned dimensions can also be envisioned.

[0071] The end-effectors disposed on the cleaning cart 10 can be autonomously operated using a robot 152 available within the fabrication facility. In some implementations, the robot 152 is disposed on a second cart 150. Similar to the cleaning cart 10, the second cart 150 is designed as a mobile, detachable unit, wherein the second cart 150 can be brought proximate to a process module to perform a maintenance operation and, upon conclusion of the maintenance operation, moved away. To differentiate the second cart with the robot from the cleaning cart 10 with the end-effectors, the second cart 150 is also referred to as a “main cart” (150). In some

implementations, the main cart 150 is used to house only the robot 152. In other implementations, the main cart 150 houses other components in addition to the robot, wherein the other components are used to assist in or perform other maintenance operations. For example, the other components can include a bolt plate 154 that is used to store bolts used for securing a top plate over an opening of the process module, a gel applicator turntable 220 with a consumable part (e.g., an edge ring made of ceramic) 222 received thereon for applying gel strips, one or more end-effector robot interface 119 received at an end-effector receiving station 158, to name a few. The end-effector receiving station 158, in some implementations, can be defined on a portion of a surface of the main cart that is used for housing other end-effectors, such as bolt head end-effector (not identified), etc. The end-effector robot interfaces 119 received at the end-effector receiving station 158 are similar to an end-effector robot interface 119 defined at an end-effector (e.g., end-effector 118 of Figures 1 and 1B) disposed in the cleaning cart 10 and is therefore identified using the same reference numeral.

[0072] The robot 152 includes a robot arm 156 with a robot end-effector connector (not identified) defined on one end and the other end attached to the main cart 150. The robot arm 156 can be manipulated using signals from a controller (not shown) coupled to the robot 152. The controller can be located within the main cart 150 or can be remotely located within the fabrication facility. For details related to the robot and the various components disposed on the main cart 150 and the function of the robot, reference can be made to the commonly owned, co-pending U.S. Patent Application No. 17/908,235, entitled, “Collaborative Robot System on a Mobile Cart with a Chamber Docking System”, filed on August 30, 2022, which is incorporated herein by reference in its entirety.

[0073] When the maintenance operation is to be performed at a process module (not shown), both the cleaning cart 10 and the main cart 150 are brought proximate to the process module. The cleaning cart 10 is coupled to a first side of the main cart 150 and a second side of the main cart is coupled to the process module. The coupling of the cleaning cart 10 to the main cart 150 can be through a docking mechanism 216. In one implementation, the docking mechanism includes a docking plate 216a, one or more bumpers 216b and one or more toggle clamps 216c. A first side of the docking plate 216a is coupled to the cleaning cart 10 and a second side of the docking plate 216a is coupled to a first side of the main cart 150. One or more bumpers 216b are disposed between the first side of the docking plate 216a and the cleaning cart 10 to provide a cushion there-between and prevent any damage when the cleaning cart 10 is being coupled to the main cart 150. In some implementations, the one or more bumpers are made of rubber. In other implementations, the one or more bumpers are made of non-slip material. In some implementations, the docking plate is made of metal, such as aluminum. The materials used for

the bumpers 216b and the docking plate 216a are provided as examples and should not be considered restrictive and that usage of other materials can also be envisioned. A pair of toggle clamps 216c are disposed on the cleaning cart 10 and used to engage the docking plate 216a to reliably secure the cleaning cart 10 to the first side of the main cart 150.

[0074] Figure 2B illustrates an overhead view of the cleaning cart 10 docked to the main cart 150 and one or more components of the main cart 150 being moved out of the way so that the robot arm 156 can access different areas or components that are disposed on the main cart 150. The main cart 150 includes a top support surface for receiving one or more components of the process module or components used for performing a maintenance operation within the process module. In the example illustrated in Figure 2B, a top plate assembly 117 was removed from a process module and stored in a housing defined on a portion of the top support surface of the main cart 150. Similar to the cleaning cart 10, the main cart 150, in some implementations, is designed to have one or more housings to receive and support different components. In some implementations, the portion having the housing to support one or more component(s) is designed to be moved independently, and such movement can be to move the component closer to or away from a process module requiring maintenance operation, when the main cart 150 is docked to the process module. For example, in some cases, the different housings may be designed on the main cart such that they may be stacked one on top of the other to save real-estate space on the main cart 150. In the example illustrated in Figure 2B, the housing for receiving the top plate assembly 117 is defined over a housing that is designed to receive and store a gel applicator tray 205, thereby inhibiting the robot arm 156 from accessing the gel applicator tray 205. In order to provide access to the gel applicator tray 205, the portion of the top support surface housing the top plate assembly 117 needs to be extended out (e.g., swung out) so that the gel applicator tray 205 with a consumable part, such as a ceramic edge ring (CER), received thereon can be accessed.

[0075] Accessing the different components and performing the different maintenance operations is automated using the robot by coupling the robot to a controller (not shown). The controller can be a computer used to provide the necessary signals to the robot to enable the robot to engage with and operate the different end-effectors. In some implementations, the controller is located on the main cart 150 and is used to independently control the operation of the robot 152. In other implementations, the controller is located on the main cart 150 and is communicatively connected to a central server within the fabrication facility or to a remote server (e.g., cloud server) via a server in the fabrication facility. In these implementations, the central or remote server is coupled to the controller on the main cart 150 via a network using application programming interfaces (APIs). The network can be a private or proprietary network. In yet

other implementations, the controller is remotely located in the fabrication facility and the main cart 150 is communicatively coupled to the controller through a wired or wireless connection. In any of the aforementioned implementations, the robot on the main cart 150 receives the signals from the controller and performs the necessary maintenance operation using the end-effectors located in the cleaning cart 10 and/or the main cart 150. Data generated from the maintenance operation is collected and used to determine the maintenance status of the different process modules and to schedule the maintenance operations.

[0076] Figure 3A illustrates some of the components of a chamber cover 100 that is used to cover an opening of a process module targeted for performing a maintenance operation, in some implementations. Typically, an opening of the process module is covered by a top plate that is designed to completely seal the opening when the process module is engaged to perform a fabrication operation on a substrate received within. The top plate is secured to the process module with a plurality of bolts. When a maintenance operation is to be performed at the process module, the top plate is removed by removing the bolts and the opening is then covered with the chamber cover 100. The removal operation is to be performed by loosening the bolts in a specific sequence, with specific torquing values, and follow this pattern over a number of rounds and the robot is engaged to ensure the specific removal sequence is followed. Like the top plate, the chamber cover 100 is sized to seal the opening of the process module. In addition to sealing the opening, the chamber cover 100 is designed to provide access to the inside of the process module for performing the maintenance operation. As noted, in some implementations, the chamber cover 100 is housed in the top assembly portion 12 of the cleaning cart 10 and is designed to be handled autonomously by a robot available in the fabrication facility (e.g., robot disposed on a main cart 150). The mobile, detachable cleaning cart 10 is brought proximate to the process module, when a maintenance operation is to be performed, and moved away from the process module after the maintenance operation has been completed.

[0077] To perform the maintenance operation, the robot 152 disposed on the main cart 150 is brought close to the process module and is engaged to autonomously remove the top plate covering the opening of the process module, retrieve the chamber cover 100 from the housing on the cleaning cart 10, and install the chamber cover 100 over the opening of the process module so as to seal the opening of the process module. The installed chamber cover 100 is ready for receiving an end-effector to perform the maintenance operation.

[0078] The chamber cover 100 includes a plurality of rings and cover plate to seal the opening of the process module and a hole defined in a portion of the chamber cover 100 to accommodate an end-effector and provide the end-effector with access to the inside of the process module. The different components of the chamber cover 100, in some implementations, includes a base

plate 107, a sliding ring 106, a mid ring 104 and a cover plate 102. The base plate 107 provides a support surface over which other rings of the chamber cover 100 are received. The base plate 107 is configured to be installed over a top surface of the process module to cover and seal the opening. The base plate 107 can be installed over the top surface of the process module using one or more base plate fasteners 108. In some implementations, the base plate fastener 108 is a unitary piece. In alternate implementations, the base plate fastener 108 is made of two units - a separate base plate fastener head 108a and a base plate fastener body 108b. In such implementations, the base plate fastener head 108a can include threading that can be used to engage with corresponding threading in the base plate fastener body 108b received inside. The coupling of the base plate 107 to the top surface of the process module is not restricted to the aforementioned base plate fastener 108 nor is the coupling restricted to the structure of the base plate fastener 108. Other types of fastener units can also be employed.

[0079] The sliding ring 106 is disposed immediately above the base plate 107. The sliding ring 106, in some implementations, includes one or more rotating bearings (not shown) to allow the sliding ring 106 to rotate along an axis of rotation, such as a horizontal axis. The mid ring 104 is received over the sliding ring 106 and the cover plate 102 is received immediately over the mid ring 104. The mid ring 104, in some implementations, provides a sealing interface between the cover plate 102 and the sliding ring 106. In some implementations, the mid ring 104 is made of a foam-like material that is conducive to withstand the chemistry and the environment within the process module to which the chamber cover will be exposed during the maintenance operation, while effectively providing a seal to the opening of the process module when the chamber cover 100 is installed. In some implementations, the cover plate 102 is coupled to the mid ring 104 and the sliding ring 106 using fasteners (e.g., cover fasteners) 110 to form a unitary component. This allows the different rings of the chamber cover 100 to move in unison, when operated by an end-effector. The fasteners 110 can be screws or can be any other type of fastening units. The cover plate 102, in some implementations, is made of a material that provides a view of the inside of the process module. The visual allows a maintenance operator to ensure that the maintenance operation performed in the process module is thorough and has covered all the inside surfaces of the process module. In some implementations, the cover plate is made of a polycarbonate sheet. However, the implementations are not restricted to the aforementioned material and that usage of other materials that provide similar functionality can also be envisioned.

[0080] The hole 116 (i.e., through-hole) defined in a portion of the cover plate surface is lined using an interlock face plate 112. The interlock face plate 112 is fastened to the cover plate 102 of the chamber cover using one or more interface fasteners 114. The interface fasteners 114 can

be screws or any other type of fastening units. The interlock face plate 112 includes a locking component (also referred to interchangeably as interlock component) to securely receive the end-effector in the hole 116 and lock the end-effector in place. Additionally, the locking component is designed to allow vertical movement of the end-effector received in the hole so as to allow the end-effector to extend to different heights within the process module. In some implementations, the locking component can employ a press-fit mechanism that uses a press or push force to secure the end-effector in place within the hole 116, allow vertical movement, while providing the necessary seal. In other implementations, the interlock component can employ other types of coupling mechanism to secure the end-effector into the hole 116 and to securely hold the end-effector at different heights due to vertical movement of the end-effector.

[0081] In addition to allowing the vertical movement, the locking component allows the end-effector received in the hole to rotate the cover plate and along with it the remaining components of the unitary component, which includes the cover plate 102, the mid ring 104 and the sliding ring 106, along the axis of rotation (e.g., a horizontal axis) using the one or more rotating bearings of the sliding ring 106. The rotation allows the different portions of the inside surfaces of the process module to get exposed to the end-effector received inside the hole while the interlock face plate continues to engage the locking mechanism to hold the end-effector in place. In some implementations, the end-effector maybe a cleaning tool that is engaged to perform a cleaning operation. In such implementations, the rotation of the unitary component of the chamber cover with the end-effector allows different portions of the inside surface of the process module to get exposed to a cleaning chemistry applied through a cleaning head defined at a bottom of the end-effector. The structure of the chamber cover 100 disclosed in Figure 3A is provided as a mere example and should not be considered restrictive. Fewer or additional rings can be included to define the chamber cover 100. Additionally, different structure of the chamber cover 100 can also be envisioned so long as the chamber cover is able to accommodate an end-effector within the hole defined on the cover plate and provide the end-effector with access to the inside of the process module during a maintenance operation.

[0082] Figures 3B and 3C illustrate perspective views of a portion of a process module 101 on which the chamber cover 100 has been received and installed, in preparation for performing a maintenance operation, in some implementations. The cover plate 102 of the chamber cover 100 with the hole 116 lined with the interlock face plate 112 is shown to be receiving an end-effector 118. Figure 3B shows the end-effector 118 being aligned over the hole 116 in the chamber cover 100 and Figure 3C shows the end-effector 118 received in the hole 116 of the chamber cover 100. The end-effector 118 is a cleaning tool and is configured to supply a cleaning chemistry through a cleaning nozzle 126 defined in a lower tubular section of the end-effector

118. The end-effector 118 is coupled to a robot end-effector connector 156a disposed on the robot arm 156 of a robot 152 located in a main cart 150 through an end-effector robot interface 119 defined at the end-effector 118. The coupling allows the robot arm to operate the end-effector 118 autonomously by guiding the robot arm 156 with the end-effector 118 toward the hole 116 in the cover plate 102 of the chamber cover 100, securely install the end-effector 118 in the hole 116 using the interlock component of the interlock face plate lining the hole 116, and operate the end-effector to perform the maintenance operation. The autonomous operation of the end-effector by the robot is through signals provided by a controller (not shown) disposed in the fabrication facility. The controller can be provided on the cleaning cart 10 or the main cart 150 or can be disposed elsewhere in the fabrication facility and communicatively coupled to the robot so that signals from the controller can be communicated to the robot. The robot arm is used to provide the push force to lock the end-effector 118 within the hole 116, and such force is applied based on signals from the controller. The robot arm can also be used to move the end-effector up and down along a vertical axis to allow the cleaning nozzle 126 received inside the process module to move to different heights and the locking component (i.e., interlock component) is used to secure the end-effector at the different heights. The cleaning nozzle 126 is used to provide blasts of the cleaning chemistry to the inside sidewalls causing the polymer residues that have adhered to the sidewalls during fabrication operations to be released. The released polymer residues are promptly removed with the cleaning chemistry using a vacuum flow channel defined in the end-effector 118. The structure of the end-effector will be discussed in greater detail with reference to Figures 4A-4H.

[0083] Figures 4A-4H illustrate cross-sectional views identifying various components of an end-effector 118 used for performing a maintenance operation (e.g., a cleaning operation), in some implementations. Figure 4A illustrates a first side view of an end-effector 118 used for performing a maintenance operation. The end-effector 118 illustrated is a cleaning tool used to perform a cleaning operation. Consequently, the end-effector 118 is used to provide a cleaning chemistry to a cleaning site, such as a portion of an inside surface of a process module, when the end-effector is inserted into and engaged for performing the cleaning operation within the process module. The end-effector 118 is defined by an upper tubular extension 118a and a lower tubular extension 118b with an interlock stopper 120 defined between the upper tubular extension 118a and the lower tubular extension 118b. The upper tubular extension 118a of the end-effector 118 includes an end-effector robot interface 119, which is a connector interface that is used to couple the end-effector 118 to an end-effector connector (not shown) disposed on a robot arm 156 of a robot 152 allowing the robot arm 156 to control movement and operation of the end-effector 118 during the cleaning operation. The upper tubular extension 118a also

includes a chemistry port 136 for receiving a cleaning chemistry from a cleaning chemistry source. The cleaning chemistry, in some implementations, can be dry ice, which is a solidified form of carbon dioxide. The cleaning chemistry source can be an ice box 24 that is used to generate the dry ice by cooling the gaseous form of the carbon dioxide to predefined temperature and supplying the dry ice through a coldjet machine 21 to the end-effector 118 for applying to the cleaning site. The end-effector 118 also includes a vacuum port 134 connected to a vacuum cleaner 22 (Figures 1A, 1B) to provide the vacuum (i.e., suction force) that can be used to remove the cleaning chemistry and any polymer residues released from sidewalls of the process module during the cleaning operation. In the implementations illustrated in Figures 1A and 1B that houses the end-effector 118 discussed with reference to Figures 4A-4H, the ice box 24, the coldjet machine 21 and the vacuum cleaner 22 are shown to be disposed on the cleaning cart 10 (shown in Figures 1A and 1B), making it a self-contained unit that includes all the necessary components for performing the cleaning operation. The lower tubular extension 118b includes a vacuum window 128 defined in the bottom portion. The vacuum window (also referred to as “cleaning head”) 128, in some implementations, covers an area surrounding a cleaning site where the cleaning chemistry is applied. A cross-sectional view A-A of the interlock stopper 120 shown in Figure 4A will be described with reference to Figure 4C.

[0084] Figure 4B illustrates a second side perspective view of the end-effector 118 showing some of the components of an interlock stopper 120 disposed between the upper tubular extension 118a and the lower tubular extension 118b of the end-effector 118 illustrated in Figure 4A. To avoid duplication, the different components that are common between Figures 4A and 4B are not described. As shown, the interlock stopper 120 includes a spring mechanism, which includes a pair of “leaf springs” (or simply referred to as “springs”) 120a and an interlock face plate 120b. The interlock stopper 120 is coupled to the lower tubular extension 118b to enable the pair of springs 120a to be engaged during insertion of the lower tubular extension 118b through the hole 116 in the chamber cover 100 into the process module and during dynamic extension of the lower tubular extension 118b to different heights within the process module. The interlock face plate 120b includes a locking component that is used to lock the end-effector into the opening on the cover plate and at different heights so as to allow the end-effector to cover different portions of the inside sidewalls and other surfaces of the process module that need to be cleaned as well as provide sufficient seal, when the end-effector 118 is received. The lower tubular extension 118b shows the vacuum window / cleaning head 128 defined in the bottom portion. The cleaning head 128 is designed to cover an area surrounding a chemistry application site defined by a cleaning nozzle 126 included in the cleaning head 128. Details of

the inside structure of the end-effector 118 with the cleaning nozzle 126 and the cleaning head 128 will be discussed in the cross-sectional view B-B illustrated in Figure 4D.

[0085] Figure 4C illustrates a magnified, vertical, cross-sectional view A-A of an interlock stopper 120 shown in Figure 4A, in one implementation. As noted above, the interlock stopper 120 includes a pair of springs 120a and an interlock face plate 120b that are used during insertion of the end-effector 118 into the process module. The pair of springs 120a can get activated, in one implementation, by a force applied by the robot 152 when inserting the end-effector 118 into the hole 116 of the chamber cover. The activated springs 120a are used to adjust the height of the lower tubular extension 118b inside the process module. When the height of the lower tubular extension 118b is adjusted, the height of the upper tubular extension 118a coupled to the lower tubular extension 118b is also adjusted. The interlock face plate 120b is configured to stay in a constant position and the pair of springs 120a provides the freedom of movement for the upper and the lower tubular extensions (118a, 118b). In some implementations, the interlock face plate 120b is a slidable cover that seals the opening of the hole 116 and the locking component of the interlock face plate 120b holds the upper and the lower tubular extensions (118a, 118b) in place at defined heights.

[0086] When the end-effector 118 is locked in place to the chamber cover 100, the end-effector 118 can be rotated, in response to signals from the robot, along an axis of rotation (e.g., horizontal axis). The rotation of the end-effector 118 causes the cover plate 102 of the chamber cover 100 to which the end-effector 118 is coupled to rotate along the horizontal axis. By rotating the end-effector 118, different portions of the inside sidewalls along the first height are exposed to the cleaning chemistry applied through the cleaning head 128. After the first pass covering the different portions along the first height, the height of the end-effector 118 can be dynamically adjusted via signals from the robot 152 to extend the cleaning head 128 in the process module to a second height and a second pass of the cleaning operation can be carried out by rotating the end-effector 118 to cover the sidewalls along the second height. The end-effector 118 can thus be used to perform multiple passes of cleaning, wherein each pass is defined to cover a distinct height to which the lower tubular extension with the cleaning head 128 is extended into the process module so that the entirety of the sidewalls of the process module can be cleaned. In some implementations, signals from the robot are used to adjust the height to which the lower tubular extension with the cleaning head 128 is extended into the process module.

[0087] Figure 4D illustrates a magnified, vertical, cross-sectional view of a portion of the end-effector 118 corresponding to section B-B illustrated in Figure 4B, in one implementation. The end-effector 118 illustrated in Figure 4D is a cleaning tool providing cleaning chemistry and

includes an inner chemistry channel 140 that is encompassed by an inner channel liner 141. The chemistry channel 140 extends a length of the end-effector 118 from a chemistry port 136 in the top to a cleaning head 128 in the bottom of the end-effector 118. The cleaning head 128 in the bottom portion of the chemistry channel 140 includes a cleaning nozzle 126 that extends outwardly from within the cleaning head 128. The cleaning nozzle 126 is disposed at an angle in relation to a straight angle of the chemistry channel 140. In some implementations, the angle is an acute angle. During the cleaning operation, the cleaning head 128 of the end-effector 118 extending inside the process module is brought proximate to a portion of an inside sidewall of the process module corresponding to a first height and the cleaning chemistry is applied to the portion causing the polymer residues that have adhered to the portion of the sidewalls to get released. In this implementation, the cleaning head is designed to perform contactless cleaning as a separation distance exists between the cleaning head 128 and the sidewalls. The narrowness and the orientation angle of the cleaning nozzle 126, the type of cleaning chemistry (e.g., dry ice) used, the separation distance between the end-effector 118 and the sidewall, the force at which the cleaning chemistry is applied at the cleaning site drives the exposure time and number of passes that has to be performed to achieve a level of cleaning desired for the cleaning operation.

[0088] A vacuum flow channel 144 is defined between the inner channel liner 141 of the chemistry channel 140 and an outer channel liner 142 surrounding the vacuum flow channel 144. Like the chemistry channel 140, the vacuum flow channel 144 extends the length of the end-effector 118 from a vacuum port 134 at the top to the cleaning head 128 in the bottom. The vacuum port 134, as noted before, is coupled to the vacuum cleaner 22 and, in some implementations, to a filter module 23, so that vacuum can be generated in the vacuum flow channel 144 to assist in extracting the cleaning chemistry and the polymer residues from the process module. The vacuum provides a suction force that forces the cleaning chemistry and the freed polymer residues to flow through the vacuum flow channel 144 toward the vacuum cleaner 22. In some implementations, the vacuum cleaner 22 is coupled to and configured to vent out to a vacuum exhaust of the fabrication facility. In some implementations, the chemistry channel 140 is disposed in the center of the end-effector 118 and the vacuum flow channel 144 is designed to surround the chemistry channel 140. In such implementations, the cleaning nozzle 126 at the end of the chemistry channel 140 is disposed in the center of cleaning head (i.e., vacuum window) 128 with the vacuum flow channel surrounding the cleaning nozzle 126. The end-effector design with the central chemistry channel 140 and the peripheral vacuum flow channel 144 is provided as an example and other orientations of the chemistry channel 140 and the vacuum flow channel 144 within the end-effector can also be envisioned.

[0089] Figure 4E illustrates variations in the cleaning nozzle 126 defined in the cleaning head 128 of the end-effector 118 used for providing the cleaning chemistry, in some implementations. The cleaning nozzle 126, in some implementations, includes a fixed nozzle head 126a, in that the nozzle head extending outwardly from the cleaning head 128 is fixedly mounted to the chemistry channel 140 at a defined angle in relation to the straight angle of the chemistry channel 140. In another implementation, the cleaning nozzle 126 includes a flexible/moveable nozzle head 126b, in that the nozzle head 126b of the nozzle is mounted to the chemistry channel using a flexible connector 127. The flexible connector 127 is designed to allow the nozzle head 126b to pivot along one or more axes of rotations, thereby allowing the nozzle head 126b to apply the cleaning chemistry to an expansive area along the inside sidewall of the process module. As with the movement of the end-effector, the pivoting of the nozzle head 126b can be controlled using signals from a controller coupled to the robot operating the end-effector. The flexible nozzle head 126b can be used to perform fewer passes to clean the inside sidewalls of the process module, as each pass covers an expansive area.

[0090] Figure 4F illustrates an expanded view of the vacuum window (i.e., cleaning head) 128 defined at the bottom of the lower tubular extension 118b of the end-effector 118, in some implementations. The cleaning head 128 is shown to be a rectangular shaped window although other shapes (e.g., square, hexagon, circular, octagon, etc.) can also be envisioned. The cleaning nozzle 126 is shown to be extending outwardly from inside the cleaning head 128 at an angle. As noted above, in some implementations, the cleaning head 128 is designed to perform contactless cleaning by positioning the cleaning head 128 at a predefined distance away from the sidewall of the process module and initiating the cleaning operation. In some implementations, the predefined distance for positioning the cleaning head 128 from the sidewall of the process module is defined to be between about 0.5 mm and about 1.5 mm. In some other implementations, the predefined distance is defined to be about 1 mm.

[0091] In other implementations, the cleaning head (i.e., vacuum window) 128 defined at the bottom portion of the end-effector 118 is defined to provide for contact cleaning. In such implementations, an outer surface of the opening defined in the cleaning head 128 is lined by an O-ring 129. The O-ring 129 is used to seal the opening of the cleaning head 128 with the portions of the inside sidewall of the process module during the cleaning operation to provide contact cleaning. The interface between the sidewall and the O-ring, in some implementations, is a metal-to-plastic interface, wherein the sidewall is made of metal and the O-ring is made of plastic or similar material. The sealing is provided to contain the cleaning area and to prevent polymer residues released from the sidewall to fly out and settle in other areas of the process module, thereby contaminating those areas. In some implementations, the sealing can result in

excessive suction force being developed within the vacuum flow channel 144 of the end-effector 118. To relieve the excessive suction force in the vacuum flow channel 144, one or more bleed holes 130 are provided at the bottom side of the lower tubular extension 118b of the end-effector 118 leading to the vacuum flow channel 144. The bleed holes 130 allow the air from the surrounding environment within the process module to circulate within the vacuum flow channel 144 thereby relieving the excess suction force generated during the contact cleaning. The size and number of bleed holes 130 are based on the amount of pressure relief needed to reduce the excessive suction force generated within the vacuum flow channel 144 from the contact cleaning.

[0092] Figure 4G illustrates a side, perspective view of a portion of the interlock stopper 120 of the end-effector 118', in one implementation. The end-effector 118', in this implementation, includes a heat shrink 132 disposed between the upper tubular extension 118a and the interlock stopper 120. The heat shrink is provided to sufficiently seal the end-effector 118, thereby preventing any leaks from the process module during the cleaning operation. The heat shrink is also used, in some implementations, to insulate the inside of the end-effector 118.

[0093] Figure 4H illustrates another implementation, wherein the end-effector 118 is devoid of any heat shrink. The end-effector 118 in this implementation is similar in structure to the end-effectors 118 shown in Figures 4A-4D. In such implementations, the vacuum applied through the cleaning head 128 provides sufficient negative pressure inside the process module leading to an effective seal of the end-effector 118, thereby preventing leaks.

[0094] Figure 5A illustrates a vertical cross-sectional view of a process chamber (i.e., process module) 101 that is identified to undergo a maintenance operation, such as a clean wipe operation, in some implementations. The clean wipe operation can be performed after a cleaning operation is performed using the end-effector 118 illustrated in Figures 4A-4H or can be performed after a fabrication operation. The surfaces that are to be wiped clean can include the sidewalls of the process module, the sidewalls of a lower electrode, such an electrostatic chuck (ESC), received in a lower portion of the process module 101, underside surface of the ESC, etc. Depending on the surface that needs to be wiped clean, one or more end-effectors are used to perform the clean-wipe operation(s), in some implementations. For example, the end-effectors to perform the clean-wipe operation can include one or more cleaning wand end-effectors (also referred to simply as "cleaning wands").

[0095] Figures 5B and 5C illustrate a side view of cleaning wand end-effectors 170 and 173, respectively, used in the process module 101 for wiping the different surfaces clean. Figure 5B shows a first cleaning wand 170 that is designed for wiping the sidewalls of the process module 101 and the sidewalls of the ESC, and Figure 5C shows a second cleaning wand 173 that is

designed for cleaning an underside surface of the ESC, in some example implementations. The underside surface of the ESC is generally a hard-to-clean area as the space to reach the underside is very limited (i.e., narrow). The first and the second cleaning wands (170 and 173) are designed to be inserted into the confines between the chamber walls and the ESC. Figure 5A shows the cleaning wands 170 and 173 inserted on different sides of the process module 101 to wipe the respective surfaces clean. The structure and function of each of the cleaning wands 170 and 173 will be described in greater detail with reference to Figures 5D-5J.

[0096] Figures 5D and 5E illustrate different components of the cleaning wand end-effector 170 used for wiping the surfaces of the ESC and the sidewalls of the process module, in one implementation. Referring simultaneously to both Figures 5D and 5E, the cleaning wand end-effector 170 is defined by a wand handle 171 defined in an upper portion and a contoured wipe head 172 defined in a lower portion of the cleaning wand end-effector 170. In some implementations, the dimensions of the wand handle 171 and the wipe head 172 and the shape and orientation of the wipe head 172 in relation to the wand handle 171 are defined to match or conform to the shape of the chamber liner and/or other components of the process modules whose surfaces are being cleaned using the cleaning wand end-effector 170. For example, a length of the wand handle 171 is defined to ensure that the cleaning wand end-effector 170 can reach the different regions of the process module for performing the wiping operation. In some implementations, a length of the wand handle 171 is defined to be between about 18" and about 22". In some other implementations, the length of the wand handle 171 is defined to be about $20" \pm 1"$. In some implementations, the contour of the wipe head 172 is defined to enable inserting the cleaning wand end-effector 170 into the region between different components of the process module to perform the wiping operation. The contour of the wipe head 172, in some implementations, is defined by a vertical upper portion and a horizontal lower portion disposed at an angle in relation to the vertical upper portion, wherein the angle of the contour is defined to be an acute angle. In some implementations, the wand handle 171 and the wipe head 172 are sufficiently flexible to adapt to the geometry of the confines to allow insertion and for performing an effective wiping operation.

[0097] In some implementations, the bottom and / or the top surface of the wipe head 172 of the cleaning wand end-effector 170 is configured to be lined with a wipe material (not shown), such as a wiping foam or sponge, so that the surfaces that the wipe head 172 comes in contact with can be wiped clean.

[0098] In some other implementations, the cleaning wand end-effector 170 is designed to securely hold a cleaning wipe used for wiping the different surfaces. Toward this end, the wipe head 172 of the cleaning wand end-effector 170, in some implementations, is designed to include

an upper arm 172a and a lower arm 172b. A first end of the upper arm 172a is coupled to a first end of the lower arm 172b using a hinge mechanism 190, and a second end of the upper arm 172a is connected to a second end of the lower arm 172b using a clip mechanism 180. The hinge mechanism 190 is defined in a bottom portion of the wand handle 171 coupling the wand handle 171 to the top portion of the wipe head 172. The hinge mechanism 190 includes a shaft for receiving either the upper or the lower arm of the wipe head 172. The shaft allows the arm received thereon to pivot around an axis of rotation.

[0099] In some implementations, the shaft of the hinge mechanism 190 is defined along a top portion of the lower arm 172b and the top portion of the upper arm 172a is received on and pivots around the shaft of the hinge mechanism 190. Figures 6A-6C illustrate an expanded view of the hinge mechanism 190 used in the cleaning wand end-effector 170, in some implementations. The hinge mechanism 190 includes a shaft 192 defined in the top portion of the lower arm 172b and the top portion of the upper arm is received over and pivots around the shaft 192. In these implementations, the upper arm 172a is defined to be the hinged arm (i.e., the moveable arm 193) and the lower arm 172b is the fixed arm. In alternate implementations, the shaft of the hinge mechanism 190 can be defined along a top end of the upper arm 172a and the lower arm 172b can be received on and pivot around the shaft. In such alternate implementations, the lower arm 172b is defined to be the hinged or the moveable arm and the upper arm 172a is the fixed arm. In some implementations, the cleaning wand end-effector 170 is defined using three-dimensional printing, such that the entire cleaning wand end-effector 170 including the hinge mechanism 190 is printed as a single piece using 3D (three-dimensional) printing with one of the arms (either the lower or the upper arm) having the pivoting capability.

[00100] Referring back to Figures 5D and 5E, the clip mechanism 180 is defined at the second end of the upper and the lower arms (172a, 172b) coupling the two arms together. Figure A shows an expanded view of the clip mechanism 180 used in the cleaning wand end-effector 170, in some implementations. The coupling of the two arms (172a, 172b) at the second end using the clip mechanism 180 is shown as an example and other ways of coupling the two arms can also be envisioned so long as the functionality of the clip mechanism is met. The clip mechanism 180 includes a snap-fit feature 182 and an actuator 184. In some implementations, the snap-fit feature 182 is defined at the second end of the lower arm 172b and the actuator 184 is defined at the second end of the upper arm 172a. The clip mechanism 180 works by applying pressure at an inner end or an outer end of the snap-fit feature 182. When a pressure is applied at the outer edge of the snap-fit feature 182, the snap-fit feature moves from a relaxed state (i.e., un-deformed state) to a deformed state releasing the actuator 184. This causes the wipe head 172 to move to an unlocked state. When the pressure is applied at the inner edge of the snap-fit

feature 182, the snap-fit feature 182 compresses providing room to allow the actuator 184 to be pressed into place. Figure 5F shows examples of the snap-fit feature 182 profile when in a relaxed or un-deformed state 182a (i.e., locked state) and when it is moved to a deformed state 182b (i.e., unlocked state). In the unlocked state, the upper arm 172a can pivot around the shaft and can move away from the lower arm 172b. In the unlocked state, a cleaning wipe 172c (shown as dotted line along the lower arm 172b in Figure 5E) can be wrapped around to cover the bottom and the top surface of the lower arm 172b. Upon receiving the cleaning wipe 172c, the snap-fit feature 182 can be activated by applying pressure at an inner edge of the snap-fit feature 182 and pushing the actuator 184 toward the snap-fit feature 182 locking the actuator 184. This results in the wipe head 172 moving to a locked state securely locking the cleaning wipe 172c received therein, in place.

[00101] In some implementations, the cleaning wand end-effector 170 with the cleaning wipe 172c can be used by the robot to perform the wiping operation by inserting the cleaning wand end-effector 170 between the sidewall of the process module and the ESC (also referred to as “bias” or lower electrode) and wiping the surfaces along the sidewalls and the underside of the lower electrode. The materials used to define the cleaning wand 170 provide the necessary flexibility to allow the cleaning wand 170 to conform to the shape of the narrow space defined between the components when inserted and the dimensions of the cleaning wand end-effector 170 ensures that the cleaning wand can reach hard-to-reach areas, such as the underside of the ESC, to perform an effective wiping operation. Although the cleaning wand end-effectors 170 and 173 are described to be handled by a robot arm of a robot to perform the cleaning operation on and between different surfaces of the cleaning chamber, the cleaning wand end-effectors 170 and 173 can also be used to perform manual cleaning.

[00102] Figures 5G-5J illustrate a second cleaning wand end-effector 173 being used to perform wiping operation on an underside surface of the lower electrode (ESC), in one example implementation. Figure 5G illustrates a representation of the second cleaning wand end-effector 173, in one implementation. As with the cleaning wand 170, the cleaning wand end-effector 173 includes a wand handle 174 and a wipe head 175. A bottom portion of the wand handle 174 is coupled to a first end of the wipe head 175 through a hinge mechanism 190 and a second end of the wipe head 175 includes a clip mechanism 180. The wipe head 175 is defined by an upper arm 175a and a lower arm 175b, with the upper and the lower arms (175a, 175b) being coupled using the snap-fit feature 182 and the actuator 184 of the clip mechanism 180 at the second end. However, unlike the cleaning wand 170 where the snap-fit feature 182 is disposed on the lower arm 172b and the actuator is disposed on the upper arm 172a, the snap-fit feature 182, in some implementations, is disposed on the upper arm 175a and the actuator 184 is disposed on the

lower arm 175b. Figures 5I and 5J show an upside-down view of the wipe head 175 illustrating one such representation, wherein the upper and the lower arms (175a, 175b) of the wipe head 175 include the hinge mechanism 190 at the first end and the clip mechanism 180 at the second end. In the implementations illustrated in Figures 5I and 5J, the snap-fit feature 182 at the upper arm 175a, when activated, releases the lower arm 175b and moves the wipe head 175 to the unlocked state. In the unlocked state, the lower arm 175b with the actuator 184 becomes the hinged or moveable arm as it pivots around the shaft of the hinge mechanism 190 and the upper arm 175a with the snap-fit feature 182 becomes the fixed arm. A cleaning wipe 175c is used to cover the top and the underside surface of the lower arm 175b and the clip mechanism 180 and the hinge mechanism 190 are used to secure the cleaning wipe 175c in place. The cleaning wipe 175c is used to wipe the underside surface of the lower electrode, when the cleaning wand end-effector 173 is operated by the robot. In alternate implementations, the arm with the snap-fit feature can become the moveable arm and the arm with the actuator can become the fixed arm. In some implementations, the cleaning wipe can be received on both the upper arm and the lower arm to enable the wipe head to wipe surfaces of two different components.

[00103] Referring back to Figure 5G, in addition to the differences in the location of the snap-fit feature 182 and the actuator 184, the second cleaning wand end-effector 173 varies from the cleaning wand end-effector 170 with regards to the shape and orientation of the wipe head 175. The wipe head 175 of the second cleaning wand end-effector 173 includes a curved shape along a length of the wipe head 175 and extends along a single plane, as shown in Figure 5H. This is different from the wipe head 172 of Figures 5D-5E, wherein the wipe head 172 included a top vertical portion and a bottom horizontal portion. As a result, the orientation of the wand handle 174 in relation to the wipe head 175 is different from the corresponding orientation defined in the cleaning wand end-effector 170. Figure 5G illustrates the orientation of the wand handle 174 in relation to the wipe head 175. In some implementations, the wand handle 174 is oriented at an acute angle in relation to the wipe head 175. The orientation of the wipe head 175 in relation to the wand handle 174 is to ensure that, when second cleaning wand end-effector 173 is inserted, there is consistent contact maintained between the wipe head 175 and the underside of the lower electrode (i.e., ESC).

[00104] The dimensions of the wand handle 174 and the wipe head 175 are defined to ensure that the cleaning wand end-effector 173 can reach the center of the underside surface of the lower electrode. In some implementations, a length of the wand handle 174 is defined to be between about 16" and about 20" and a length of the wipe head 175 is defined to be between about 8" and about 12". In other implementations, the length of the wand handle 174 is defined to be about 18" and the length of the wipe head 175 is defined to be about 10". The curved

contour shown in Figure 5H ensures the cleaning wand 173 can fit between the lower electrode and the sidewall of the process module and reach the center of the lower electrode while also performing a thorough cleaning of the surfaces that the cleaning wand 173 comes in contact. In some implementations, the curved contour has an angle of curvature that is an acute angle.

[00105] Figures 7A-7B illustrate a vertical cross-sectional view of a process module where a maintenance operation is to be performed and a valve sealing tray unit is used to collect debris released from different surfaces that underwent cleaning operation, in some implementations. Figure 7A shows the vertical cross-section of the process module 101 identifying the valve slot 196 that can be used to insert the valve sealing tray unit 200 to collect the polymer residues released from a cleaning/wiping operation. The valve slot 196 can be accessed from a lateral side. The process module 101 includes a lower electrode (e.g., ESC) defined in a bottom portion and a showerhead is disposed in a top portion. The ESC provides a support surface to receive a substrate for processing and the showerhead provides the process gas(es) to generate plasma within a plasma region defined between the showerhead and the ESC. The plasma is applied in the process module 101 to process the substrate during a fabrication operation. The process module (i.e., process chamber) 101 used for performing a fabrication operation has to have high-precision control and isolation of vacuum and gas flows. To achieve such control, a valve device is mounted along an exhaust path of the plasma to isolate the vacuum areas, such as a plasma region of the process module. In some implementations, the valve device is disposed in the process module 101 below the ESC and access to the region is provided via a valve slot 196 defined on a lateral side of the process module. The valve slot 196 is shown as broken white line in Figure 7A.

[00106] In some implementations, the valve device is a pendulum valve device operated using a vertically hanging paddle that is supported on and operates about a hinge 194 defined in the valve slot 196. The valve device regulates the flow of process gas(es), for example, by operating the paddle. For instance, in the vertical, free hanging position, the valve paddle 195 is said to be in a closed position. When a load, such as process gas(es), flowing from the process region contacts the valve paddle 195, the paddle is rotated along a vertical axis from its closed (i.e., vertical) position causing a cam to rotate. The rotation of the cam opens a valve of the pendulum valve device allowing the process gas(es) to flow out from the process module. The amount of gas(es) flowing out of the plasma region is controlled by the amount of rotation of the cam (i.e., amount to which the valve is opened).

[00107] In order to catch and extract the polymer residues released during the cleaning operation using the end-effector 118 and/or the wiping operation using the cleaning wands 170, 173 described above, and to protect the underlying and adjacent components, such as turbo

pumps, etc., near the ESC, a valve sealing tray unit 200 is contemplated. The valve sealing tray unit 200 is a replaceable unit, in that it is used to replace the pendulum valve device. The valve sealing tray unit 200 is designed to be inserted below the ESC by accessing the same valve slot 196 used by the pendulum valve device, from the lateral side. The valve sealing tray unit 200 is configured to conform with the dimensions of the valve slot 196 so that the valve sealing tray unit 200 can be received in the valve slot 196 and is designed to sufficiently seal the area below and adjacent to the valve slot 196 in order to insulate the components that are below and/or adjacent to the ESC. The valve sealing tray unit 200 is used to collect any particulates (e.g., polymer residues) released during the cleaning/wiping operation. The valve sealing tray unit 200 is inserted into the valve slot 196 by first swinging the valve paddle 195 of the pendulum valve device out about a vertical axis using the hinge 194, removing the valve paddle 195 from the hinge 194, and replacing with the valve sealing tray unit 200. The valve sealing tray unit 200 is then moved to a closed position by swinging the valve sealing tray unit 200 about the vertical axis using the hinge 194 so that the valve sealing tray unit 200 is fully received inside the valve slot 196. Once valve sealing tray unit is fully received inside the valve slot 196, a rotating handle (not shown) disposed on the outer surface of the process chamber proximal to the valve slot and coupled to the mechanism that operates the valve sealing tray unit, is operated to a closed position causing the valve sealing tray unit to be pushed up/locked in to place within the valve slot essentially sealing the area around the valve slot. Depending on the design of the rotating handle, the rotating handle can be operated to a closed position using a rotating motion, or a sliding motion, or by applying a pushing or pulling motion, etc. The seal ensures that the polymer residues released during the cleaning operation are captured within the valve tray and protects the underlying and adjacent components, such as turbo pumps, etc., near the ESC.

[00108] Figure 7B illustrates the components of the valve sealing tray unit 200, in one implementation. The valve sealing tray unit 200 includes a valve bowl 201 and a mounting flange 202. The valve bowl 201, in some implementations, is made of a non-stick material, such as Polytetrafluoroethylene (PTFE) or similar type of material that is conducive for use in the process module 101 and is easier to clean after a cleaning operation. The mounting flange 202 is defined to cover an opening of the valve slot 196. The valve bowl 201 and the mounting flange 202 are coupled together using mounting screws or other type of fastening mechanisms to define a unitary valve sealing tray unit 200. The valve sealing tray unit 200 is inserted into the valve slot and locked into place.

[00109] When not in use, the valve sealing tray unit 200 is stored in a housing defined on the cleaning cart 10. During the cleaning/wiping operation, the valve sealing tray unit 200 is retrieved from the housing on the cleaning cart 10 and manually inserted into the process

module. In other implementations, the valve sealing tray unit 200 is configured to be installed with the help of a robot of the fabrication facility. When robot is used, the robot retrieves the valve sealing tray unit 200 from the housing on the cleaning cart 10 and aligns to the valve slot 196 and to the hinge 194 so that the valve sealing tray unit 200 can be received on the hinge 194. Once received on the hinge, the valve sealing tray unit 200 is swung about the axis of rotation (i.e., vertical axis) defined by the orientation of the hinge 194 to move the valve sealing tray unit 200 to a closed position by completely moving it into the valve slot 196 and locked into place. A locking mechanism can be employed to secure the valve sealing tray unit 200 inside the valve slot 196. To engage the locking mechanism once the valve sealing tray unit 200 is received within the valve slot 196, the valve sealing tray unit 200 can be pushed up and snapped in place. The locking mechanism can be a snap-fit or a clasp mechanism, or any other similar or suitable locking mechanism. When the valve sealing tray unit 200 is to be removed, which can be after every cleaning and/or wiping operation, for example, the valve sealing tray unit 200 is unlocked by unsnapping and pushing the valve sealing tray unit 200 down and swung out. The valve sealing tray unit 200 is used to capture the finer polymer residues that make their way below the ESC during cleaning and/or wiping operation, for example. Upon completion of the maintenance operation, the valve sealing tray unit 200 is removed and the paddle 195 of the pendulum valve device is re-inserted in preparation for conducting fabrication operations.

[00110] In some implementations, valve sealing tray unit 200 can be operated using a valve spring mechanism (not shown) to automatically lock and unlock the valve sealing tray unit 200 received in the valve slot 196. For example, the valve spring mechanism is a spring-loaded mechanism that is disposed in the front of the mounting flange and can be activated by moving a lock spring to a “raise/stow” position, which causes the valve sealing tray unit 200 to be pushed in and snapped up to a locked position within the valve slot 196. When the valve sealing tray unit 200 is to be removed from the valve slot 196, the valve spring mechanism can be turned to a “lower” position, which causes the locking mechanism holding the valve sealing tray unit 200 to release and push down and out the valve sealing tray unit 200. The unlocked valve sealing tray unit 200 can be removed from the hinge 194. In some implementations, the valve sealing tray unit 200 is generated using three-dimensional printing.

[00111] Figures 8A–8C illustrate perspective views of an example end-effector engaged to perform a maintenance operation, such as gel-strip application operation, on a consumable part (e.g., an edge ring), in some implementations. The end-effector is a gel-applicator end-effector 206 and, as with the aforementioned end-effectors, is housed on the cleaning cart 10 and retrieved, handled by a robot 152 available in the fabrication facility, when the gel strips have to be applied to the edge ring. In some implementations, the edge ring is a ceramic edge ring

(CER). Referring simultaneously to Figures 8A-8C, the gel-applicator end-effector 206 includes a plurality of components that are useful for retrieving and handling the gel-applicator end-effector 206 and for reliably lifting the gel strip from a holding container (e.g., a gel strip container) and applying on to a portion of the CER (not shown) received on a gel applicator tray (not shown). Toward this end, the gel-applicator end-effector 206 includes an end-effector robot interface 206a, one or more vacuum ports 208, at least one suction cup 210, a vacuum plate 218 and a light source 212. The gel-applicator end-effector 206 is not restricted to just the aforementioned components but can include additional components to assist in the effective use of the gel-applicator end-effector 206. The end-effector robot interface 206a is used to mate with a corresponding robot end-effector connector 156a disposed on a robot arm 156 of the robot 152 to allow the robot 152 to mate with and manage operation of the gel-applicator end-effector 206. The robot 152 can be disposed on a main cart 150 and used to retrieve the gel-applicator housed on the cleaning cart 10. In the implementation illustrated in Figures 8A-8C, a pair of vacuum ports 208 are provided. The vacuum ports 208, in some implementations, are coupled to a vacuum machine to provide high suction flow rate. The amount of suction provided through the vacuum ports 208 is defined to ensure that the gel strip can be reliably retrieved from a gel strip container and moved to the gel strip application site defined over a portion of the CER received on a gel applicator tray 205. The gel applicator tray 205 can be received and supported on the main cart 150, in some implementations. In some implementations, the gel applicator tray 205 can be received and supported on the cleaning cart 10. In some implementations, the gel applicator tray 205 is defined to support a gel applicator turntable (not shown) received thereon. The gel applicator turntable is used to support the CER firmly in place during the gel strip application operation.

[00112] The suction cup 210 is used to provide sufficient suction force to enable the gel-applicator end-effector 206 to engage with and peel off a gel backer defined on both sides of the gel strip so that the gel strip can be affixed to a portion of the CER. In some implementations, the gel strip is aligned over the portion of the CER by aligning a gel hole (not shown) defined on each gel strip with a corresponding CER hole (not shown) defined on the CER. The CER hole acts as a fiducial marker for rotating the gel-applicator end-effector, the CER received on a gel applicator tray 205, and for aligning the gel strip. Precision alignment and placement is done using the robot arm 156 with the aid of a vision system (e.g., light source) 212 that is used to illuminate a site where the gel-applicator end-effector 206 is to apply the gel strip. The light source 212 is also used to illuminate an area on the gel applicator tray 205 where operations related to a gel strip application is to be performed, such as aligning the gel strip retrieved from the gel strip container prior to moving over and precisely placing on the portion of the CER

where the gel strip is to be applied. The light source 212, in some implementations, is also used to illuminate the portion of the CER where the gel strip is to be installed so that the gel-applicator end-effector 206 can map the location of the CER hole in the portion and define a virtual boundary with the CER hole in the center. The gel strip is then removed from the gel strip container and aligned with the virtual boundary on the portion of the CER where the gel strip is to be applied. The alignment of the gel strip to the portion of the CER may not be precise. However, with the aid of the robot 152 and the virtual boundary mapping, the installation of the gel strip over the portion of the CER can be done within a specific predefined tolerance.

[00113] The vacuum plate 218 defined at a bottom surface of the gel-applicator end-effector 206 provides a support surface for receiving and transporting a gel strip from a gel strip container to the gel application site defined on a portion of the CER. The vacuum plate 218 is so named to indicate the vacuum force applied through the vacuum ports 208 to provide the necessary suction force at the bottom surface. The suction force is used to reliably support and transport the gel strip. In some implementations, the vacuum plate 218 is defined to include a grid pattern on the bottom side. The grid pattern is used to improve the suction force when retrieving and transporting (i.e., moving) the gel strip to an application site.

[00114] Figures 9A-9E provide details of a turntable used for receiving a consumable part for applying gel strips. In some implementations, the consumable part is an edge ring. In some implementations, the edge ring is made of ceramic material, and, hence, is also referred to as a “ceramic edge ring (CER)” for applying the gel strip, in some implementations. In other implementations, other types of consumable parts may be used for applying gel strips. The turntable 220 is defined on a gel applicator tray 205 defined on the main cart, for example. The gel applicator tray 205 provides a working surface for receiving and supporting the CER received on the turntable 220. The turntable 220 includes a plurality of rings for receiving a consumable part and for rotating the consumable part 222 to expose different surface portions of the consumable part 222 for gel strip installation. In some implementations, the consumable part 222 is an edge ring (222). In some implementations, the edge ring (222) is made of ceramic and hence also referred to as a “ceramic edge ring” (CER 222). The turntable 220 provides a support surface on which a mounting ring 224 and a middle ring 223 are disposed. The mounting ring 224 is received and secured on the support surface of the turntable 220. The mounting ring 224, in some implementations, includes bearings with gears to allow the rotation about an axis (e.g., horizontal axis). In some implementations, the mounting ring 224 is a slewing ring with the gears of the bearings allowing fixed rotation about the horizontal axis. The gears, in some implementations, allow the mounting ring 224 and along with it the CER 222 to rotate about the

horizontal axis to different positions. In some implementations, the gears of the bearings allow the slewing ring to be rotated to 9 different positions. The number of positions is provided as an example and should not be considered restrictive and that the gears of the bearings can be designed to rotate the CER to fewer or additional positions.

[00115] The middle ring 223 is mounted over the mounting ring 224. The middle ring 223 and the mounting ring 224 are designed to allow the middle ring 223 to properly mate with the mounting ring 224, when mounted. The consumable part, such as the CER 222, is mounted onto the middle ring using a locking mechanism. In some implementations, the locking mechanism is designed to hold and lock the CER 222 in place during the gel application operation. In some implementations, the CER 222 is held in place within a locking recess 227 defined in the middle ring 223. In some implementations, the middle ring 223 is made of Polyoxymethylene material. In some implementations, the Polyoxymethylene can be in the form of acetal, polyacetal, polyformaldehyde, etc. The aforementioned forms of the Polyoxymethylene material are collectively referred to as Delrin (i.e., durable plastic material) and hence the middle ring is also referred to as a “Delrin fixture” 223. In alternate implementations, the middle ring 223 can be made of other types of material that are similar in chemical, physical and/or thermal properties as the Delrin material. In some implementation, the locking mechanism is a cam.

[00116] Figures 9B-9E illustrates how the cam works in locking the CER 222 in place on the middle ring received on the turntable 220. Figure 9B shows how the cam is used to unlock the CER 222 from the middle ring 223. Figure 9C and 9E show the process used to lock the CER 222 to the middle ring 223 and Figure 9D shows an overhead view of the lock mechanism locking the CER 222 using a flat-on-flat contact. As shown, the cam lock mechanism, in some implementations, includes a lock plate 225 and a lock fixture 226. The top portion 225a of the lock plate 225 is flat and the bottom portion has a chamfered inner edge. The locking fixture, in some implementations, is in the form of a screw 226. As the screw 226 is tightened, as illustrated by the downward arrow, the flat portion of the lock mechanism pushes out and, due to the presence of the chamfered inner edge, presses against the CER 222, holding the CER in place against the middle ring 223 and essentially locking the CER 222, as illustrated by left arrow in Figure 9C. The CER inherently, at the inner diameter, has a small flat side (shown in Fig. 9E) and the locking mechanism does a flat-on-flat contact to lock the CER in place. The other two pins on either side of the screw 226 are fixed. The turntable 220 with the CER 222 locked in place is ready for receiving and placing gel strips on different portions of the CER 222.

[00117] Figures 10A-10H illustrate a gel strip placement sequence performed by a robot 152, as one of the autonomous maintenance operations, in some implementations. A gel

applicator turntable 220 is placed on the gel applicator tray 205. The gel applicator tray can, in turn, be arranged on the main cart 150 that includes a robot for operating the gel-applicator end-effector used for placing the gel strips on a consumable part, such as a ceramic edge ring. The gel placement sequence can be an autonomous process that is accomplished by engaging the robot 152. The process begins with the placement of the CER 222 on the gel applicator turntable 220. The CER 222, as noted above, is placed over and locked to the middle ring 223, as illustrated in Figure 10A. Next, a gel strip is retrieved from a gel strip container (not shown) that is available on the main cart 150 or the cleaning cart 10, as illustrated in Figure 10B. The gel strip is retrieved by coupling the gel-applicator end-effector 206 to the robot arm 156 of the robot 152, wherein the coupling is between the end-effector robot interface 206a of the gel-applicator end-effector 206 and the robot end-effector connector 156a on the robot arm 156.

[00118] The retrieved gel strip is placed on a backlight faceplate 228 available at the gel applicator tray 205 so that the gel strip can be aligned before placing on a portion of the CER 222. The backlight faceplate 228, in some implementation, is made of frosted plastic surface or similar type of material that is illuminated from the underside using a light source, such as a light emitting diode (LED), so that an article, such as the gel strip, placed on the backlight faceplate 228 is illuminated from the underside to provide a clean image of the article – i.e., the backlight faceplate 228 provides an accurate resolution of the gel strip. Using the image, the robot arm 156 aligns the gel strip at the backlight faceplate 228 before picking the aligned gel strip and placing it on the portion of the CER 222 by the gel-applicator end-effector 206, as illustrated in Figure 10E.

[00119] After placement of the gel strip on the portion of the CER 222, the turntable 220 with the CER 222 is rotated to bring a different portion of the CER 222 under the gel-applicator end-effector 206 for placement of the gel strip, as illustrated in Figure 10F. As noted above, in some implementations, the turntable 220 is rotated using rotating bearings, wherein the rotating bearings can be metal bearings. In alternate implementations, the rotating bearings can be plastic bearings or bearings made of other similar type of material. In some implementations, the rotating bearings are printed using 3D printing. The gel strip that is placed on the portion of the CER 222 is compressed using a gel compressor 229, as illustrated in Figure 10G. The gel compressor 229 can work in parallel with the gel-applicator end-effector 206 by following the end-effector and compressing the gel strip that was just placed by the gel-applicator end-effector 206. The gel strip is compressed to ensure that no air bubbles are present. As the gel strip is being compressed by the gel compressor 229 in a first portion of the CER 222, the gel-applicator end-effector 206 can place a second gel strip on a second portion.

[00120] After the gel compressor has compressed the gel strip into place on the portion of the CER 222, the gel-applicator end-effector 206 is used to remove the gel backer from the top of the gel strip, as illustrated in Figure 10H. Figure 10H shows the CER 222 with the gel strips received thereon. Upon completion of the gel strip application, the CER 222 can be used in the process module in preparation for performing a fabrication operation. The CER 222 with the gel strip is received and held in place using the sticky gel strips.

[00121] Figures 11A-11D illustrate cross-sectional view of a bolt that can be used to install or de-install a top plate of a process module (i.e., process chamber), in some implementations. The top plate can be used to completely seal the process module in preparation for conducting a fabrication operation. The top plate is different from the chamber cover, in that the top plate is used to completely seal the process module while the chamber cover is used to seal the process module while providing an end-effector with access to the inside of the process module for performing a maintenance operation. The top plate is usually secured to the top of the process module using a plurality of bolts. The number of bolts used to secure the top plate depends on the size of the top plate. To ensure proper seal of the process module, the bolts had to be secured in a particular sequence. A robot was used to torque the top plate in the particular sequence to ensure proper seal. However, the bolts that were used for installing and de-installing the top plate had reliability issues in connecting the bolt driver to the bolt recess (e.g., hex key recess). This could be attributed to the fact that it was difficult to locate exact position of the bolt and the hex key recess for torquing. In trying to locate the hex key recess (i.e., bolt head recess) within the bolt head, the bolt head was damaged by the impact of the bolt driver, resulting in ridges being formed due to the bolt driver improperly engaging with the bolt head recess leading to grinding and unreliable torquing.

[00122] To ensure reliable engagement with the bolt head recess and proper torquing, the bolt head 231 of a bolt 230 is designed to include a chamfer feature on a top inside surface of the bolt head. The chamfer is defined to extend for a chamfer length (i.e., length from the top side of the bolt head to a bottom of the chamfer) within the bolt head recess and include a chamfer angle so as to provide sufficient tolerance for the robot arm of the robot with the bolt driver to reliably seek and engage with the bolt head recess. Even when the bolt driver is not fully aligned with the bolt head, the chamfer aids in the bolt driver to slide into the hex key recess/bolt head recess. Figures 11A-11D illustrate overhead and cross-sectional views of a bolt that was designed to allow a hex key driver to quickly and reliably engage with a hex key recess, in some implementations. The chamfer assists in guiding the bolt driver operated by the bolt head end-effector to reliably access and engage with the hex key recess so that the torquing can be carried out reliably and with consistent results.

[00123] Figure 11A illustrates an overhead view of a re-designed bolt 230, in some implementations, and Figures 11B-11D illustrate a simplified vertical cross-sectional view of a bolt 230 used to reliably engage the bolt head driver, thereby addressing the torquing issue experienced with conventional bolts. The bolt 230 includes a bolt head 231, a bolt body 233 and a bolt thread 234. A chamfer 232 is defined at the inner top edge of the bolt head 231 to assist the hex key (i.e., bolt driver) to reliably access and engage with a hex key recess 235 defined in the bolt head for proper torquing and de-torquing. A chamfer length of the chamfer 232 is defined to allow the hex key recess 235 to have sufficient depth so that the hex key can engage with the bolt head and not slip away from the hex key recess 235. In some implementations, the length 'l1' of the chamfer 232 defined from a top straight edge of the bolt head 231 to a bottom of the chamfer (i.e., top of the hex key recess) is defined to be between about 0.03" and about 0.05". In some implementations, the height of the chamfer 'h1' is defined to be between about 0.03" and about 0.05", when the bolt head 231 has a length of about 0.25". In some implementations, the length l1 is equal to the height h1 of the chamfer. In such implementations, the chamfer is defined to be a 45° chamfer. In some implementations, the height of the chamfer 'h1' is about 0.04". In some implementations, the height 'h2' of the hex key recess 235 is defined to be between about 0.10" and about 0.20". In some implementations, the height h2 of the hex key recess 235 is defined to be about 0.13". In some implementations, a length 'l2' of the top edge of the bolt head that is straight is defined to be between about 0.02" and about 0.04". In some implementations, the length 'h3' of the chamfer between point A and point B is defined to be between 0.27" +/- 0.01" and the angle of the chamfer extending between the top of the chamfer at the bolt head defined by points 'A' and 'B' and the bottom of the recess 235 is about 90°. In some implementations, the height of the bolt head 231 is defined to be between about 0.23" and about 0.27". In some other implementations, the height of the bolt head 231 is defined to be about 0.25". The bolt body 233 extends for a height of between about 3.50" and about 3.75", in some implementations. In other implementations, the bolt body extends for a height of about 3.625". In some implementations, the bolt 230 includes bolt thread 234 at the bottom of the bolt body 233. The bolt thread 234 enables reliable mating of the bolt with the bolt recess defined in the top plate.

[00124] Figures 12A-12D illustrate automation of torquing of bolts to secure a top plate 117 of a process module 101, in some implementations, wherein the bolts having the chamfer feature in the bolt heads as described with reference to Figures 11A-11D. The installation of the top plate 117 involves performing specific actions and in specific sequences to ensure that the top plate is installed/de-installed correctly. Automating the installing/de-installing of the bolts ensures that the top plate is installed/de-installed correctly in proper sequence and using correct amount of

torquing. The automation is done using a bolt end-effector 203 that is retrieved from a housing on the cleaning cart 10, or alternatively from the main cart 150. Figure 12A shows a side view of a portion of a robot arm 156 with the robot end-effector connector 156a coupled to the end-effector robot interface 203a of the bolt end-effector 203 and used for installing the bolts on the top plate 117. The bolt end-effector 203 is a hex key driver that is used to reliably engage into the hex key recess on the bolt head 231 and torqued. Figure 12B illustrates an expanded view of the bolt end-effector 203 approaching the bolt head 231 of the bolt 230 on the top plate 117 for torquing/de-torquing. Figure 12C shows a perspective view of the system for performing the maintenance operation, such as the torquing/de-torquing of bolts on the top plate 117 of the process module 101. The bolt that is being installed includes a chamfered bolt head to allow the hex key driver to quickly locate and engage with a hex key recess defined on the bolt head 231. In some implementations, a light source 212 is used to direct the bolt end-effector 203 over the bolt 230 for torquing/de-torquing.

[00125] The plurality of end-effectors discussed in the various implementations are used in automating the maintenance operations. The automation allows repeatable maintenance operations are repeatable, are performed with precision and are in accordance to the standards established for each maintenance operation. Further, the automation saves the amount of time needed to perform each maintenance operation, and prevents the maintenance personnel from getting exposed to toxic environment and workplace injuries.

[00126] A brief description of the main cart 150 and the robot 152 disposed on the main cart 150 and used in performing the maintenance operations is provided to help in understanding the various implementations. For additional details related to the robot and the various components disposed on the main cart 150 and the function of the robot 152, reference can be made to the commonly owned, co-pending U.S. Patent Application No. 17/908,235, entitled, “Collaborative Robot System on a Mobile Cart with a Chamber Docking System”, filed on August 30, 2022, which is incorporated herein by reference in its entirety.

[00127] The robot 152 is disposed on a mobile cart (e.g., main cart 150) to allow the robot 152 to be moved proximal to different process modules within the fabrication facility to perform autonomous maintenance operations (e.g., service different process modules). The main cart 150 is defined by a cart frame that includes a plurality of sides, including a frame top, a frame bottom that is oriented opposite to the frame top, and lateral sides that extend between the frame top and the frame bottom. The mobility to the main cart 150 is provided by a plurality of casters disposed on the frame bottom. The casters are configured to move the main cart 150 in different directions. A caster lock is provided to lock each caster, and hence the main cart 150, when needed, such as when the main cart 150 is aligned to a process module that is to be serviced.

The main cart 150 is aligned with the process module along a lateral side of the process module. In some implementations, the lateral side of the process module along which the main cart 150 is aligned may include one or more sensors (e.g., lasers, proximity sensors) for proximity detection and for proper alignment.

[00128] Similar to the cleaning cart 10, the cart frame of the main cart 150 is configured to house a plurality of component assemblies, such as a computer, a robot controller, an alternate current (AC) power supply, a direct current (DC) power supply to power the computer, the robot controller and other components received in the cart frame, additional power supply (e.g., uninterruptible power supply – UPS), etc. A display screen (e.g., a touch screen display) can be coupled to the computer located on the main cart 150 and disposed on the main cart 150 for providing inputs to adjust operation parameters of an operation (e.g., maintenance operation). As previously stated, in alternate implementations, the computer may be remotely located in the fabrication facility or may be part of cloud service, and the display screen of the computer can be located on the main cart 150 and communicatively coupled to the computer so that inputs provided at the display screen can be used to perform maintenance operations, wherein the communication between the computer and the display screen can be via wired or wireless connections. Location of the various component assemblies within the cart frame of the main cart 150 may be defined and the component assemblies fixed at specific locations to provide stability during move and to provide sufficient balance when the robot is to be operated. For example, when the robot arm 156 is to be extended away from the main cart 150 and onto the cleaning cart 10 or to the process module 101, the shift in the center of gravity of the cart frame of the main cart will be considered when defining the placement of the various components. In some implementations, additional counter-weights may be provided on the main cart 150 to ensure the stability of the main cart 150 does not get compromised during movement, during alignment to the process module and/or the cleaning cart 10, or during use of the robot 152. A cover may be provided around the lateral sides of the cart frame of the main cart 150 to shield the component assemblies received on the cart frame. A docking fixture may be used to dock the main cart 150 to the process module 101 and a docking mechanism 216 discussed with reference to Figure 2A may be used to dock the cleaning cart 10 to the main cart 150. The docking fixture and/or the docking mechanism 216 can be a fixture that is permanently mounted to the main cart and/or the cleaning cart 10 or can be a removable fixture.

[00129] An arm frame (e.g., robot arm frame 157 of Figure 2B) disposed on the main cart 150 is coupled to the robot arm 156. The arm frame provides the support to the robot 152. The arm frame can include a hinge mechanism, for example, to swing the arm frame with the robot arm 156 about a vertical axis of rotation. Locking mechanism may be provided to lock the arm

frame in any position. When the main cart 150 with the arm frame is brought proximate to the process module 101 and the cleaning cart 10, the arm frame is configured to freely move the robot arm 156 of the robot 152 about the hinge so as to access and retrieve the different components (e.g., different end-effector robot interfaces 203a, 206a, etc.) disposed on the cleaning cart 10 using the end-effector connector. The retrieved end-effectors are handled by the robot arm 156 in the process module 101 to perform the maintenance operation, wherein each end-effector is designed to perform a specific maintenance operation. As previously noted, in addition to the end-effector connector, the robot arm 156 includes a vision system to align and illuminate the site where the maintenance operation is to be performed (e.g., inside surfaces of the process module, side surfaces of the ESC, etc.), wherein the vision system can include one or more light fixtures. In addition to the vision system, the robot arm 156 can also include tracking system to precisely identify the location where the maintenance operation is to be performed and the state of the maintenance operation at different stages. For example, one or more image capturing devices (e.g., cameras) may be used to capture images at various stages of the maintenance operation performed on the surfaces of the component(s), one or more sensors (e.g., motion sensors, gyroscopes for inertial sensor processing, pressure sensors, temperature sensors, speed sensors, torque sensors, power sensors, leveling sensors, etc.) for controlling alignment and to track other aspects of the maintenance operation, and lasers to obtain orientation of the component(s), and for inspecting a state and alignment of the component(s). The various tracking and the image capturing devices are part of, what is called, “on-the-spot metrology tools,” and used to capture the metrology parameters. The data collected from the vision system (e.g., images and the metrology parameters) are recorded and used for validation, inspection, diagnostics purposes, installation and maintenance standardization, etc., all of which are used for performing predictive maintenance operations.

[00130] In some implementation, the main cart 150 also includes a working platform. The working platform may be made of sheet metal and configured to receive and support different types of parts used for performing the maintenance operation. For example, the working platform can be used to receive a bolt box for storing bolts 230 that were used to install a top plate of a process module. When the main cart 150 with the robot 152 is to be moved within the fabrication facility, the arm frame supporting the robot arm 156 is kept in a folded position so that the arm frame is kept within the boundaries of the cart frame of the main cart 150 till the main cart 150 is docked to the process module 101 and to the cleaning cart 10. After the main cart 150 is docked and the robot arm is ready to perform a maintenance operation, the arm frame is extended by swinging about the hinge taking the robot arm with it, and the robot arm is used to retrieve and handle the end-effectors on the cleaning cart 10.

[00131] The robot can be programmed to specify the various parameters for each maintenance operation, so that the maintenance operation can be carried out with precision. Such precision is hard to get using manual method as maintenance operator fatigue, lapse in memory of the operator, relativity in terms of precision, (i.e., 1st operator's standard of clean may be different from the 2nd operator's standard) etc., can come into play.

[00132] The main cart 150 with the robot disposed thereon is a mobile, detachable, autonomous maintenance tool that can be used in a semiconductor fabrication facility to perform repeatable maintenance operations (i.e., tasks). As noted with reference to the cleaning cart 10, the main cart 150 can be a self-contained cart and include power source (e.g., battery) to power components, such as robot, computer, etc., disposed on the cart, or may be connected to a separate power source, such as a plug-in power source. The plug-in power source may be part of the AC power supply included in the cart frame to power other components or may be a separate power supply to power the robot and/or the main cart. Data collected from the robot is used by machine learning (i.e., artificial intelligence (AI) algorithm) for predicting maintenance schedules for the different process modules. In some implementations, the actions and sequences of an operation are learnt and coded into an algorithm (e.g., machine learning (ML) algorithm) that controls the robot arm. The ML algorithm provides detailed instructions for performing each movement (e.g., details related to location, speed, height, distance, direction, etc., the robot arm has to be moved) of the desired servicing operation. More than one robot can be provided in the fabrication facility and the process operations performed by various robots at different process modules are gathered from across the floor of the fabrication facility. The information gathered from various robots is analyzed to build and train AI models. The AI models can be queried to determine the process a robot will have to follow to perform the desired maintenance operation on a particular process module. The machine learning is optional and may be used to optimize the role of the robot in the maintenance of the process modules.

[00133] In some implementations, the various components of the fabrication facility (e.g., cluster of process modules, individual process modules, robots, etc., may be integrated with electronics for controlling their operation before, during, and after processing of a semiconductor substrate and maintenance operation conducted in a process module. The electronics may be referred to as the "controller," as it may control various components or subparts of the fabrication facility as a whole. The controller, depending on the processing requirements and/or the type of operation (e.g., fabrication operation, maintenance operation, etc.) being performed, may be programmed to control any of the fabrication processes, including the delivery of processing gases, temperature settings (e.g., heating and/or cooling), pressure settings, vacuum settings, power settings, radio frequency (RF) generator settings, RF matching circuit settings,

frequency settings, flow rate settings, fluid delivery settings, positional and operation settings, substrate transfers into and out of a process module and other transfer modules and/or load locks connected to or interfaced with a specific system. The controller can also be programmed to control any of the maintenance operations, including torquing, de-torquing of bolts from a top plate, cleaning operation, wiping operation, gel strip installation operation, etc.

[00134] The controller, broadly speaking, may be defined as electronics having various integrated circuits, logic, memory, and/or software that receive instructions, issue instructions, control operation, provide operational parameters to enable maintenance operations, enable endpoint measurements, and the like. The integrated circuits may include chips in the form of firmware that store program instructions, digital signal processors (DSPs), chips defined as application specific integrated circuits (ASICs), and/or one or more microprocessors, or microcontrollers that execute program instructions (e.g., software). Program instructions may be instructions communicated to the controller in the form of various individual settings (or program files), operational parameters for carrying out a particular process on or for a semiconductor wafer, on or within a process module, etc.

[00135] The controller, in some implementations, may be a part of or coupled to a computer that is integrated with, coupled to the cleaning cart, coupled to the main cart, or otherwise networked to a computer system defined in the fabrication facility or may be part of a “cloud system”, or any combinations thereof.

[00136] Without limitation, example of systems within the fabrication facility may include one or more plasma etch chambers or modules, one or more deposition chambers or modules, one or more spin-rinse chambers or modules, one or more metal plating chambers or modules, one or more clean chambers or modules, one or more bevel edge etch chambers or modules, one or more physical vapor deposition (PVD) chambers or modules, one or more chemical vapor deposition (CVD) chambers or modules, one or more atomic layer deposition (ALD) chambers or modules, one or more atomic layer etch (ALE) chambers or modules, one or more ion implantation chambers or modules, one or more track chambers or modules, and any other semiconductor processing systems that may be associated or used in the fabrication and/or manufacturing of semiconductor wafers.

[00137] Figures 13A-13E illustrate a gel strip package 270 that is used to store, transport and retrieve gel strips for applying to a consumable part, such as an edge ring and Figure 13F illustrates gel strip placement on a portion of the edge ring, in some implementations. The edge ring, as discussed above with reference to some implementations, can be a ceramic edge ring (CER) 222. The CER 222 is received on a turntable defined on a main cart or a secondary cart within the fabrication facility and is accessed by a robot to apply gel strips in preparation for

installing the CER 222 in a process module of a processing tool. Details of the turntable used for receiving a consumable part for applying gel strips have been discussed with reference to Figures 9A-9E. A gel-applicator end-effector (206) is used by a robot arm (156 of Figure 8C) of the robot (152 of Figure 8C) to retrieve the gel strips from a gel strip package and apply it to a portion of the CER 222. Details of the different components of the gel-applicator end-effector (206) used by the robot arm for applying the gel strips to different portions of the CER 222 have been discussed with reference to Figures 8A-8C. The sequence followed by the robot in placing the gel strips on a portion of the CER 222 has been discussed with reference to Figures 10A-10H.

[00138] In one conventional design of a gel strip package, the gel strip package included the gel strips being laid out horizontally on a single gel strip sheet (i.e., single plane). During installation of the gel strip, the robot arm was guided to an appropriate location on the gel strip sheet where the gel strip was located to allow the robot arm to hold and peel the gel strip from the gel strip sheet and move to align over a portion of the CER 222 before pressing the gel strip in place over the portion.

[00139] In an alternate conventional design, the gel strip package was designed to include a number of gel strips placed one top of another in a vertical orientation. When the robot arm was guided to retrieve a gel strip from the gel strip package received on a gel tray, the robot arm sometimes ended up retrieving more than one gel strip from the gel strip package. This could be attributed to the fact that the backer and the liner of the gel strips have smooth surfaces resulting in the two or more gel strips clinging to one another due to friction.

[00140] In order to prevent the gel-applicator end-effector from retrieving more than one gel strip at a time and to have a compact gel strip package, the conventional vertically oriented gel strip package is re-designed so that the gel strips do not experience any static clinging and the gel-applicator end-effector can consistently pick up only one gel strip from the gel strip package at a time.

[00141] The gel strip package 270 of Figures 13A-13E show an implementation that allows the gel-applicator end-effector to reliably retrieve one gel strip 251 from the gel strip package 270 at a time for placing on a portion of the CER 222. Figure 13A shows the layering of different components to define a gel strip package 270. The gel strip package 270 includes a gel strip container 260 in which gel strips 251 are received as a stacked structure (250). The depth of the gel strip container 260 is designed to accommodate a defined number of gel strips 251 that is to be used to completely layer a consumable part, such as the CER 222, with gel strips 251. In one implementation, the number of gel strips 251 accommodated in the gel strip package 270 is 9. The number of gel strips 251 that can be part of each gel strip package 270 is not restricted to 9

but can vary based on the size of the CER 222 and the size of the gel strips 251. Consequently, the number of gel strips 251 included in each gel strip container 260 can be 5 or 7 or 11 or 13, etc. In addition to the gel strip container 260, the gel strip package 270 includes a gel package top cover 262 that is disposed to cover an opening in the top of the gel strip container 260. The gel package top cover 262 is secured using a plurality of package secure means, such as a package secure tape (i.e., sticky tape) 263 (see top broken rectangle with 5 package secure tape 263 of Figure 13A). The package secure means is not restricted to the package secure tape 263 but can include any other secure means. The gel strip package 270 with the stacked structure 250 of the gel strips 251 secured inside the gel strip container 260 can be safely transported to and within the fabrication facility where the gel strips 251 are to be used.

[00142] Figure 13B shows a top-side view and a bottom-side view of the gel strip package 270 that includes the layered components shown in Figure 13A. The top-side view shown on the top left of Figure 13B shows the gel package top cover 262 facing up with the package secure tapes 263 securing the gel strip container 260, and the bottom side 264 of the gel strip container disposed opposite to the gel package top cover 262 shown in the bottom (i.e., facing down). The bottom-side view shown on the bottom right of Figure 13B shows the bottom side 264 of the gel container 260 facing up and the gel package top cover 262 facing down. The package secure tapes 263 are shown along the bottom side of the gel strip container 260.

[00143] Figure 13C shows an example composition of the gel strip 251 used to line the CER 222, in some implementations. As previously noted, each gel strip 251 includes a plurality of layers, including a backer layer (also referred to as a first gel backer or simply a “backer”) 252 defining a top surface of the gel strip 251, a liner layer (also referred to as a second gel backer or simply a “liner”) 254 defining a bottom surface of the gel strip 251, and a gel layer 253 that is disposed between the backer 252 and the liner 254. The gel strip 251 with the different layers are stacked one on top of each other with an inter-layer 255 disposed between each consecutive pair of the gel strips 251.

[00144] Figure 13D shows an example of an inter-layer 255 that is disposed between each consecutive pair of gel strips 251. To prevent the gel strips 251 from clinging to each other, the inter-layer 255 is defined to have an uneven surface. The uneven surface of the inter-layer 255 creates air pockets between the inter-layer and the gel strips 251 when the inter-layer 251 is stacked between the two adjacent gel strips (e.g., between gel strips 251-1, 251-2).

[00145] Figure 13E shows an example of a stacked structure 250 of gel strips 251 that is stored and transported in a gel strip container 260. The stacked structure 250 includes inter-layers 255 with uneven surfaces (i.e., both top and bottom surfaces) disposed between adjacent pairs of gel strips 251. Thus, the gel strip stacked structure 250 includes an inter-layer 255-1 disposed

between 1st and 2nd gel strips (251-1, 251-2), a second inter-layer 255-2 disposed between the 2nd and 3rd gel strips (251-2, 251-3), and so on. The inter-layers 255 ensure that the gel strips 251 that are stacked inside do not stick to each other, thereby preventing the gel strips 251 from experiencing static clinging. In addition to providing inter-layers 255 between each pair of gel strips, an inter-layer 255 is disposed at the bottom of the stacked structure 250 that is part of the gel strip package 270.

[00146] In one example illustrated in Figure 13E, the gel strip package 270 includes 9 gel strips (251-1 – 251-9), an inter-layer 255-1 at the bottom and 8 inter-layers (255-2 – 255-9) disposed between each pair of the gel strips all stacked vertically for a total of 18 layers in the stacked structure 250. The gel strip container 260 is defined to have sufficient depth to accommodate the 18 layers. In this example, a gel strip 251 is disposed on the top of the gel strips stacked structure 250 and the inter-layers 255 are disposed in the bottom and in-between each consecutive pair of gel strips 251. The gel strip stacked structure 250 (Figure 13A) thus includes every other layer having the gel strip 251 and every in-between layers including the bottom layer having the inter-layer 255. In another example (not shown), the gel strip package 270 includes a total of 5 gel strips. In this example, the depth of the gel strip container 260 is designed to accommodate a total of 10 layers with 5 gel strips (251) and 5 inter-layers (255). An inter-layer (255) is disposed in the bottom and between every pair of gel strips with the top of the gel strip stacked structure 250 being the gel strip 251. Thus, the gel strips stacked structure 250 is based on the number of the gel strips 251 included in the gel strip package 270, and the gel strip container 260 is defined to ensure that the defined number of gel strips and inter-layers can be comfortably accommodated and tightly stacked.

[00147] The uneven surfaces cause air-pockets 256 to be created between the inter-layer 255 and either the backer 252 of a first gel strip (e.g., 251-1) or the liner 254 of a successive gel strip (e.g., 251-2). These air-pockets 256 ensure that the gel strips 251 do not exhibit any static clinging with one another. In some implementations, the uneven surface can be a ribbed surface. The uneven surface is not restricted to ribbed surface but can include any other type of surface unevenness, which is able to create air-pockets to prevent the static clinging. In some implementations, the uneven surface is defined, such that uniform air-pockets 256 are created between the surfaces of the gel strips 251 and the inter-layer 255. In alternate implementations, the uneven surface is defined, such that non-uniform air-pockets 256 are created between the surfaces of the gel strips 251 and the inter-layer 255. In some implementations, the inter-layer 255 is defined to include sufficient thickness so that the air-pockets defined by the uneven surface can have sufficient height. As noted, the numbers of gel strips and the inter-layers in a gel strip package 270 depend on the CER 222. In some implementations, the thickness of each

inter-layer 255 is defined to be between about 0.15 mm and about 0.35 mm. In some implementations, the inter-layer is made of low-density polyethylene (e.g., Polyethylene Terephthalate). The material used and the thickness of the inter-layer 255 is provided as mere examples and that other materials and/or thickness can also be envisioned.

[00148] In some implementations, the dimension (e.g., length, width) of the backer 252 is same as the dimension of the liner 254. In alternate implementations, the dimension of the backer 252 is defined to be smaller than the dimensions of the liner 254. In some implementations, the dimensions of the backer 252 and the liner 254 are defined to be greater than the dimensions of the gel layer 253 that is received there-between. In some implementations, the dimension of the inter-layer 255 is defined to be greater than the dimension of the backer 252 and the liner 254. It is to be noted that the dimensions of the different components of the gel strip and the gel strip package depicted in Figures 13A-13E are provided as examples to distinctly show the different components. In reality, the relative size of the different components of the gel strips and the gel strip package may be similar or different to what is shown in Figures 13A-13E.

[00149] In some implementations, the gel strips are defined to be between about 0.50 mm and about 1.25 mm in thickness. The materials for the inter-layer and the gel strips as well as the respective dimensions are provided as mere examples and should not be considered restrictive and that other materials and/or other dimensions that provide similar functionality can also be envisioned. In some implementations, the profile of the gel strips matches the profile of the consumable part, such as CER 222, on which the gel strips are applied, in that the gel strips are defined to have a curved profile matching the circular profile of the consumable part with an outer edge (i.e., surface along an outer radius) of the gel strip being longer than an inner edge (i.e., surface along an inner radius). In some implementations, the outer edge of the gel strip extends for a length of between about 30 mm and about 45 mm.

[00150] Figure 13F shows an example implementation of a gel applicator tray 205 accessible to a robot of a fabrication facility for supporting a gel strip stacked structure 250 and for retrieving and applying gel strips 251 from the gel strip stacked structure 250 to a consumable part, such as CER 222. The gel applicator tray 205 supports a gel applicator turntable 220. The gel applicator turntable 220 includes a plurality of positional indexers 220a to index the CER 222 so that appropriate portions of the CER 222 is exposed to the robot for applying the gel strips 251. The number of positional indexers 220a defined on the gel applicator turntable 220 depends on the size of the CER 222 and the size of the gel strips 251, and corresponds with the number of gel strips 251 included in the gel strip package 270. The gel applicator tray 205, in some implementations, is defined on a main cart (e.g., 150 of Figure 8C) that includes a robot (e.g., 152 of Figure 8C) with robot arm (e.g., 156 of Figure 8C) for operating a gel-applicator end-

effector 206 for retrieving gel strips 251 received on the gel applicator tray 205 and placing the gel strips onto the CER 222. Toward this end, the gel applicator tray 205 includes one or more gel trays 242. The gel trays 242 are defined as insets on the surface of the gel applicator tray 205, in some implementations, and are designed as package receiving stations. In some implementations, the gel applicator tray 205 includes two gel trays (i.e., package receiving stations) 242a, 242b, with each gel tray configured to receive the stacked structure of gel strips 250 retrieved from a gel strip container 260 in preparation for applying the gel strips 251 to the CER 222. The gel applicator tray 205 also includes a backlight faceplate 228 that is illuminated from an underside by a light source. The backlight faceplate 228 is used to align the gel strips 251 before the gel strips 251 are applied to different portions of the CER 222, for example. A trash bin 271 is disposed on the gel applicator tray 205 and is used as a receptacle for receiving unwanted materials, such as the backer 252 and the inter-layer 255, peeled and discarded by the robot. A gel-applicator end-effector 206 of the robot 150 and a gel compressor 229 work together to install the gel strip 251 onto a portion of the CER 222, as described in Figures 10A-10H with reference to the gel placement sequence.

[00151] As noted, the gel placement sequence can be an autonomous process that is accomplished by engaging the robot 152. The robot 152 equipped with the gel-applicator end-effector 206 on the robot arm 156 performs the gel application process by first indexing the CER 222 so as to align an appropriate portion of the CER 222 to the robot 152 to aid in the placement of the gel strip 251 on the aligned portion. The robot 152 then retrieves the gel strip 251 (i.e., the top layer) from the gel strip stacked structure 250 received at one of the gel trays (e.g., 242a, 242b), aligns the retrieved gel strip 251 using the backlight faceplate 228, and placing the aligned gel strip on the portion of the CER 222. After placing the retrieved and aligned gel strip 251 on the portion, the gel-applicator end-effector 206 indexes the CER 222 so that the next portion of the CER 222 is aligned with the robot 152 for the next gel strip installation. Following the indexing of the CER 222, the robot 152 then moves to the gel tray 242 and uses the gel-applicator end-effector 206 to remove the inter-layer 255, which is the next layer in the gel strip stacked structure 250 and discard it in the trash bin 271 before moving to retrieve the next gel strip 251 from the gel strip stacked structure 250 in the gel tray 242 for installing on the next portion of the CER 222.

[00152] The edge ring indexing is performed by rotating the CER 222 received on the gel applicator turntable 220 along a horizontal plane so as to expose appropriate portions of the CER 222 for receiving the gel strip 251 retrieved from the gel strip stacked structure 250. A plurality of positional indexers 220a are defined on the gel-applicator turn table 220 to assist in the positional indexing of the CER 222. Figure 13E shows the gel-application end-effector 206

having deposited the gel strip 251 on a portion of the CER 222 and moving away. A gel compressor 229 disposed on the gel applicator tray 205 is used to press the gel strip 251 into place on the portion of the CER 222. Figure 13F shows the gel compressor 229 positioning over the portion of the CER 222 that has received the gel strip 251 in preparation for pressing the gel strip 251 into place on the portion of the CER 222. In some implementations, the alignment of the gel strip 251 using the backlight faceplate 228 is done using fiduciary markers (e.g., hole, notch or any other surface indicator) defined on the gel strips 251 and the portions of the CER 222. Alternately or additionally, the alignment is done by mapping the location of the portion of the CER 222 where the gel strips are to be installed and using the robot arm to precisely move the gel strips (either directly from the gel strip container 260 or from the backlight faceplate 228) to the portion of the CER 222 using the location coordinates. The inter-layer 255, in one implementation, is a disposable component of the gel strip package 270. The process of retrieving the next gel strip 251 and placing it on a next portion of the CER 222 continues till all the gel strips in the gel strip container 260 have been applied to the CER 222.

[00153] By providing the inter-layer 255 between two gel strips in the gel strip stacked structure 250, the static clinging can be eliminated, thereby ensuring that only a single gel strip is retrieved from the gel strip stacked structure at any given time. As a single gel strip is retrieved each time, uniform placement of the gel strips on the CER 222 is achieved, making this a more efficient gel strip packaging. Further, providing an inter-layer at the bottom of the gel strip container 260 ensures that the last of the gel strips 251 in the gel strip container 260 can be reliably retrieved, thereby avoiding the gel strip 251 from sticking to the gel strip container 260. Other advantages of the use of the gel strip package will become obvious to one skilled in the art.

[00154] Figures 14A-14C illustrate a ring press fixture 1400 and various components of the ring press fixture 1400 used for installing gel strips on a consumable part, in some implementations. The ring press fixture 1400 is an end-effector that is designed to cover an entire width of the consumable part so that a clamp force applied to the ring press fixture 1400 can be conveyed uniformly to all the gel strips received on the entire surface of the consumable part. In some implementations, the consumable part is a ceramic edge ring (CER) 222. The CER 222 is sized to receive a certain number of gel strips of uniform dimensions. In some implementations, the width of the CER 222 is defined to receive about 9 gel strips to collectively cover an entire ring area. In such implementations, the gel strips are arranged in a single row. Each gel strip that is used to arrange in a single row, in some implementations, consists of a double row of gel strips (inner gel strip and outer gel strip) that are integrated into each single gel strip. In such implementations, the width of the CER 222 is defined to accommodate the

double row gel strips. In alternate implementations, the CER 222 is sized to receive about 18 gel strips to cover the entire ring area. In these implementations, the width of the CER 222 is defined to accommodate the 18 gel strips in two rows of 9 gel strips each – an inner row and an outer row, with the gel strips in each row having uniform dimensions. In some implementations, each gel strip in the two-row arrangement is installed sequentially, with the outer row of gel strip installed first and the inner row installed after. Further, a size of each gel strip in the inner row is smaller to correlate with the size of the inner ring and a size of the gel strip in the outer row is larger than the inner row gel strips so as to correlate with the size of the outer ring.

[00155] The ring press fixture 1400 includes a plurality of components that are designed to cover a top surface of the CER 222 and exert uniform clamp force over the gel strips received over the top surface of the CER 222, during gel strips installation. The ring press fixture 1400, in some implementations, is sized to correspond or correlate with a size of the CER 222. Figure 14A shows an implementation of the ring press fixture 1400, which includes a top presser plate 1401, a foam ring 1404, and a tool changer 1406. The top presser plate 1401, in some implementations, may include a plurality of ring cut-outs defined between a center portion and an outer portion of the top presser plate 1401. In some implementations, the outer portion is sized in accordance to a size of a foam ring received below it. Figure 14B illustrates the ring cut-outs 1405 defined in the top presser plate, in one implementation. The number and/or size of the ring cut-outs may be defined to reduce the amount of material used to define the top presser plate 1401. In some implementations, the top presser plate 1401 is made of Aluminum and a size, thickness and number of ring cut-outs 1405 are defined to reduce the overall mass of the ring press fixture. In some implementations, an outer diameter of the top presser plate 1401 is defined to correspond with an outer diameter of the CER 222 (i.e., consumable part). In alternate implementations, the outer diameter of the top presser plate 1401 can be greater than the outer diameter of the CER 222.

[00156] In some implementations, in addition to the ring cut-outs 1405, the top presser plate 1401 also includes a nest access opening 1403. The nest access opening 1403 is defined at a defined distance from the outer circumference of the top presser plate 1401, wherein the defined distance is based on a size of a foam ring 1404 that is disposed below the top presser plate 1401. The distance from the outer circumference and a size of the nest access opening 1403 is defined to allow a side arm of a nest arm to extend through the nest access opening 1403 unhindered, when the ring press fixture 1400 is stored on a nest arm defined on a moveable cart, such as a cleaning cart (10 of Figure 1A) or a main cart (150 of Figure 2A), or any other cart used for performing the maintenance operations in a process chamber. Details of the nest arm used for storing the ring press fixture 1400 will be discussed in more detail with reference to Figures

15A-15D. In some implementations, a thickness of the top presser plate 1401 is defined such that the top presser plate exhibits sufficient amount of rigidity and is able to uniformly convey sufficient amount of clamp force to the underlying components, when the clamp force is applied at the top presser plate. In some implementations, the thickness of the top presser plate 1401 is defined so as to have minimal deflection.

[00157] The foam ring 1404 of the ring press fixture 1400 is disposed below and aligned with the top presser plate 1401. In some implementations, a width and depth (i.e., thickness) of the foam ring 1404 is defined to ensure that the clamp force applied at the top presser plate 1401 can be conveyed to the underlying gel strips received on the CER 222 without damaging or displacing the gel strips or any part of the CER 222. Figure 14C illustrates a top perspective view of a foam ring 1404 of the ring press fixture used in installing the gel strips. In some implementations, the foam ring 1404 is made of silicone material. The materials used for the top presser plate 1401 and the foam ring 1404 are provided as mere examples and should not be considered restrictive, and usage of other materials capable of providing the similar functionality can also be envisioned.

[00158] In some implementations, the tool changer 1406 can be coupled directly to the top presser plate 1401. The coupling can be done using one or more fastener means, such as screws, dowels, etc. The tool changer 1406 is coupled at a center of the top presser plate 1401. The tool changer 1406 is configured to act as an end-effector robot interface and couple to an end-effector connector disposed on a robot arm (156 of Figure 2A) of a robot (152 of Figure 2A). In some alternate implementations, the tool changer 1406 is coupled to the top presser plate 1401 using an additional component, such as a coupling cap 1407. Figure 14B illustrates one such example, wherein a coupling cap 1407 is engaged in coupling the tool changer 1406 to the top presser plate 1401. The fastener means illustrated in Figure 14B is provided as an example and other types of fastener means can also be used.

[00159] Figures 14D-14F illustrate alternate implementations of a ring press fixture 1400' for use in pressing the gel strips over the consumable part. The ring press fixture 1400' varies from the ring press fixture 1400 illustrated in Figures 14A-14C, in that the top presser plate 1401' is designed to include a set of press plate ears 1402 that extend outwardly along an outer circumference. The set of press plate ears 1402 are distributed uniformly around the outer circumference. In some implementations, the press plate ears 1402 are defined to have the same thickness as the top presser plate 1401'. In alternate implementations, the thickness of the press plate ears 1402 can be greater than the thickness of the top presser plate 1401'. Figure 14D illustrates a side perspective view and Figure 14E illustrates an overhead view of the top presser plate 1401' showing a set of three press plate ears 1402 defined equidistant (i.e., disposed at

120°) from one another around the outer circumference. Further, Figure 14E shows an expanded view of a portion of the top presser plate that includes the press plate ear 1402. The number of press plate ears 1402 are provided as mere examples and that fewer or greater than three press plate ears can be defined along the outer circumference of the top presser plate 1401'. In some implementations, the top of each press plate ears 1402 is covered by a pad, such as a silicon pad, 1412. The silicon pads 1412 may be used to provide a reliable (e.g., non-slip) surface for engaging with a clamp used to provide a clamp force to the top presser plate 1401'. In the implementations of the top presser plate 1401' illustrated in Figures 14D-14F, the tool changer 1406 is coupled directly to the central portion of the top presser plate using fastener means 1 and 2 (e.g., dowels 1408 and screws 1409). The other components of the top presser plate 1401' are similar to the top presser plate 1400 that was discussed with reference to Figures 14A-14C.

[00160] Figures 15A-15D illustrate a nest arm 1415 used for storing the ring press fixture 1400 (or 1400'), when the ring press fixture 1400 is not in use. As noted before, the nest arm 1415 can be disposed on a top surface of a cart, such as a cleaning cart 10 (illustrated in Figure 2A), wherein various end-effectors for performing maintenance operation in a process chamber are disposed or a main cart 150 (illustrated in Figure 2A) on which the robot 152 (shown in Figure 2A) with the robot arm 156 is disposed. In some implementations, the nest arm 1415 is a three-dimensional (3D) printed component made out of polylactic acid (PLA). In alternate implementations, the nest arm 1415 can be made of any other material that is capable of providing similar functionality as the nest arm 1415 made of PLA.

[00161] In some implementations, the nest arm 1415 is disposed in a vertical orientation on the top surface of the cart so as to minimize the real-estate space used for storing the ring press fixture 1400. However, the vertical orientation may result in some deflection along a vertical axis, when a ring press fixture 1400 is received thereon. The deflection can occur due to the weight of the ring press fixture. To minimize the vertical deflection, the ring press fixture 1400 is designed to include ring cut-outs so as to reduce the overall mass and the nest arm 1415 is designed to provide stable support. The nest arm 1415 is designed to include a base plate 1416, a stand 1417, and a side arm 1418. The base plate 1416 is disposed on and coupled to the top surface of the cart (e.g., cleaning cart or main cart) using one or more fastening means. The location on the top surface of the cart for defining the nest arm 1415 is selected so as to provide the robot arm 156 unhindered access to the ring press fixture 1400 received thereon, as well as access to other components defined on or proximal to the nest arm defined on the top surface. In one implementation, the stand 1417 is defined to extend vertically from a center of the base plate 1416 for a defined height and has a defined width. Figure 15A illustrates one such example of the nest arm 1415 wherein the stand 1417 is defined at the center of the base plate 1416. In

some implementations, the height of the stand 1417 is defined based on a size of the ring press fixture 1400, which can, in turn, depend on the size of the CER (e.g., consumable part) 222. The width of the stand 1417 is defined to ensure that the nest arm 1415 is able to provide a rigid support (i.e., not deflect) when storing the ring press fixture 1400, and during engagement of the robot arm with the ring press fixture.

[00162] Figure 15B illustrates an alternate implementation of the nest arm 1415'. In the alternate implementation, the stand 1417' is designed so as to provide better support to the ring press fixture, during storage, and minimize any deflection that can occur during the fixture storage. The stand 1417', in some implementations, is designed to have variable dimensions along its length with a broad base portion and a narrow top portion. In some implementations, the broad base can include one or more stand cut-outs 1417a. The size of the stand cut-outs 1417a are defined to reduce the amount of material used for the nest arm and the overall mass of the nest arm while ensuring minimal to non-existent deflection. Even with the stand cut-outs 1417a, the broader base portion provides a better stability control and minimizes the deflection, when the ring press fixture is received on the nest arm. The stand with the broader base portion is disposed so as to extend from a center toward an outside boundary along a lateral side of a base plate 1416.

[00163] The side arm 1418 of the nest arm 1415 (or 1415') extends out in a perpendicular direction to the stand 1417 and is defined near a top of the stand 1417, wherein the height at which the side arm 1418 is defined on the stand 1417 is driven at least by the size of the ring press fixture. The various components of the nest arm 1415 are designed such that the entire nest arm 1415 with the ring press fixture is inside a boundary of the top surface. In some implementations, the side arm 1418 is designed to include an inset (e.g., ring inset) 1419 on a top surface so as to reliably receive and support the ring press fixture 1400 (i.e., ensure the ring press fixture does not slip out). Accordingly, the inset 1418 is defined to extend a width that is at least equal to the depth of the ring press fixture 1400 (i.e., cover at least the depths of the top presser ring 1402 and the foam ring 1404). Further, the dimensions of the nest access opening 1403 on the top presser plate 1401 of the ring press fixture 1400 and the side arm 1418 of the nest arm 1415 are defined such that the side arm 1418 is able to extend through the nest access opening 1403 and provide reliable support for the ring press fixture, when received for storing. In alternate implementations, the side arm 1418 can be defined to include a flat top surface with a stepped-up edge having a size that allows the ring press fixture to be received and supported.

[00164] Figure 15C illustrates a side perspective view of the nest arm 1415 disposed in a vertical orientation with the ring press fixture 1400 supported thereon. As shown, the base plate 1416 of the nest arm 1415 is coupled to a top surface of a main cart 150. In some alternate

implementations, the nest arm 1415 can be installed on a cleaning cart 10 or any other moveable or fixed cart used for performing maintenance operation in the process chamber. Figure 15D shows an expanded view of a portion of the nest arm that includes the side arm extending through the nest access opening 1403 and the ring press fixture resting on the inset of the side arm 1418. In the embodiment shown in Figure 15D, the ring press fixture 1400' is shown to include the top presser plate 1401, the foam ring 1404 and the support pad over the press plate ears 1402. As shown, the height of the stand 1417 is defined to ensure that the ring press fixture (1400 or 1400') does not touch any surface of the base plate 1416 or the top surface.

[00165] Figures 16A-16C illustrate a nest arm 1415 disposed in a vertical orientation on a top surface of a cart, such as a main cart 150, in some implementations. The ring press fixture 1400 is stored on the nest arm 1415 between the gel strip installations. In addition to housing the nest arm 1415, the top surface of the cart, in some implementations, includes a gel applicator turntable 220 supported on a gel applicator tray 205. The gel applicator turntable 220 is configured to receive the CER for gel strip installation. Additional components, such as one or more end-effectors used for servicing a process module, etc., may also be disposed on the top surface of the main cart 150. Figure 16A shows the ring press fixture being engaged by a robot arm 156 of a robot 152, in preparation for moving the ring press fixture 1400 from the nest arm 1415 to over the consumable part (222) received on a gel applicator turntable 220 supported on a gel applicator tray 205. Figure 16B shows the ring press fixture 1400 removed from the nest arm by the robot arm 156 and moved to align over the gel applicator turntable 220. Figure 16C illustrates the placement of the ring press fixture 1400 on the gel applicator turntable 220 in preparation for gel strip installation.

[00166] Figures 17A-17F illustrates a plurality of clamps disposed on the gel applicator tray 205 for providing the clamp force during gel strip installation, in some implementations. The plurality of clamps 1420 are disposed just outside of and adjacent to the gel applicator turntable 220 defined on the gel applicator tray 205. The plurality of clamps is uniformly distributed around the circumference of the gel applicator turntable 220.

[00167] Figures 17A-17C illustrates a plurality of swing clamps that are distributed around a gel applicator turntable supported on the gel applicator tray 205. In the implementation illustrated in Figure 17A, a total of 3 swing clamps are shown to be uniformly distributed about the gel applicator turntable 220. The number of swing clamps are provided as mere examples and are not considered to be restrictive. In some other implementations, fewer or greater than 3 swing clamps can be used to provide the clamp force.

[00168] During gel strip installation, a ceramic edge ring (CER) 222 is received on the gel applicator turntable 220. A gel-applicator end-effector (206 of Figure 8C) is retrieved from the

respective storage position by a robot arm (156 of Figure 8C) of a robot (152 of Figure 8C) and used to retrieve the gel strips from a gel strip package and apply it to a portion of the CER 222. Details of the different components of the turntable (220) used for receiving the consumable part for applying gel strips have been discussed with reference to Figures 9A-9E. Details of the different components of the gel-applicator end-effector (206 of Figure 8C) used for applying the gel strips has been discussed with reference to Figures 8A-8C. The sequence followed by the robot in placing the gel strips on corresponding portions of the CER 222 has been discussed with reference to Figures 10A-10F and 10H. The gel strip package can be in the form of a gel strip container (260 of Figure 13A) with gel strips provided in a stacked structure with inner layer (254 of Figure 13A) disposed between each consecutive pair of gel strips. The details of the gel strip package and the process of retrieving the gel strips one at a time from the gel strip package (i.e., gel strip container) and applying the gel strips to the different portions of the CER 222 have been discussed with reference to Figures 13A-13F.

[00169] In the implementations where the ring press fixture 1400 (or 1400'), is used, all the gel strips are applied to the entire surface of the CER 222 first and the ring press fixture is moved on top of the CER 222 and a clamp force of defined magnitude (e.g., 30 lbs of force at each clamp) is applied uniformly using a plurality of clamps, across the entire surface of the CER 222 for a predefined press time. In the case where the CER 222 is sized to receive a double-row gel strips in a single row, the clamp force is applied once for a pre-defined period of time. In the case where the CER 222 is sized to receive two rows of gel strips (e.g., inner and outer rows of 9 gel strips each), the clamp force is applied twice, once for each row for a pre-defined period of time. For instance, the gel strips of the inner row are placed first and the clamp force is applied to the inner row to allow the inner row of gel strips to adhere to the CER 222. Next, the gel strips of the outer row are placed and the clamp force applied to allow the outer row of gel strips to adhere to the CER 222.

[00170] In some implementations, each double-row gel strip is defined to include varying thickness. For example, each of the inner gel strips and the outer gel strips of the double-row gel strip can have varying thickness. For example, the inner gel strips is defined to have a first thickness and the outer gel strips is defined to have a second thickness, wherein the first thickness is less than the second thickness. In such implementations, the clamps are used to provide the clamp force to press the inner row of gel strips (i.e., a first thickness, which has lower height) into place. After the inner row is installed, the clamps are used to provide the clamp force to press the outer row of gel strips (i.e., a second thickness, which has taller height) into place.

[00171] In some implementations, the CER 222 can have a step at or near the inner diameter, wherein the step can be a step-up or a step-down. For example, the CER 222 can be defined to have a step-down feature defined at the inner diameter. In another example, the CER 222 can be defined to have a step-up feature defined near the inner diameter. The step-up feature, in this example, can be defined at a distance from the inner diameter so as to accommodate the inner row gel strips at the inner diameter. The gel strips that are installed on the CER 222 along the inner diameter with the step-down feature (i.e., inner row gel strips), the thickness of the gel strips is greater than the gel strips that are installed along the outer row, wherein the thickness variation can be equal to a height of the step-down feature, so that when the inner and the outer row gel strips are installed on the top surface of the CER 222, the top surface of the inner row and the outer row of gel strips is sufficiently flat. The gel strips that are installed on the CER 222 having the step-up feature near the inner diameter, the thickness of the gel strips in the inner row is greater than the thickness of the gel strips in the outer row, wherein the thickness variation being equal to a height of the step-up feature.

[00172] In some alternate implementations, instead of using the gel strips of varying thickness in the inner and outer rows, the clamps may be configured so that the arms (e.g., swing arms) of the clamps can be adjusted laterally so as to apply focused clamp force to the inner row of gel strips and then to the outer row. In such implementations, the gel strips in the inner row and the outer row can be of uniform thickness, but the size of the gel strips in the inner row can be smaller than the gel strips in the outer row (due to varying diameter of the inner row and the outer row). By providing focused clamp force to each row, gel strip adhesion is achieved successfully.

[00173] In the implementations where swing clamps 1420 are used, to provide the clamp force, the ring press fixture 1400 is retrieved from the nest arm 1415 by a robot arm 156 and aligned over and placed on top of the CER 222, and the swing clamps 1420 are rotated about a vertical axis from a resting position to an operating position so as to align with the top presser ring of the ring press fixture 1400. Figure 17A illustrates the alignment of the ring press fixture 1400 over the CER 222 received on the gel applicator turntable 220 supported on the gel applicator tray 205. Further, the swing clamps 1420 are shown to be in the resting position (i.e., away from the gel applicator turntable). Figure 17B illustrates the ring press fixture 1400 received over the CER 222 and the swing clamps 1420 moved to the operating position over a portion of the top presser plate of the ring press fixture and a clamp force of defined magnitude is applied to the top presser plate 1401 of the ring press fixture 1400. The clamp force applied to the top presser plate 1401 is then conveyed uniformly to all the gel strips received on the CER 222. The clamp

force is applied for a defined period (e.g., about 10 minutes) to allow the gel strips to be pressed in place.

[00174] Figure 17C illustrates the different components of a swing clamp 1420 used for providing the clamp force, in some implementations. The swing clamp 1420 includes a clamp cylinder 1422 having a center bore 1424. The clamp cylinder 1422 is coupled to a top surface of the gel applicator tray 205 using fastening means (e.g., screws). A piston 1426 is disposed within the center bore 1424 and is coupled to and operated using a pneumatic mechanism. The pneumatic mechanism is used to provide vertical motion and to impart a defined clamp stroke to the piston. A swing arm 1428 is defined on the piston 1426 such that a first end of the swing arm 1428 is coupled to the top of the piston 1426, and a second end of the swing arm 1428 includes a clamp head 1430. The clamp stroke imparted to the piston 1426 is conveyed as clamp force by the clamp head 1430 to the gel strips on the CER 222 via the top presser plate 1401 of the ring press fixture 1400. When the CER 222 has two rows of gel strips, the gel strips are first applied to an inner row of the CER 222 and where the swing arm 1428 is designed to have lateral movement, the swing arm 1428 is moved laterally to align over the inner row and the clamp force is applied to the inner row for a predefined period of time (e.g., about 10 minutes). After installing the inner row of gel strips, the gel strips are applied to an outer row of the CER 222 and the swing arm 1428 is adjusted laterally to align over the outer row and the clamp force applied to the outer row for the predefined period of time.

[00175] The swing clamps are coupled to the controller and the activation of the swing clamps (i.e., activating the piston, rotation motion of the swing arm, etc.) to provide the clamp force and movement of the swing arm are controlled by signals from the controller. In the implementations illustrated in Figures 17A-17C, the top presser plate 1401 of the ring press fixture 1400 is designed to without any press plate ears 1402.

[00176] Figures 17D-17F illustrate an alternate implementation wherein a variation of the ring press fixture 1400' and a variation of the clamps 1432 are used for pressing the gel strips in place on the top surface of the CER 222. In the implementations illustrated in Figure 17D, the top presser plate 1401 of the ring press fixture 1400' includes a set of press plate ears 1402 (as shown in Figures 14D-14F) defined uniformly along an outer circumference. A set of clamps (e.g., pneumatic clamps) 1432 are distributed uniformly adjacent to and outside of the outer circumference of the ring press fixture 1400'. During gel strip installation, the gel applicator turntable 220 with the CER 222 and the ring press fixture 1400' received thereon is rotated so as to align the press plate ears 1402 with the corresponding flanges of the clamps 1432. Figure 17D illustrates one such alignment of the press plate ears 1402 of the top presser plate 1401 with the flange of the clamps 1432 (i.e., press plate ears received within the space defined by the

flange). Upon successful alignment, the clamps 1432 are activated so that the flanges move to an engaged mode. In the engaged mode, the flanges are compressed imparting a clamp force to the press plate ears 1402 received therebetween. The clamp force applied at the press plate ears 1402 are conveyed to the underlying gel strips of the CER 222, enabling gel strip installation on the CER 222.

[00177] Figure 17E illustrates a clamp 1432 in an engaged mode and Figure 17F illustrates the clamp 1432 in a disengaged mode. The clamp 1432 varies from the swing clamp 1420 illustrated in Figures 17A-17C, in that the clamp 1432 does not include a swing arm with a clamp head. Instead, the clamp 1432 includes a pneumatically operable flange 1433. Consequently, in the implementations of the clamps in Figures 17E and 17F, the flange is fixed and is not configured to have a rotational motion about a vertical axis.

[00178] Figures 17E and 17F illustrate various components of the clamp 1432. Similar to swing clamps 1420, the clamps 1432 illustrated in Figures 17E and 17F include a clamp cylinder 1422 with a center bore 1424 and a piston 1426 disposed inside the center bore 1424. The piston is coupled to and is operable using a pneumatic mechanism (although a hydraulic mechanism or other type of mechanism can also be envisioned). However, unlike the swing clamps 1420 which includes a clamp head, the clamp 1432 includes a flange 1433 disposed on top of the piston. The flange is used for aligning with the ring press fixture 1400' using the press plate ears 1402 on the top presser plate 1401, and to impart the pre-defined clamp stroke that can be conveyed as clamp force to the gel strips. The clamp force is applied for a defined amount of time to enable gel strip adhesion.

[00179] To assist in providing the clamp force, the clamps 1432 are designed to include a plurality of adjustable sections that enable the clamps 1432 to move along a vertical axis. The clamp cylinder can be square/rectangular or circular in shape. Toward this end, in some implementations, a side of the clamp cylinder (e.g., a lateral side, in the case where the clamp cylinder is a rectangular/square structure, or a portion of a circular sidewall, in the case where the clamp cylinder is a cylindrical structure) is coupled to a stepped elevator wall. The stepped elevator wall is defined to include a plurality of stacked sections and one end of the flange disposed on top of the piston is coupled to a top of the stepped elevator wall, such that when the flange moves vertically with the piston, the stacked sections of the stepped elevator wall extends or collapses. For example, the plurality of stacked sections is designed to extend to an extended position, when the clamp is deactivated (i.e., the clamp is in a disengaged mode), and collapse to a compressed position, when the clamp is activated (i.e., the clamp is in an engaged mode). In the disengaged mode, the stacked sections of the clamp are extended so as to release the ring press fixture, and in the engaged mode, the stacked sections are collapsed to pinch and hold the

ring press fixture so that the clamp force can be imparted through the ring press fixture to the gel strips received on the CER 222. The activation or deactivation of the clamp is driven by the presence or absence of the clamp stroke, which are controlled using signals from a controller to which the clamps are coupled. In some implementations, the piston and, hence, the flange is operated using pneumatic mechanism.

[00180] In some implementations, the plurality of stacked sections in the stepped elevator wall includes at least a first section and a second section (although additional sections (i.e., 3 or more sections) can also be envisioned). The first section is disposed in a bottom portion of the stepped elevator wall that is adjacent to the top surface of the cart where the clamps are coupled. The second section is stacked over the first section. In some implementations, the second section includes a stop shelf defined along one or more inside walls of the second section. The stop shelf acts as a hard stop for the second section. Thus, when the clamp is activated (i.e., the piston and the flange are moved to an operation mode), the stop shelf defines the height to which the second section collapses over the first section. In some implementations, the height of the stop shelf is defined to avoid pinch hazard, when the second section collapses inside of the first section.

[00181] The design and use of the ring press fixture 1400 or 1400' is different from the gel compressor (229 of Figure 13D), in that the gel compressor 229 is sized and designed to press one gel strip at a time (for a defined period) before moving to the next gel strip and repeating the process. Using the gel compressor 229 increased the press time and, hence, the cycle time of gel adhesion (i.e., gel strip installation) when installing the gel strips on the CER 222. Whereas, the ring press fixture 1400 is sized and designed to apply the clamp force uniformly at once to all the gel strips received on the CER 222, thereby significantly reducing the press time and, hence, the cycle time of gel adhesion.

[00182] Typically, a cycle time of gel adhesion includes a gel strip pick and place time and a gel press time. The gel pick and place time includes retrieving a gel strip from the gel strip package, stripping the inter-layer and/or backer layer, aligning the gel strip applicator end-effector over an appropriate portion of the CER 222, and placing the gel strip on to the appropriate portion of the CER 222. As noted, the CER 222, in some implementations, is designed (i.e., sized) to receive 9 gel strips in a single row. In alternate implementations, the CER 222 is designed to receive 18 gel strips. In the case of 18 gel strips, the CER 222 may be defined to be wide enough to receive the gel strips in two concentric rows, with an inner row and an outer row of 9 gel strips each.

[00183] Typically, each gel strip is retrieved from a gel package and placed on a corresponding portion of the CER 222 using a gel-applicator end-effector and pressed into place using a gel

compressor (e.g., 229 of Figure 13D) and the process is repeated. In these cases, the pick and place time is about 1 minute per gel strip for a total of 9 minutes for a 9 gel segment CER and 18 minutes for a 18 gel segment CER. The press time is about 10 minutes for each gel strip for a total of 90 minutes for 9 gel segment CER and 180 minutes for 18 gel segment CER. Typically, the average vision target time to complete pressing gel strips on an entire CER is about 20 minutes when the CER is sized to have 9 gel segments and double the time (about 40 minutes) for the CER having 18 gel segments. Based on various test runs conducted by individually varying time used to apply a force of certain magnitude as well as by varying force applied to the gel strips to determine the efficiency of time vs. pressure (i.e., force) applied, it was determined that the gel adhesion was more a function of time and not so much a function of pressure. To improve the press time, additional single-segment gel presser end-effector can be considered. However, with the use of additional gel pressers, variances in the gel adhesions were noticed.

[00184] To avoid variances and to improve the gel press time and consequently, the cycle time of gel adhesion, a full ring press fixture (i.e., ring press end-effector) is used. As noted, the full ring gel press end-effector is designed to press the 9 segments all at once for a CER 222 with 9 segments and for a CER 222 with 18 segments, the full ring press end-effector is designed to perform the gel press twice (with each ring having 9 segments), one for each row. Using the ring press fixture, the press time and the total cycle time of gel adhesion is significantly reduced and is less than the average vision target time, which is typically 20 minutes for CER 222 with 9 segments and 40 minutes for CER 222 with 18 segments. For example, with the ring press fixture, the total cycle time for a 9 segment CER 222 is about 19 minutes (i.e., 9 minutes for peel and place and 10 minutes of press time) and for an 18 segment CER 222, it is about 38 minutes (i.e., 19 minutes for each row of gel strips). The reduced cycle time and the reliable gel strip adhesion make the ring press fixture a more desirable alternative to a single gel compressor 229.

[00185] Figure 18 is a simplified schematic diagram of a computer system for implementing embodiments. In some implementations, the computer system can be used to provide instructions, signals to the robot to enable the robot to perform the maintenance operations discussed herein. By way of example, some of these components may be part of the controller or part of a separate computer used to execute operations associated with the disclosed embodiments. It should be appreciated that the methods described herein may be performed with a digital processing system, such as a conventional, general-purpose computer system. Special purpose computers, which are designed or programmed to perform only one function, may be used in the alternative. The computer system includes a central processing unit (CPU) 1804, which is coupled through bus 1810 to random access memory (RAM) 1828, read-only

memory (ROM) 1812, and mass storage device 1814. System controller program 1808 resides in random access memory (RAM) 1828, but can also reside in mass storage 1814.

[00186] Mass storage device 1814 represents a persistent data storage device such as a floppy disc drive or a fixed disc drive, which may be local or remote. Network interface 1830 provides connections via network 1832, allowing communications with other devices. It should be appreciated that CPU 1804 may be embodied in a general-purpose processor, a special purpose processor, or a specially programmed logic device. Input/Output (I/O) interface provides communication with different peripherals and is connected with CPU 1804, RAM 1828, ROM 1812, and mass storage device 1814, through bus 1810. Sample peripherals include display 1818, keyboard 1822, cursor control 1824, removable media device 1834, etc.

[00187] Display 1818 is configured to display the user interfaces described herein. Keyboard 1822, cursor control 1824, removable media device 1834, and other peripherals are coupled to I/O interface 1820 in order to communicate information in command selections to CPU 1804. It should be appreciated that data to and from external devices may be communicated through I/O interface 1820. The embodiments can also be practiced in distributed computing environments where tasks are performed by remote processing devices that are linked through a wire-based or wireless network.

[00188] Embodiments may be practiced with various computer system configurations including hand-held devices, microprocessor systems, microprocessor-based or programmable consumer electronics, minicomputers, mainframe computers and the like. The embodiments can also be practiced in distributed computing environments where tasks are performed by remote processing devices that are linked through a network.

[00189] With the above embodiments in mind, it should be understood that the embodiments can employ various computer-implemented operations involving data stored in computer systems. These operations are those requiring physical manipulation of physical quantities. Any of the operations described herein that form part of the embodiments are useful machine operations. The embodiments also relate to a device or an apparatus for performing these operations. The apparatus may be specially constructed for the required purpose, such as a special purpose computer. When defined as a special purpose computer, the computer can also perform other processing, program execution or routines that are not part of the special purpose, while still being capable of operating for the special purpose. Alternatively, the operations may be processed by a general purpose computer selectively activated or configured by one or more computer programs stored in the computer memory, cache, or obtained over a network. When data is obtained over a network the data may be processed by other computers on the network, e.g., a cloud of computing resources.

[00190] One or more embodiments can also be fabricated as computer readable code on a computer readable medium. The computer readable medium is any data storage device that can store data, which can thereafter be read by a computer system. Examples of the computer readable medium include hard drives, network attached storage (NAS), read-only memory, random-access memory, CD-ROMs, CD-Rs, CD-RWs, magnetic tapes and other optical and non-optical data storage devices. The computer readable medium can include computer readable tangible medium distributed over a network-coupled computer system so that the computer readable code is stored and executed in a distributed fashion.

[00191] Although the method operations were described in a specific order, it should be understood that other housekeeping operations may be performed in between operations, or operations may be adjusted so that they occur at slightly different times, or may be distributed in a system which allows the occurrence of the processing operations at various intervals associated with the processing, as long as the processing of the overlay operations are performed in the desired way.

[00192] Although the foregoing embodiments have been described in some detail for purposes of clarity of understanding, it will be apparent that certain changes and modifications can be practiced within the scope of the appended claims. Accordingly, the present embodiments are to be considered as illustrative and not restrictive, and the embodiments are not to be limited to the details given herein, but may be modified within the scope and equivalents of the appended claims.

CLAIMS

1. An end-effector for use to perform a maintenance operation within a process module disposed in a fabrication facility, comprising:
 - an upper tubular extension coupled to a cleaning chemistry source at a first end;
 - a lower tubular extension with a top portion coupled to a second end of the upper tubular extension and a bottom portion having a cleaning head with an opening defined to cover an area;
 - an interlock stopper disposed between the second end of the upper tubular extension and the top portion of the lower tubular extension, the interlock stopper coupled to the lower tubular extension and is configured to move the lower tubular extension into the process module for performing the maintenance operation,
 - a chemical channel embedded within and extending a length between the first end of the upper tubular extension and the cleaning head of the lower tubular extension, the chemical channel coupled to the cleaning chemistry source at the first end and to a nozzle at the cleaning head, the chemical channel configured to flow a cleaning chemistry;
 - a vacuum flow channel embedded within and extending the length between the first end of the upper tubular extension and the cleaning head at the bottom portion of the lower tubular extension, the vacuum flow channel coupled to a vacuum machine at the first end, the vacuum machine applying vacuum within the vacuum flow channel to allow extraction of cleaning chemistry and any polymer residues released from the area; and
 - an end-effector robot interface disposed in a portion of the upper tubular extension, the end-effector robot interface configured to mate with an end-effector connector disposed on a robot available within the fabrication facility.
2. The end-effector of claim 1, wherein the end-effector is a cleaning tool and the maintenance operation is a cleaning operation, and
 - wherein the end-effector is housed in a cleaning cart and is configured to be autonomously operated by the robot to perform the maintenance operation.
3. The end-effector of claim 1, wherein the process module includes a chamber cover to seal the process module, the end-effector moved into the process module through a hole defined in the chamber cover, the hole lined with an interlock face plate, and
 - wherein the interlock stopper includes a spring mechanism and a locking mechanism, the spring mechanism coupled to the lower tubular extension and designed to dynamically adjust a height to which the lower tubular extension with the cleaning head is extended into the process module through the hole in the chamber cover, when engaged to perform the maintenance operation, from a first height covering the portion to a second height covering a second portion

of an inside sidewall of the process module, and the locking mechanism is configured to securely lock the end-effector to the interlock face plate at the second height.

4. The end-effector of claim 3, wherein the end-effector received in the hole is configured to rotate the chamber cover along a horizontal axis while the interlock face plate continues to engage the locking mechanism to hold the end-effector in place, the rotation allowing different portions of the inside sidewall of the process module to get exposed to the cleaning chemistry supplied via the cleaning head, the rotation enabled using signals from the robot used to handle the end-effector.

5. The end-effector of claim 3, wherein the end-effector is a cleaning tool and the maintenance operation is a cleaning operation designed to be performed in multiple passes, and wherein each pass is defined to cover a distinct height to which the lower tubular extension with the cleaning head is extended inside the process module, the dynamic adjustment performed in response to a signal from the robot operating the end-effector.

6. The end-effector of claim 1, wherein the nozzle extends outwardly through the opening at an angle defined in relation to a straight angle of the chemical channel.

7. The end-effector of claim 6, wherein the nozzle includes a fixed nozzle head.

8. The end-effector of claim 6, wherein the nozzle includes a moveable nozzle head, the moveable nozzle head connected to a bottom of the chemical channel using a flexible connector to allow the moveable nozzle head to pivot along one or more axes of rotations, the flexible connector coupled to the robot and is controlled using signals from the robot,

wherein the robot is communicatively coupled to a controller in the fabrication facility and is configured to receive signals to operate the end-effector and the flexible connector of the nozzle.

9. The end-effector of claim 1, wherein the maintenance operation is a cleaning operation, the cleaning operation initiated by positioning and maintaining the cleaning head at a predefined distance away from an inside sidewall of the process module, during operation, to provide contactless cleaning.

10. The end-effector of claim 9, wherein the predefined distance is defined to be between about 0.75 mm and about 1.25 mm.

11. The end-effector of claim 1, wherein the end-effector is designed to perform a cleaning operation and the cleaning head is designed to provide contact cleaning, and

wherein an outer surface of the opening of the cleaning head is lined using an O-ring to enable the O-ring to seal the opening of the end-effector with the portion of an inside sidewall of the process module during the cleaning operation during the contact cleaning.

12. The end-effector of claim 11, wherein a bottom side of the lower tubular extension includes one or more bleed holes, the bleed holes used to allow circulation of air from an environment within the process module into the vacuum flow channel to relieve a suction force generated from the contact cleaning.
13. The end-effector of claim 1, wherein the chemical channel is disposed in a center of the end-effector and the vacuum flow channel is disposed to surround the chemical channel.
14. The end-effector of claim 1, wherein a height of the end-effector within the process module is dynamically adjustable by the robot to allow a different portion of the process module to get exposed to cleaning chemistry.
15. The end-effector of claim 1, wherein the end-effector further includes,
a cleaning hose to couple the first end of the upper tubular extension to the cleaning chemistry source, the cleaning hose housed in a hose retractor disposed in the cleaning cart, the hose retractor allowing extension of the cleaning hose during insertion of the end-effector into the process module and retraction of the cleaning hose during removal of the end-effector from the process module.
16. The end-effector of claim 1, further includes a heat shrink disposed between the interlock stopper and the second end of the upper tubular extension, the heat shrink defined to provide an insulation and a seal between the upper tubular extension and the interlock stopper.
17. The end-effector of claim 1, wherein the cleaning cart is a mobile, detachable unit and is coupled to a main cart carrying the robot for performing the maintenance operation, and
wherein the main cart is a second mobile, detachable unit and is coupled to the process module for performing the maintenance operation.
18. The end-effector of claim 17, wherein the cleaning cart is coupled to the main cart using a docking mechanism, the docking mechanism includes a docking plate, one or more bumpers and one or more toggle clamps, the one or more bumpers are disposed between a first side of the docking plate and the cleaning cart, a second side of the docking plate is mounted to the main cart, the one or more toggle clamps are disposed on the first side of the docking plate to securely mount the cleaning cart to the first side of the docking plate,
wherein the one or more bumpers are made of non-slip material, and
wherein the docking plate is made of a metal.
19. The end-effector of claim 17, wherein a first side of the main cart is coupled to the cleaning cart using a second docking mechanism, a second side of the main cart is docked to the process module during the maintenance operation, the coupling of the cleaning cart and the main cart allowing the robot on the main cart to retrieve and guide the end-effector disposed on the cleaning cart into the process module through a hole defined in a chamber cover covering a top

of the process module and control operation of the end-effector during the maintenance operation.

20. An end-effector for use to perform a maintenance operation within a process module disposed in a fabrication facility, comprising:

a wand handle extending a length between a top portion and a bottom portion, the bottom portion of the wand handle having a hinge mechanism, and

a wipe head disposed on a shaft of the hinge mechanism defined in the bottom portion of the wand handle, the shaft allowing the wipe head to pivot around an axis of rotation, wherein the wipe head includes an upper arm and a lower arm,

wherein the hinge mechanism is disposed at a first end of the upper arm and the lower arm and a clip mechanism is disposed at a second end of the upper arm and the lower arm, the clip mechanism including a snap-fit feature to couple the upper arm to the lower arm at the second end.

21. The end-effector of claim 20, wherein the snap-fit feature is defined on the lower arm and an actuator is defined on the upper arm, the snap-fit feature is configured to cause the wipe head to move to an unlocked state by releasing the actuator, when a pressure is applied at an outer edge of the snap-fit feature, and cause the wipe head to move to a locked state by locking the actuator, when the pressure is applied at an inner edge of the snap-fit feature.

22. The end-effector of claim 21, wherein the upper arm is hinged and the lower arm is fixed, such that in the unlocked state, the upper arm is configured to pivot around the shaft and in the locked state, the upper arm is locked in place.

23. The end-effector of claim 21, wherein a cleaning wipe is received to cover a top surface and a bottom surface of the upper arm, the cleaning wipe secured in place by activating the snap-fit feature of the clip mechanism.

24. The end-effector of claim 20, wherein the snap-fit feature is defined on the upper arm and an actuator is defined on the lower arm, the snap-fit feature is configured to cause the wipe head to move to an unlocked state by releasing the actuator, when a pressure is applied at an outer edge of the snap-fit feature, and cause the wipe head to move to a locked state by locking the actuator, when the pressure is applied at an inner edge of the snap-fit feature, wherein the lower arm is fixed and the upper arm is hinged and configured to pivot around the shaft of the hinge mechanism, and

wherein a cleaning wipe is received to cover a top surface and a bottom surface of the lower arm, the clip mechanism used to secure the cleaning wipe in place.

25. The end-effector of claim 20, wherein the wipe head includes a curved contour, and wherein an angle of curvature is defined to be an acute angle.
26. The end-effector of claim 20, wherein the end-effector is a cleaning wand and the maintenance operation is a wiping operation, the cleaning wand used to wipe an inside sidewall of the process module, between the inside sidewall and a lower electrode defined in a lower portion of the process module, and an underside surface of the lower electrode, and wherein the end-effector is housed in a cleaning cart and is configured to be handled by a robot available within the fabrication facility for performing the maintenance operation.
27. The end-effector of claim 20, wherein the top portion of the wand handle includes an end-effector robot interface that is configured to be coupled with a robot end-effector connector disposed on a robot arm of the robot, the coupling allowing the robot to control movement of the end-effector during the maintenance operation.
28. The end-effector of claim 20, wherein the end-effector is a single, 3D printed unit.
29. A chamber cover used for sealing an opening of a process module disposed within a fabrication facility, during a maintenance operation, comprising:
a base plate providing a supporting surface for the chamber cover;
a sliding ring disposed on top of the base plate, the sliding ring having a rotating bearing to allow rotation of the sliding ring along an axis of rotation;
a mid ring disposed on top of the sliding ring;
a cover plate disposed on top of the mid ring, the cover plate having a hole defined in a portion of a surface to provide access to an inside of the process module, when the chamber cover is installed over the opening of the process module, the cover plate is coupled to the mid ring and the sliding ring to form a unitary component; and
an interlock face plate disposed to provide a lining for the hole defined in the portion of the cover plate, the interlock face plate including a locking component to lock an end-effector received in the hole of the cover plate, for performing the maintenance operation.
30. The chamber cover of claim 29, wherein the mid ring provides a sealing interface between the cover plate and the sliding ring.
31. The chamber cover of claim 29, wherein the cover plate is made of a polycarbonate sheet.
32. The chamber cover of claim 29, wherein the chamber cover is handled autonomously by the robot and installed in place over the opening of the process module.
33. The chamber cover of claim 29, wherein the end-effector is configured to rotate the cover plate of the unitary component along the axis of rotation, while the interlock face plate maintains the end-effector in place using the locking component so as to allow different portions

of an inside surface of the process module to be exposed to a cleaning chemistry applied through the end-effector.

34. The chamber cover of claim 29, wherein the chamber cover is housed in a cleaning cart and is configured to be handled by a robot for sealing the opening of the process module, when the maintenance operation is to be performed at the process module.

35. The chamber cover of claim 34, wherein the robot is housed in a main cart and wherein the cleaning cart is a mobile, detachable unit that is moved proximate to and coupled to the main cart housing the robot, the main cart coupled to the process module to enable the robot to retrieve and move the chamber cover from the housing in the cleaning cart and over the opening of the process module and secure in place, prior to performing the maintenance operation.

36. The chamber cover of claim 29, wherein the base plate is coupled to a top of the process module using a plurality of base plate fasteners,

wherein the sliding ring, the mid ring and the cover plate are coupled together using a plurality of cover fasteners to form the unitary component, and

wherein the interlock face plate is coupled to the cover plate using a plurality of interface fasteners.

37. A bolt used for securing a top plate to an opening of a process module disposed in a fabrication facility, comprising:

a bolt head defined in a top portion of the bolt, the bolt head includes a chamfer on an inside top edge and a recess to engage a hex key used for installing and de-installing the bolt on the top plate, the chamfer extending for a length;

a bolt body disposed immediately below the bolt head; and

a bolt thread defined in a bottom portion of the bolt body, the bolt thread used to secure the top plate over the opening of the process module.

38. The bolt of claim 37, wherein the length of the chamfer is defined to allow the recess to have at least a predefined height, the predefined height defined to enable the hex key to engage with the bolt head during tightening or loosening of the bolt.

39. The bolt of claim 38, wherein the height of the recess defined in the bolt head by the chamfer is sufficient to allow the hex key to engage with the bolt head.

40. The bolt of claim 38, wherein the length of the chamfer is defined to be between about 0.26" and about 0.28".

41. The bolt of claim 38, wherein a height of the recess is defined to be between about 0.10" and about 0.20".

42. A valve sealing tray for use during a cleaning operation of a process module disposed within a fabrication facility, comprising:

a valve bowl defined to fit into a valve slot disposed below a lower electrode of the process module, a dimension of the valve bowl matching an inside dimension of the valve slot; and

a mounting flange with through holes defined therein for securing to a side of the valve bowl, the mounting flange designed to cover an opening of the valve slot, when the valve sealing tray is inserted into the valve slot,

wherein the valve bowl is configured to be received on and pivoted around a vertical shaft of a hinge defined in the valve slot, and

wherein the valve slot is defined along and accessible from a lateral side of the process module.

43. The valve sealing tray of claim 42, further includes a spring-loaded mechanism disposed on a front side of the mounting flange, the spring-loaded mechanism, when activated, is designed to move the valve sealing tray into the valve slot and lock into place and unlock and move the valve sealing tray out of the valve slot.

44. The valve sealing tray of claim 43, wherein the spring-loaded mechanism is configured to be operated autonomously by a robot disposed in the fabrication facility.

45. The valve sealing tray of claim 42, wherein the valve sealing tray is a replaceable unit and used to replace a pendulum valve device received in the valve slot, when the cleaning operation is to be performed, the valve sealing tray replaced by the pendulum valve device after the cleaning operation.

46. The valve sealing tray of claim 42, wherein the valve sealing tray is generated using three-dimensional printing.

47. The valve sealing tray of claim 42, wherein the valve sealing tray is made of Polytetrafluoroethylene material.

48. The valve sealing tray of claim 42, wherein a height of the valve bowl is designed to match an internal height of the valve slot.

49. An end-effector for use to install a gel strip on a consumable part used within a process module disposed in a fabrication facility, comprising:

at least one vacuum port defined in a body of the end-effector, the at least one vacuum port connected to a vacuum pump to provide a suction force;

a suction cup for gripping and removing a backer layer disposed on the gel strip;

a vacuum plate disposed in a bottom portion of the end-effector, the vacuum plate used to retrieve the gel strip from a holding container, hold, move and place the gel strip at a gel applicator site defined on a portion of the consumable part received on a turntable; and

a vision system to illuminate the gel applicator site for precision placement of the gel strip.

50. The end-effector of claim 49, wherein the vacuum plate includes a grid pattern on a bottom side, a geometry of the grid pattern defined to improve the suction force during retrieval and movement of the gel strip from the holding container to the gel applicator site on the consumable part.

51. The end-effector of claim 49, wherein the end-effector is housed in a cleaning cart and is configured to be handled by a robot available for installing the gel strip, and

wherein the cleaning cart is a mobile, detachable unit that is moved proximate to and coupled to a main cart housing the robot, the main cart coupled to the process module to enable the robot to retrieve and operate the end-effector during the installation of the gel strip at the gel applicator site defined on a portion of the consumable part.

52. The end-effector of claim 49, wherein the turntable is defined on the cleaning cart, the turntable defined by,

a mounting ring capable of rotating about an axis;

a middle ring mounted over the mounting ring, the mounting allowing the middle ring to rotate with the mounting ring; and

the consumable part mounted onto the middle ring using a locking mechanism, the locking mechanism configured to hold and lock the consumable part in place, the rotation of the mounting ring redefining the gel applicator site to cover different portions of the consumable part.

53. The end-effector of claim 52, wherein the locking mechanism is a cam operated mechanism.

54. The end-effector of claim 52, wherein the mounting ring is a slewing ring having a bearing with gears to rotate about the axis.

55. The end-effector of claim 52, wherein the turntable includes a backlight faceplate illuminated by a light source, the backlight faceplate used to align the gel strip using the end-effector before placing on the gel applicator site defined on the consumable part.

56. The end-effector of claim 49, wherein the consumable part is an edge ring, and
wherein a top portion of the end-effector includes an end-effector robot interface that is used to couple with a robot end-effector connector disposed on a robot arm of the robot, the

coupling allowing the robot to control movement of the end-effector during application of the gel strip on the consumable part.

57. A package for gel strip used for installing on a consumable part used in a process module of a fabrication facility, comprising:

a plurality of gel strips, each gel strip includes a backer defining a top surface, a liner defining a bottom surface, and a gel layer disposed between the backer and the liner, the plurality of gel strips is disposed one on top of another to create a stacked structure; and

an inter-layer disposed between each consecutive pair of gel strips of the plurality of gel strips in the stacked structure, the inter-layer providing a separation interface for the gel strips.

58. The package of claim 57, wherein the inter-layer is defined to include an uneven surface, the uneven surface creating air pockets between the gel strip and the inter-layer, when disposed between the consecutive pair of gel strips.

59. The package of claim 58, wherein the inter-layer is defined to have a thickness that is sufficient to create air-pockets of a defined depth.

60. The package of claim 58, wherein the thickness of the inter-layer is defined so that the air pockets formed between the inter-layer and the gel strip are uniform in depth across an entire length of the inter-layer.

61. The package of claim 58, wherein the thickness of the inter-layer is defined so that the air pockets formed between the inter-layer and the gel strip are of varying depths across a length of the inter-layer.

62. The package of claim 57, wherein a first dimension of the inter-layer is equal to a second dimension of the liner of the gel-strip.

63. The package of claim 57, wherein a first dimension of the inter-layer is greater than a third dimension of the gel layer defined in said each gel strip.

64. The package of claim 57, wherein a thickness of the inter-layer is between about 0.25 mm and about 0.35 mm.

65. The package of claim 57, wherein a first number of gel strips of the plurality of gel strips is greater than a second number of inter-layers disposed in the package.

66. The package of claim 57, wherein the inter-layer is made of a low-density polyethylene material.

67. The package of claim 57, wherein the inter-layer is a disposable component of the package.

68. A ring press fixture for use in installing gel strips over a consumable part used in a process chamber, comprising:

a top presser plate;

a foam ring disposed below and aligned with the top presser plate; and
a tool changer disposed at a center of a top surface of the top presser plate, the tool changer configured to couple to an end-effector connector of a robot arm disposed on a cart, wherein the ring press fixture is used for pressing the gel strips into place over the consumable part.

69. The ring press fixture of claim 68, wherein the tool changer is coupled to the top presser plate via a coupling cap using a plurality of fastener means.

70. The ring press fixture of claim 68, wherein the top presser plate and the foam ring are sized to match to a size of the consumable part such that the ring press fixture is configured to convey at least a portion of a clamp force applied on the top presser plate to the gel strips received on a surface of the consumable part.

71. The ring press fixture of claim 68, wherein the top presser plate includes a set of press plate ears extending from and disposed uniformly along an outer circumference, each press plate ear in the set is used to align with a corresponding clamp disposed on a top surface of a cart, so as to receive and convey a predetermined amount of clamp force provided at the clamp to the gel strips received on the consumable part.

72. The ring press fixture of claim 71, wherein the set of press plate ears includes 3 press plate ears distributed uniformly around the top presser plate.

73. The ring press fixture of claim 68, wherein the consumable part has a defined width that is sized to accommodate a single row of gel strips, and the ring press fixture has a ring width that correlates with the defined width of the consumable part.

74. The ring press fixture of claim 68, wherein the consumable part has a defined width that is sized to accommodate an inner row and an outer row of gel strips, wherein the inner row is defined immediately adjacent to and inside of the outer row, the gel strips in the inner row are sized smaller than the gel strips in the outer row, and

wherein the ring press fixture is sized to cover the defined width of the consumable part.

75. The ring press fixture of claim 68, wherein the ring press fixture is stored on a nest arm defined on a top surface of the cart, the nest arm disposed on the top surface in a vertical orientation.

76. A cart for storing a ring press fixture used for installing gel strips over a consumable part used in a process chamber, comprising:

a top surface having,

a ring receiving area for receiving the consumable part and the ring press fixture,

a nest arm used for storing the ring press fixture, the nest arm disposed in a vertical orientation on the top surface;

a set of clamps disposed outside of and adjacent to an outside circumference of the ring receiving area, the set of clamps used to apply a clamp force to the consumable part through a ring press fixture, during operation, wherein the ring press fixture is disposed on top of the consumable part, and

wherein the set of clamps are coupled to a controller that is used to provide signals to control the clamp force applied to the consumable part through the ring press fixture.

77. The cart of claim 76, wherein the cart is a movable unit, and wherein the ring press fixture includes,

a top presser plate having a set of press plate ears extending from and disposed uniformly along an outer circumference, each press plate ear in the set is used to align with a corresponding clamp and to convey the clamp force applied to the gel strips on the consumable part;

a foam ring disposed below and aligned with the top presser plate; and

a tool changer disposed at a center of a top surface of the top presser plate and coupled to the top presser plate using one or more fastener means, the tool changer configured to couple with a robot arm disposed on a cart,

wherein the ring press fixture is used for pressing the gel strips into place over the consumable part.

78. The cart of claim 76, wherein the nest arm includes,

a base plate configured to be coupled to the top surface of the cart;

a stand disposed over the base plate and extend vertically up for a height; and

a side arm defined in a top portion of the stand, the side arm extending out for a length and ending in a step-up to define an inset on a top surface of the side arm, a height of the step-up and the length of the side arm defined to at least correspond with a depth of the ring press fixture so as to securely receive and hold the ring press fixture in place during storage.

79. The cart of claim 78, wherein the stand has a variable width along the height,

wherein the variable width is defined by a bottom portion extending for a first width and a top portion extending for a second width,

wherein the first width is greater than the second width, the bottom portion having a stand cut-out, and

wherein the stand is disposed on the base plate so as to have the bottom portion extend from the center of the base plate to a lateral side.

80. The cart of claim 78, wherein stand has a uniform width along the height.

81. The cart of claim 76, wherein the ring receiving area is defined on a gel applicator turntable supported on a gel applicator tray received on the top surface, the gel applicator tray including,

- a) a gel strip stacked structure providing the gel strips used for installing on the consumable part;
- b) a trash bin with a receptacle for discarding backer and inter-layer peeled from the gel strips retrieved from the gel strip stacked structure; and
- c) the set of clamps distributed uniformly along an outer circumference of the gel applicator turntable.

82. The cart of claim 76, wherein each clamp in the set of clamps includes,
a clamp cylinder having a center bore, the clamp cylinder coupled to the top surface of the cart, a lateral side of the clamp cylinder coupled to a stepped elevator wall with a plurality of stacked sections, the stepped elevator wall configured to move along a vertical axis;

a piston disposed in the center bore and operated using an actuator coupled to a pneumatic mechanism, the actuator used to impart a defined clamp stroke to the piston so as to generate a pre-determined amount of the clamp force;

a flange defined on top of the piston, one end of the flange coupled to a top of the stepped elevator wall to allow the flange to move with the piston along the vertical axis, in response to the clamp stroke applied to the piston, the flange used to align to the ring press fixture and configured to convey the clamp force defined by the clamp stroke through the ring press fixture to the gel strips received on the consumable part, when the clamps are activated,

wherein each clamp in the set is coupled to a controller that is configured to provide signals to activate the flange and control the clamp stroke imparted to the piston.

83. The cart of claim 82, wherein when said each clamp is deactivated, the plurality of the stacked sections of the stepped elevator wall extend up to an extended position so as to release the ring press fixture, and when said each clamp is activated, the plurality of stacked sections of the stepped elevator wall collapse to a compressed position, the compressed position defined to impart the clamp force to the consumable part through the ring press fixture.

84. The cart of claim 82, wherein the flange is a pneumatic flange operated using the pneumatic mechanism.

85. The cart of claim 82, wherein the plurality of stacked sections of the stepped elevator wall includes at least a first section and a second section, the first section defined in a bottom portion of the stepped elevator wall adjacent to the top surface of the cart, and the second section includes a stop shelf defined at a height along one or more inside walls, such that when said each

clamp is activated, the second section collapses over the first section up to the height defined by the stop shelf.

86. The cart of claim 85, wherein the height of the stopper shelf is defined to prevent pinch hazard.

87. The cart of claim 76, wherein each clamp in the set of clamps is a swing clamp, each swing clamp in the set configured to rotate along a vertical axis between an operating position and a resting position and move laterally along a horizontal axis, so as to receive and convey a predetermined amount of clamp force provided at the set of swing clamps to the gel strips received on the consumable part.

88. The cart of claim 87, wherein each swing clamp includes,

a clamp cylinder having a center bore and configured to couple to a surface of the ring receiving area;

a piston disposed in the center bore, the piston coupled to a pneumatic mechanism used to impart a defined clamp stroke to the piston so as to apply a pre-determined amount of clamp force to the ring press fixture; and

a swing arm extending for a length and coupled to the piston, the swing arm configured to rotate about a vertical axis so as to move between an operating position and a resting position, wherein a first end of the swing arm is attached to a top end of the piston and a second end of the swing arm is coupled to a clamp head, the clamp head used to convey the pre-determined amount of clamp force to the gel strips received on the consumable part,

wherein said each swing clamp is coupled to a controller used to provide signals to control the clamp stroke and to rotate the swing arm between the operating position and the resting position.

89. The cart of claim 88, wherein the length of the swing arm is configured to be laterally adjustable to cover different circumferential portions of the consumable part, when the swing arm is moved to the operating position.

90. The cart of claim 89, wherein the consumable part has a defined width that is sized to accommodate an inner row and an outer row of gel strips, wherein the inner row is defined immediately adjacent to and inside of the outer row, and the ring press fixture is sized to cover the defined width of the consumable part, and

wherein the operating position of the swing clamps is defined to include an inner operating position and an outer operating position, the length of the swing arm of each of the swing clamps is designed to adjust laterally to an inner operating position so as to apply the clamp force to the inner row of gel strips and to an outer operating position so as to apply the clamp force to the outer row of gel strips.